Consolidated Responses to JRP's Information Requests
Packages 12, 12a, 12b, 13, and Clarifications to IR-EIS-12-513 for
Deep Geologic Repository Project for
Low and Intermediate Level Waste

Note: The above pages numbers are the page numbers of the PDF file, shown on the right top corner of each page.

May 30, 2014

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<tr><td>EIS 12-510</td><td>• Section 11.3 Significance of Residual Effects
• Section 2.6 Study Strategy and Methodology</td><td><i>Information Request:</i>
<i>Significance Determination for Residual Adverse Effects</i>
<i>Provide a detailed narrative to explain how the significance of each residual adverse effect on the biophysical environment (Geology, Hydrogeology and Surface Water, Terrestrial Environment, Aquatic Environment, Radiological Conditions, Air Quality, Noise and Vibrations) and on Aboriginal Interests was determined. Provide a separate narrative for each residual adverse effect.</i>
<i>The narrative must explain the logic behind the significance determinations and is to use context-based reasoning. Arbitrary category limits for criteria such as magnitude are not required. Rather, the context for the predicted measurable change should be explained in sufficient detail that the reader may understand the relative significance of that change in terms of the magnitude, geographic extent, timing and duration, frequency and degree of irreversibility criteria. If the social/ecological context of the adverse effect was also assessed, the rationale for this criterion must be explained. Defensibility is to be provided by references to the literature (peer-reviewed and “grey” literature). Sufficient information must be provided to allow a third party reviewer to understand how the conclusion was reached.</i>
<i>The narratives provided in the Socio-Economic Assessment are sufficiently clear and do not require further elaboration.</i>
<i>Context:</i>
<i>In Dr. Duinker’s hearing submission (PMD 13-P1.175), he expresses concerns about the lack of transparency of the decision trees and the apparent arbitrariness in professional judgement used to determine significance (pages 5-7 of the PMD). The determination of significance of adverse impacts is fundamental to the environmental assessment. Therefore, the rationale for the determination of significance must be credible, defensible, clear, reliable, and appropriate.</i>
<i>Narrative Requirements:</i>
• <i>Clear explanation of the “measurable change” leading to identification of adverse effect in terms of comparison pre and post-impact, and the assumed measurement error. Would the change be detectable using standard monitoring methods? Have similar changes occurred in the study area and would these changes be described as “measurable”?</i>
• <i>Avoidance of arbitrary low/medium/high categorization in favour of narrative reasoning that is well supported by literature citations and examples from comparable projects. For example, the context for magnitude may include references to the toxicological literature, risk quotients, or population and community monitoring and modelling from comparable projects which have similar effects on the biophysical environment or upon Aboriginal interests.</i>
• <i>Avoidance of the “may not be significant” determination. Instead, explain the level of confidence in each of the</i></td></tr>
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		significance conclusions. The level of confidence must be explained in terms of the precautionary principle; i.e. the application of risk avoidance, adaptive management and preparation for surprise requirements associated with each significance determination. For example, if the assessment team judges that the consequences of being wrong about the significance of a particular effect are such that explicit monitoring, contingency planning, or further risk reduction measures are required, then these measures must be described in association with the significance result.
		OPG Response: Attachment A presents a detailed narrative explaining how the significance of each residual adverse effect on the biophysical environment was determined in the Environmental Impact Statement (EIS) (OPG 2011). The narrative provides an explanation of the logic used in the significance assessments and further clarifies the significance assessments presented in Sections 7.2.3, 7.3.3, 7.4.3, 7.5.3, 7.6.3, 7.7.3, 7.8.3, and 7.9.3 of the Environmental Impact Statement (OPG 2011). For components of the environment for which no residual adverse effects were identified (i.e., radiation and radioactivity, geology, and surface water quality), information on what would have been required for identification of a significant adverse effect and a discussion of the potential effects of the DGR Project are provided for completeness. The response includes an explanation of "measurable change" leading to the identification of adverse effects for each residual adverse effect. **References:** OPG. 2011. OPG's Deep Geologic Repository for Low and Intermediate Level Waste - Environmental Impact Statement. Ontario Power Generation report 00216-REP-07701-00001-R000. Toronto, Canada. (CEAA Registry Doc# 298)
EIS 12-511	• Section 16, Follow-Up Program	***Information Request:*** ***Geoscientific Verification Plan*** *Provide an updated Geoscientific Verification Plan (GVP) that includes more details concerning specific methods, timing, and the sequencing of sampling as well as how Ontario Power Generation will develop triggers for changes to engineering design and benchmarks for verification of the safety case.* *Verification activities that are outlined in NWMO DGR-TR-2011-08 are generally defined and lack substantive detail as to the procedures that would be used, spatial locations of testing and timing of testing. An example deficiency is provided in the following paragraph, with more details being provided in the Context section of this IR request.*

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		A primary GVP activity that is critical to final repository siting design is in-situ overcoring stress measurement that would be used to verify regional scale stress magnitude and orientation assumptions. These assumptions will be utilized to direct repository layout design in order to minimize induced stresses about rooms and access drifts, thereby maintaining least excavation rock disturbance and damage. In the GVP, stress measurement activities are planned only to take place at the location of the shaft bottom and within the Cobourg Formation, and are indicated to occur only during the initial construction interval at the time of shaft sinking. It is not indicated whether such stress measurement activity will take place within the Main Shaft and the Ventilation Shaft, or at only one site. Inasmuch as stress conditions can vary spatially over short distances, limited site testing within only one shaft, or both shafts, at the depth of the Cobourg Formation may provide insufficient data to accurately confirm previous stress orientation and magnitude assumptions that were made based on regional scale approximations. It is also indicated in the GVP that no similar testing will be conducted to assess spatial variation of in-situ stress conditions (orientation and magnitude) over the full lateral extent of the repository horizon as drifts and rooms are developed. Justification for this lack of extensive stress monitoring activity, which is critical to room layout design and necessary for modeling performance verification, must be provided. ***Context:*** *A Geoscientific Site Characterization Plan was initiated by OPG in 2006 to obtain regional data on relevant aspects of geology, geomechanics, hydrogeology, geochemistry and seismicity in order to provide evidence that the hosting rock mass environment would provide strong geosphere barrier-in-depth capability to provide safe, long-term containment and isolation of the L&ILW within the DGR. In its EIS submission, OPG provided a GVP in which procedures and plans for additional geoscientific study, to take place during construction and operations phases of the DGR, were outlined to provide support for engineering design decisions and the long-term safety case assumptions.* *Additional detail is required to provide assurance of the integrity and long-term stability of the site-specific geosphere and engineered barriers to safely contain and isolate L&ILW. To date, geoscientific information has been obtained either from regional studies (including seismic surveys) or from quantities of core material recovered from a total of eight boreholes, of which six were developed to the depth of the planned repository horizon. Accordingly, OPG has proposed a series of planned geoscientific investigations that would be conducted during vertical and lateral development, and operation, of the DGR to verify sub-surface geosphere conditions.* *During shaft sinking and lateral development, one geoscientific activity to be conducted for additional information gathering will be geological mapping. In the described mapping process, “imaging” would be conducted and “rock mass characterization” will be used for geosphere data verification. The manner in which image mapping data will be used to infer geosphere properties, what properties will be determined, and the specific procedures and outputs of rock mass characterization, are not, however, defined. It is unclear how, for this activity, information gained will be used to address design decisions and safety case assumptions.*

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		Additionally, under the activity defined as in-situ geomechanical testing, upscaling of geomechanical properties of the rock at the repository level has been presented in Tables 2.1 and 2.3 of NWMO DGR-TR-201138. The procedures for field scale sample acquisition, sample testing and the rationale for determination of field scale versus previous laboratory-derived rock properties, at smaller scale, are not described in this document and thus provide little justification for such activity planning. *The geosphere will be subject to considerable change as the construction process proceeds and development activity will influence the pre-existing geosphere environment. For this reason, verification activities that may be applied to measure geosphere environmental conditions and their influence on design aspects of the DGR over the long term should also be evaluated and described.* *The proponent, in its GVP submission, has also not provided sufficient detail to confirm that best operational practices and testing methods have been considered for information gathering. By way of example, consideration is given to, but no justification provided for, use of the United States Bureau of Mines (U.S.B.M.) deformation gauge overcore technology (used for biaxial stress condition measurement in multiple, orthogonal boreholes) versus use of triaxial gauge overcore technology (used for three-dimensional stress condition measurement in single boreholes) to assess in-situ stress conditions.* *Site characterization studies to date have relied on examination of only a limited number of core sample tests from a few boreholes, only one of which has been sited within the spatial boundary and depth of the proposed repository. Geomechanical characterization of actual repository site conditions is thus extremely limited and will require more extensive evaluation. Planning for verification work, in terms of core retrieval activities both along the shafts and within lateral development sites, the spacing and depth of boreholes within which core recovery will take place, the size of boreholes to be drilled, the number of samples to be recovered at each site, the types (and justification) of characterization tests, the number of each type of test and the application of information gained in verification of initial design assumptions, is not well described nor defined.* *The proponent, in its hearing submissions, has stated that detailed information concerning testing procedures, as partially described in the preceding paragraphs, would be submitted for licensing approval immediately prior to the start of the shaft construction phase of the proposed DGR project, should the project proceed.*
		OPG Response: In March 2011 NWMO issued a Geoscientific Verification Plan (GVP) that outlined a framework for verification activities to be performed during the underground construction of the DGR (NWMO 2011a). The purpose of the GVP was to describe activities necessary to confirm site attributes contributing to the DGR Safety Case. The 2011 GVP has since been revised to include not only proposed activities within the shaft and lateral development related to verifying the DGR

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<tr><td></td><td></td><td>Safety Case, but also specific geotechnical field verification activities necessary to confirm repository design and assure safe underground excavation practices (NWMO 2014, enclosed). Tables 1 and 2 (attached) list revisions made to the GVP.
As the detailed design of the DGR is progressed, the Geoscientific Verification Plan will be updated and reissued as necessary. As indicated in the CNSC's draft Licence Condition Handbook, attached to PMD 13-P1.2, assuming the licence is issued, OPG will be required to provide written notification to the CNSC staff of any changes to the GVP. Any comments received from the CNSC about this revision of the plan (i.e. Rev 001) will be addressed in a future revision of this plan. The plan will ultimately be developed in sufficient detail to allow the development of technical specifications for procurement of equipment and for services to execute the plan.
The scheduling of all proposed sub-surface activities will be coordinated with construction activities to ensure timely collection and assessment as required for underground excavation, verification of DGR design elements and verification of parameters used in the DGR Safety Case (see attached Table 3). It should be noted that while the revised GVP provides greater detail, particularly for real-time geotechnical data information needs during construction and the means for collection (e.g., rationale for selection of USBM method versus triaxial over-coring gauge), individual test plans would be created for each activity. The test plans would incorporate information and experience consistent with international best practice to assure data reliability. Further, the detailed test plans would stipulate confirmed design basis or 'trigger' values related to rock mass response for excavation safety, verification of the DGR engineered design and layout, and the safety case.
Data gathered during implementation of the GVP would be used to reaffirm the geosphere conceptual model and understandings presented in the DGR Geosynthesis (NWMO 2011b) and update the DGR Safety Case to re-evaluate dose consequences and margins of safety. This information would be presented as part of the DGR Operating Licence application.
As described above the revised GVP is comprised of two related sets of verification activities: 1) geotechnical verification, and 2) geoscience verification. The geotechnical verification activities support construction monitoring and design verification, whereas the geoscience verification activities are principally conducted to reaffirm the DGR Safety Case.
A brief description of how these activities would be undertaken and possible response to observed conditions inconsistent with assumptions or data used in either the engineering design or the analyses supporting the DGR Safety Case is provided under the following two headings. A final section describes issues related to the scheduling and timing of proposed activities.</td></tr>
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		Geotechnical Verification The geotechnical verification activities involve field investigations and monitoring performed during the construction of the two shafts and the underground repository. The geotechnical verification activities are designed to provide real-time information as to the in situ behaviour of the rock formations relevant to: i) the observational methods for safe underground excavation practice and ii) verifying that behaviour is within expected and predefined trigger values. In the remote event that rock mass properties and/or behaviour fall outside trigger values, the repository design will be re-examined incorporating the new parameter values to assess influence, if any, on construction methods and/or the repository design. Table 4 (attached) summarizes the various geotechnical measurements that will be obtained during construction, as well as preliminary trigger values and associated mitigation actions if results fall materially outside of these values. The trigger values and mitigation activities will be further refined at a later date when the DGR design has progressed closer to ‘issue-for-construction’ status and contractor equipment and execution approach are defined. This information will be included in future test plans for the work identified in the GVP. Geoscience Verification The geoscience verification activities involve field investigations and monitoring activities during both shaft sinking and lateral development. These activities yield data for the purpose of verifying the assumptions and geoscience data used to support the DGR Safety Case. In particular data will be gathered to confirm that the host Cobourg Formation and the overlying rock formations will act as a long-term barrier to contain and isolate the low and intermediate level waste. Geoscience verification activities will be completed, or sufficiently completed, during the construction phase such that they directly support an operating licence application and updated repository Safety Case. In certain circumstances long-term demonstration experiments initiated during construction activities will continue into the operation phase. Analyses that have been performed to support the DGR Safety Case are based on very conservative assumptions and values for various geoscience parameters. Key geoscience parameters as noted in the GVP are the Excavation Damaged Zone (EDZ) thickness and permeability, geomechanical properties, fracture infill dates, excavation response and in situ stresses, two-phase flow and hydraulic head parameters, and long-term diffusivity. While not expected, given evidence presented in the DGR Safety Case, in the remote event that the data arising from any of the various geoscience verification activities are materially different than those used in DGR safety analyses, the following actions will be taken: (a) the data will be assessed to determine its reliability and (b) new analyses will be undertaken to test the implications on the DGR Safety Case. In most cases, it is likely that there will be an initial interpretation of field measurements, followed by a slower period with more extensive analysis and reconciliation with other measurements to yield a final recommended value. Timing and Sequencing The selection of verification activities, sequencing and timing has been developed to provide the necessary information

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		to support the intended purpose (see attached Table 3). For example, geotechnical verification activities are performed during construction to assist in the assessment of ground support requirements, blasting patterns, shaft liner placement, etc. Results are available in sufficient time to support field decisions and to provide confidence that measured results fall within the range of assumed parameters. Where verification results support key design elements, such as the in situ stress and direction at the repository horizon that may influence the layout of the emplacement rooms, the scheduling of such activities (i.e. under-excavation testing in the shaft services area) and the analysis of results allow sufficient time to confirm the design or, if required, modify the design well in advance of emplacement panel development. The sequencing of geoscientific activities will be aligned with construction (i.e. main shaft instrumentation will be installed as the shaft progresses). However, the results of some of these activities will be monitored over the construction period and, in some cases, into the operations phase. The results will support the development of a revised DGR Safety Case in support of the Operating Licence application. **References:** NWMO. 2011a. Geoscientific Verification Plan. Nuclear Waste Management Organization document NWMO DGR-TR-2011-38 R000. Toronto, Canada. (CEAA Registry Doc# 300) NWMO. 2011b. Geosynthesis. Nuclear Waste Management Organization report NWMO DGR-TR-2011-11 R000. Toronto, Canada. (CEAA Registry Doc# 300) NWMO. 2014. Geoscientific Verification Plan. Nuclear Waste Management Organization document NWMO DGR-TR-2011-38 R001. Toronto, Canada. (enclosed)

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Table 1: Summary of Revisions in Geotechnical Investigation and Monitoring Activities

Geotechnical Parameter	Change in Investigation or Monitoring Activity	
	Shaft Sinking	Lateral Development
Rock Mass Quality	Added geological mapping of shaft excavation wall using LIDAR survey in addition to photographic imaging method.	Added geological mapping of tunnel and room excavation using LIDAR survey in addition to photographic imaging method.
Groundwater Inflow	Details of probe hole drilling in upper 200 m and at selected horizons.	No change
Excavation Deformation	Details of layout of extensometer arrays (6 units/array) at seven (7) depth locations in shaft. Added inclinometer system installed on inside of concrete liner (to be decided).	Details of layout of extensometers in various locations in access tunnels (20 arrays with two units – one in roof and one in floor) and rooms (34 units in roof only). Added LIDAR profiling at selected locations (to be decided).
Rock Loading	Details of pressure cells at two (2) shale horizons along concrete/rock interface.	Details of stress cell embedded in roof rock at location of each extensometer installation in access tunnels and rooms.
Geomechanical Properties	Details of up-scaling testing.	Details of up-scaling testing.
In situ Stress	Replaced two (2) orthogonal horizontal holes with one (1) vertical hole for USBM overcoring in situ stress measurements in Main Shaft excavation only. Relocated in situ stress measurement by under-excavation test in shaft and relocated to Geoscience Room.	Added one (1) USBM overcoring in situ stress measurement in Sherman Fall Formation in down ramp to shaft bottoms.
Rock Pillar Integrity	N/A	Details of pillar integrity measurements for three (3) pillars.

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Table 2: Summary of Revisions in Geoscience Investigation and Monitoring Activities

Geoscience Parameter	Change to Investigation or Monitoring Activity	
	Shaft Sinking	Lateral Development
Rock Mass Quality	No change	No change
Excavation Damaged Zone (EDZ)	Added ground penetrating radar to detect the extent of HDZ (Highly Damaged Zone) along both shafts	No change
Fracture infill mineral studies and dating	No change	No change
Two-phase flow study	N/A	No change
Long-term diffusion test	N/A	No change
Microbiology study	N/A	No change
Sealing Materials Performance Test	Added information about potential sealing material testing options in shales	Added information about sealing material testing in Geoscience Room

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Table 3: Approximate Timing of Geotechnical and Geoscience Verification Activities

Construction Milestone	Investigation or Monitoring Activity		
	Geotechnical (1)	Geoscience	Approximate Duration(2)
Shaft Sinking			
Start of shaft sinking	• Geological mapping • Probe hole drilling in advance of shaft excavation face • Seepage water collection	• Geological mapping • Sample collection for infill mineral studies and dating • Ground penetration radar for EDZ detection	Throughout sinking of Main Shaft and Ventilation Shaft with no impact on shaft sinking schedule
Shaft excavation reaches Bois Blanc Formation	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Bois Blanc and Bass Island Formation contact	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Bass Island Formation	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Salina F Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Salina C Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Salina A2 Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase

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		Shaft excavation reaches Salina A1 Unit	• Excavation response measurement using extensometer and stress cell array • Overcoring in situ stress measurements (3) • Large diameter core sampling		One week
		Shaft excavation reaches Cabot Head Formation		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
		Shaft excavation reaches Queenston Formation	• Excavation response measurement using extensometers • Liner loading using pressure cells • Overcoring in situ stress measurements (3) • Large diameter core sampling	• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase for EDZ activities
		Shaft excavation reaches Georgian Bay Formation	• Excavation response measurement using extensometers • Liner loading using pressure cells • Overcoring in situ stress measurements (3) • Large diameter core sampling	• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase for EDZ activities
		Shaft excavation reaches Blue Mountain Formation		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase

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Shaft excavation reaches Cobourg Formation	• Excavation response measurement using extensometer and stress cell array • Overcoring in situ stress measurements (3)		One week
Repository Development in Cobourg Formation			
Start of Lateral Development	• Geological mapping	• Geological mapping • Sample collection for infill mineral studies and dating	Throughout repository development
Shaft Station and Service Area Development	• Excavation response measurement using extensometer and stress cell array • Large diameter core sampling		Throughout repository development; Monitoring extends into operation phase for selected instruments
Ramp (in Sherman Fall Formation)	• Overcoring in situ stress measurements		Three days
Start of Geoscience Room Construction	• Under-excavation test to verify in situ stress		Duration of Geoscience Room excavation
Repository Panel Development	• Excavation response measurement using extensometer, convergence pins and stress cell • LIDAR profiling at selected locations • Large diameter core sampling at selected locations • Seepage water collection if any	• Rock property and response data collected via geotechnical activities • Seismic reflection survey to characterize the configuration of Precambrian surface below the repository • EDZ characterization will be conducted in the vicinity of the panel access tunnels	Throughout construction phase Monitoring extends to the closure of emplacement rooms EDZ characterization work would occur during construction phase with additional periodic follow-up characterization work in the operations phase

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Start Panel 1 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section
Mid-way through Panel 1 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section
Start of Panel 2 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section
After Panel Development, in Geoscience Room		• Two-phase flow study • Long-term diffusion test • Microbiology study • Seal material performance test	Varies depending on activities. All activities except seal material performance tests will be completed in construction phase.

Notes:

1. Geotechnical data will be used to verify assumptions and parameters used in both geotechnical design of underground openings and in geomechanical analysis of long-term stability in support of DGR Safety Case.
2. Unless otherwise noted, investigation or monitoring activities will not have an impact on shaft sinking or repository development schedule.

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		3. Overcoring, in situ stress measurements and EDZ characterization work will be carried out in the Main Shaft only. The execution of these activities will require stopping the Main Shaft sinking activities for the duration shown.

Table 4 (associated with response to IR-EIS-12-511): Geotechnical Field Verification Activities, Preliminary Trigger Values and Associated Actions

Measurement	Preliminary Trigger Value or Observation	Action
Shaft Sinking		
Geological Mapping	Rock mass rating (RMR[76] values) based on in-shaft geological mapping is found to be 20% lower than from value determined on the basis of DGR-7 and DGR-8 data.	Revisit initial rock support design and concrete liner design, and if required change either or both designs. Any decision to change initial rock support design will also take into consideration actual observed behaviour of installed rock support.
Probe Hole Drilling	Probe hole observations in top 200 m indicate total groundwater inflow rate to shaft excavation will be greater than 3 L/s (50 USGPM). Probe hole observations into the Salina A1 and Guelph formations indicate total groundwater inflow rate to shaft excavation will be greater than 0.33 L/s (5 USGPM) and 0.05 L/s (~1 USGPM), respectively. **Note:** Values are based on assumed constructability requirements for shaft dewatering and performance of the shaft grouting trials. Values may be increased based on the selected contractor's approach to shaft dewatering during construction period.	Treat bedrock in advance of shaft bottom by grouting for the purpose of reducing groundwater inflow rates into shaft excavation to less than the trigger-level inflow rates.
Seepage Water Collection	Total groundwater inflow rate (post excavation from shaft wall) from upper 4 m of Salina A1 formation exceeds 0.33 L/s (5 USGPM). Total groundwater inflow rate (post excavation from shaft wall) from upper Guelph formation exceeds 0.05 L/s (~1 USGPM). Total groundwater inflow rate from Salina A1 and Guelph formations plus any other permeable bedrock formation(s) (i.e. formations with visible saline groundwater inflow) exceeds 0.43 L/s (~7 USGPM).	Grout permeable formation(s) to reduce inflow rate to below trigger value and/or increase capacity of permanent underground pumping system.
Deformation Measurement	At the location of each deformation array, shaft wall displacements will be measured at least four times prior to	Revisit initial rock support design and concrete liner design, and if required change either or both

Measurement	Preliminary Trigger Value or Observation	Action
	casting of shaft liner; i.e. when shaft bottom excavation advances to 2.5 m, 5 m, 10 m and 15 m from the array after each corresponding blast round. Monitoring will be performed to confirm that the expected rock relaxation has occurred prior to casting of concrete liner. Action will be taken if incremental shaft wall deformation is greater than 5% of total predicted deformation (based on modeling prediction following the last blast round prior to casting of concrete liner. For example, if the total predicted shaft wall deformation is 30 mm, the allowable amount of shaft wall deformation, as the excavation face advances from 10 m to 15 m from extensometer array, is 1.5 mm or less.	designs. In case of concrete liner consider changing construction sequence so that liner is placed later to allow additional time for rock relaxation.
Rock Loading on Concrete Liner at Shale Horizons	Pressure cell measurements indicates that shale rock loading (due to time dependent deformation) exceeds values used in the design of the concrete liners.	Review deformation data from nearby extensometer installations (if still available and functioning) and/or inclinometers (if installed). Monitor concrete liner for cracking. On basis of structural analysis of liner and any observations of cracking decide whether or not to add rock support through liner.
Geomechanical Testing	Successful testing of three large-scale (i.e. 160-mm diameter) rock samples from same rock formation yields Unconfined Compressive Strength (UCS) and elastic modulus values that are one standard deviation lower than mean value determined by testing of equivalent DGR-8 borehole rock core samples.	Monitor concrete liner for cracking at and near horizon where large scale was taken. If cracking occurs then decide whether or not to add rock support through liner and/or to seal cracks in liner to eliminate possible ingress of ground water.
In situ Stresses	a) Magnitudes of major and minor horizontal principal stresses are 20% greater than values used in shaft liner design. b) Orientation of major principal horizontal stress direction at all stress measurements locations falls outside the sector bounded by N40°E and N100°E (required to verify orientation of underground emplacement rooms).	a) Assess data and perform geomechanical analyses to re-estimate remnant loads on concrete liner. Monitor rock deformation via array of extensometers in same rock formation where in situ stress measurements were perfomed. If analysis and actual deformation data justify it, change concrete liner design. Alternatively consider changing construction sequence so that liner is placed later to allow additional time for rock relaxation.

Measurement	Preliminary Trigger Value or Observation	Action
		b) Assess data and perform geomechanical analyses to assess impact of measured in situ stress conditions on performance of underground openings at repository horizon. If necessary, change layout of the underground repository so that the orientation of emplacement rooms falls within the range +/- 30° of the major principal horizontal stress direction.
Lateral Development		
Geological Characterization of Cobourg Formation Lower Member by: a) Geological Mapping b) Geophysical Surveys c) Groundwater Seepage	a) Rock mass rating (RMR[76] values) based on geological mapping of underground opening rock surfaces are 20% lower than values determined on the basis of DGR-2 to DGR-6 and DGR-8 data. b) Seismic tomographic survey of a rock pillar reveals a major structure or weakness in a rock pillar(s). c) Visible and sustained ground water inflow from one or more rock discontinuities.	a) Re-visit rock support design, and if required make changes to design. Any decision to change rock support design would also take into consideration actual observed behaviour of installed rock support and any available rock deformation data. b) Review results from seismic tomographic surveys at other rock pillar locations and determine whether or not similar structures or weaknesses exist elsewhere. Assess data and possible impact of structures or weaknesses on stability of pillars during pre-closure period. If required add rock support to strengthen pillars at affected locations. c) If possible, discontinuity(ies) will be grouted. Otherwise inflow will be directed to infloor drainage system leading to Main Sump.
Excavation Response Testing in Cobourg Formation Lower Member by: a) Geomechanical Testing b) Excavation Response & Stress Change Measurements	a) Successful testing of three large-scale (i.e. 160-mm diameter) rock samples yields median values for Unconfined Compressive Strength (UCS) that are less than 80 MPa and elastic modulus less than 30 GPa. b) Convergence of openings measured using MPBX (Multi-Point Borehole extensometer) installations, convergence pins and/or LIDAR surveys show	a) Assess data and perform geomechanical analysis with new UCS and elastic modulus data to determine possible impact on stability during preclosure period. b) Assess deformation and stress data, and perform geomechanical analysis to determine possible impact on stability during preclosure

Measurement	Preliminary Trigger Value or Observation	Action
c) Pillar Measurements	deformation exceeds 10 mm. c) Deformation of rock is greater than 10 mm. Change in stress greater than 5 MPa. Horizontal borehole inspection and/or geophysical survey of a rock pillar(s) reveals a major structure or weakness in rock pillar which would reduce its load carrying capacity.	period. c) Assess pillar data and perform geomechanical analysis to determine possible impact on pillar performance during pre-closure period. If structures or weaknesses present, assess data and peform analysis to determine possible impact on stability of affected pillar during pre-closure period. Possible remedial actions include: a) add rock support to improve stability; b) modify geometry of openings; and/or c) underground layout to thicken pillars.
In situ Stresses by Under-Excavation Test.	a) Magnitude of major horizontal principal stress exceeds 34 MPa. b) Orientation of major principal horizontal stress direction falls outside the sector bounded by N40°E and N100°E.	a) Assess in situ stress data and perform geomechanical analysis to determine possible impact on stability during preclosure period. Possible remedial actions include: a) add rock support to improve stability; and/or b) modify geometry of openings. b) Assess data and perform geomechanical analyses to assess impact of measured in situ stress conditions on performance of underground openings at repository horizon. If necessary, change layout of the underground repository so that the orientation of emplacement rooms falls within the range +/- 30° of the major principal horizontal stress direction.

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
EIS 12-512	• Section 14, Cumulative Effects	***Information Request:*** ***DGR Expansion Plans*** *Provide the existing Technical Assessment and all associated support documents for the expansion of the proposed DGR to accommodate the disposal of decommissioning waste, LLW and ILW, from the Pickering, Darlington and Bruce nuclear generating stations. The response must include plans for anticipated changes to both the physical layout of the subsurface (shafts, emplacement rooms, etc.) and surface (WRMA, SWMP, etc.) facilities and structures and their operational parameters.* *The anticipated timing of any expansion activities relative to currently proposed DGR phases must be included in this response.* ***Context:*** *The cumulative effects analysis presented in the EIS lists the emplacement of decommissioning waste from the OPG-owned and operated nuclear generating stations (Pickering, Darlington and Bruce) into the DGR as a reasonably foreseeable activity. The Hosting Agreement with Kincardine includes provision for accepting decommissioning waste into an expanded DGR (EIS, Table 10.4-3, item 31). An approximate doubling of the underground capacity was envisioned from ~200,000 m^3 to ~400,000 m^3 (IR EIS-04-145).* *Since the finalization of the EIS in 2011, the earlier than anticipated planned decommissioning of the Pickering Nuclear Facility has triggered the expectation from OPG that the L&ILW from that site would be placed into the proposed DGR. During the hearing OPG referenced the existence of an expansion Technical Assessment (Hearing Transcript Volume 23: October 28, 2013, p.121, l. 21) which details initial plans for the expansion and its impact on the proposed DGR.*
		OPG Response: The ability of the DGR Project to support the potential for future expansion is identified in the project requirements and was assessed as part of the design process. As such, a formal Technical Assessment report had not been prepared. However, the requested information is provided in Attachment A. This response includes the expansion layout referenced by OPG in the hearings as the expansion GA, or general arrangement drawing (Hearing Transcript Volume 23: October 28, 2013, p.121, l.21).

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IR#	**EIS Guidelines Section**	**Information Request and Response**
EIS 12a-512	• Section 14, Cumulative Effects	***Information Request:*** a) *Attachment A, Section 3 of the IR response relates only to waste conditions. Additional assessment of the impacts of extended operation of the repository on underground safety is required. OPG is to provide a discussion of excavation safety implications including the integrity of occupied excavations. For example, the expansion of the repository to accommodate decommissioning waste would extend the underground repository operational period which may impact the effectiveness of the planned support measures (such as rock bolts, shotcrete and other surface reinforcement tools) due to processes such as corrosion. Consideration of any changes to the frequency and extent of maintenance or replacement of support measures may also be required. Describe any underground safety-related strategies for possible future expansion that OPG has undertaken to incorporate during the initial development of the DGR. OPG referred to incorporating lessons learned from international waste repositories during the hearing (Transcript Volume 15: October 3, 2013, p. 177, l. 16), as well as in IR EIS-08-366 ("concurrent room excavation and waste emplacement, versus having these activities sequential is an important design and operational consideration").* b) *Provide further clarification regarding Short-Term and Long-Term Safety Implications of expanding the DGR.* *This information request arises from the need to determine whether factoring decommissioning waste into plans for the construction and the operation of the DGR would affect the current safety case (without decommissioning waste). Explain whether and how OPG would plan for and implement longer-term methods and measures to ensure underground safety, environmental protection, and safety of the public from the beginning of the project, illustrating a holistic understanding of the fundamental requirements for safety and environmental protection, should the project evolve.* *Examples of issues to consider during holistic planning (in addition to the two issues explicitly addressed below) include:* • *contingencies for unexpected variation in the lateral and vertical extent of the Cobourg Formation;* • *sequencing and configuration of emplacement rooms in order to optimize efficiency, safety and environmental protection (i.e., planning backwards from the inclusion of all decommissioning waste and looking for areas of risk that would require a new or enhanced mitigation approach, as well as opportunities for efficiency, such as in the timing of placement of certain types of waste);* • *the capacity that would ultimately be required for the stormwater management pond, and any associated impacts to wetlands; include consideration of handling and safe long-term disposal of solids from the bottom of the pond; and*

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IR#	**EIS Guidelines Section**	**Information Request and Response**
		- *air quality mitigation measures (contingencies that may be required for ventilation shaft emissions), given the nature of decommissioning wastes.* *The response to IR EIS-12-512 states that for Disruptive Scenarios, the impact remains within the risk criterion of 10-5 per year. Clarify the relative degree to which the criterion would be met for each disruptive scenario. It is understood that the clarification would be based upon a preliminary, qualitative assessment; however, it should be possible to provide an order of magnitude estimate of how close the disruptive scenarios may be to the risk criterion. The focus should be on the relative incremental risk created by inclusion of decommissioning waste. Provide an evaluation of new sources of risk (either the hazards themselves or changes in the likelihood of those hazards) that may be introduced by the inclusion of decommissioning waste.* *Provide further details regarding the implications of greater gas generation potential resulting from the increased volume of decommissioning waste. Provide information regarding the relative decrease in gas production potential that could be achieved through volume reduction, decontamination and recycling, and then use this information to estimate how much increased space would be required to accommodate predicted gas generation. It is understood that these additional details would be preliminary; however, it should be possible to provide the assumptions used to support the estimates of relative decrease of gas production potential as well as the estimates of additional space that may be necessary. Comment on how adding space to the repository would affect the overall design, integrity, and planned sequencing of the repository.* *c) Provide a graphic representation of the relative timelines of all phases of the conceptual expanded DGR to illustrate how these phases may interact and/or overlap with the phases of the DGR as described in the EIS. This graphic could be a modification of Figure 4.2-1 of the EIS. For additional clarity, also provide a version of Figure 2 from the response to IR EIS-12-512 (expansion layout) that shows the sequencing of panel and closure wall construction, waste emplacement, and temporary and/or permanent closures.* ***Context:*** *The IR follow up responses are required to add to the information provided in Attachment A, Section 3 of the OPG response to IR EIS-12-512 under the subheadings “Implications of Expansion on DGR Safety – Operational Safety Implications” and “Implications of Expansion on DGR Safety – Long Term Safety Implication”:*
		OPG Response: The responses are provided below.

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IR#	EIS Guidelines Section	Information Request and Response
		(a) Safety Impacts of Extended Repository Operation Ontario Power Generation (OPG) is seeking regulatory approval for a DGR site preparation and construction licence. The proposed DGR has a capacity of approximately 200,000 m^3 (packaged volume) for operational and refurbishment low & intermediate level waste (L&ILW). Once constructed, the repository is expected to receive these wastes over a nominal 40 year time period. However, the DGR facility design has taken into consideration the potential to operate beyond this timeframe by ensuring “difficult-to-replace” structures (e.g. shaft headframes, concrete shaft liners) have a nominal 100-year design life. All other structures, systems, equipment and components of the DGR will have shorter design lives (e.g. designed to National Building Code of Canada) but have considered the need for refurbishment and/or replacement. The expansion of the repository to accommodate decommissioning waste would extend the repository operational period from that currently proposed. However, the expansion would not adversely impact the effectiveness of the planned underground excavations and support measures, for example, due to processes such as corrosion. Excavations have been designed for a nominal 100-year life as there is the need to consider potential extended monitoring requirements and facility decommissioning following the operational period. Inherent in the design is the requirement for long-term stability of the repository. This is reflected through the selection of pillar widths between emplacement rooms and adjacent panels. Also, during the operating phase, the design allows for closure of waste filled rooms through the use of closure walls or plugs. Once closed in this manner, the panel or sections of emplacement rooms are isolated from possible expansion activities. To ensure the integrity of occupied underground spaces through all phases of development and operation, the following ground support installation, inspection, testing and maintenance measures have been considered: 1. Double corrosion protection for rock bolts. Bolt heads would be protected by grease caps before they are covered with shotcrete to facilitate future inspection and testing of bolts. 2. Cable bolts installed with double corrosion system such as flow-filled epoxy-coated strands or equivalent to minimize the risk of corrosion. Cathode protection systems could also be installed on all cable bolts to provide redundant corrosion protection. 3. At time of installation, selected bolts will be proof-tested and performance-tested as per recognized standard or procedure (e.g. ASTM D4435-13, BS8081:1989 or equivalent) to confirm that the bolts have been installed in accordance with specifications. If there is evidence of improper bolt installation, the load capacity of the defective bolt will be degraded and additional bolts will be installed and tested. 4. During operations there will be on-going visual inspection of the ground support systems. After approximately 20 years of operation (or sooner if visual inspection indicates problem bolts), there will be non-destructive testing

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of selected rock bolts and cable bolts to confirm integrity of bolts. Systematic testing would be performed in accordance with a recognized standard or procedure.

5. Rock deformation/movement (e.g. by extensometers and other instruments) will be performed throughout the operations phase as per the Geoscientific Verification Plan (NWMO 2014) to detect excessive rock deformation and possible overloading of rock bolts or cable bolts. Additional rock support will be installed, as required, in the event that rock deformation exceeds a predefined allowable amount of deformation.
6. In underground areas still in service or occupied after a nominal 60 years, rock support systems would be replaced by installing new rock bolts/cable bolts as needed. The new bolts would be installed, inspected, tested and maintained in a similar manner as described above.

(b) Short-Term and Long-Term Safety Implications of Expanded Repository

The response is provided in three sub-sections: (b.1) holistic planning; (b.2) disruptive scenarios; and (b.3) gas generation.

(b.1) Holistic Planning

OPG has applied a holistic planning approach to the DGR project since the conceptual design phase. As detailed in the original EIS-12-512 response (OPG 2014), several key construction and operational aspects have been assessed for potential impacts of an expanded DGR, or the need to increase the proposed facility operational life for extended DGR monitoring and decommissioning.

The characteristics of decommissioning waste will be assessed in detail closer to the time of decommissioning, and in advance of a decision to seek an expansion licence. As discussed in Section (c) below, this will be decades in the future. However, decommissioning waste packages are currently expected to meet the current waste acceptance criteria for the DGR. As such, outside of increasing the operational timeframe, the DGR could operate in a very similar manner to that currently proposed. The potential impacts to both the construction and operational periods, as described in EIS-12-512 (OPG 2014), took this into account.

The following provides additional information specific to the items identified for consideration in the information request:

- *contingencies for unexpected variation in the lateral and vertical extent of the Cobourg Formation;*

  The confidence in the Cobourg Formation for the proposed DGR has been presented based on a detailed site characterization program. This confidence will be further supported and verified through the development of the DGR. The proposed conceptual configuration of an expanded DGR shown in Figure 2 of EIS-12-512 (OPG 2014)

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<tr><td></td><td></td><td>considers features of the Cobourg Formation (e.g. dip, thickness, principle stress direction) as well as features of the proposed design (e.g. shaft locations and common services, ventilation, panel access) to minimize additional excavation and infrastructure. As indicated in Section (c) and the initial response to EIS-12-512 (OPG 2014), additional site characterization to the same level of detail as with the current application will be required to support the decision to proceed with the expansion of the DGR for decommissioning waste. To be specific, variations in the lateral and vertical extent of the Cobourg Formation would be identified and evaluated as part of the future decision to proceed.
• *sequencing and configuration of emplacement rooms in order to optimize efficiency, safety and environmental protection (i.e., planning backwards from the inclusion of all decommissioning waste and looking for areas of risk that would require a new or enhanced mitigation approach, as well as opportunities for efficiency, such as in the timing of placement of certain types of waste);*
Section (c) shows two sequencing illustrations based on the early and late decision options. The exact sequencing of emplacement rooms would be, in part, dependent on the timing of decommissioning. Based on the assumed characteristics of wastes arising from decommissioning, it is not expected that a significant postclosure safety advantage would result from mixing or segregating such wastes from wastes arising from operational and refurbishment activities. The general plan of emplacement aligns with when the wastes become available. Mixed placement of wastes arising from operations and decommissioning within panels would, in such circumstances, be operationally efficient, depending on when an expansion licence might be requested. Should waste from decommissioning be received before Panel 1 is completely filled, it would be practical to place waste in these areas first.
• *the capacity that would ultimately be required for the stormwater management pond, and any associated impacts to wetlands; include consideration of handling and safe long-term disposal of solids from the bottom of the pond; and*
As discussed in the response to EIS-12-512 (OPG 2014), the potential expansion is not expected to result in the need for additional holding capacity of the stormwater management pond. However, should this be required, there is sufficient space on the site, moving away from the north wetland, to increase the size of the pond. As for the on-going operational management of the pond (i.e. removal of fines from the pond), it is expected that these materials will be retained within the project site or the Bruce nuclear site. Prior to removal, the fines will be sampled, analysed, and should there be a need, appropriate off-site waste management plans developed.</td></tr>
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		• *air quality mitigation measures (contingencies that may be required for ventilation shaft emissions), given the nature of decommissioning wastes.* As described in the response to EIS-12-512 (OPG 2014), the waste types arising from decommissioning are expected to be fundamentally the same as the waste arising from operations and refurbishment, but the amounts of the various wastes and the key radionuclides are expected to be different. However, all waste packages must meet the DGR waste acceptance criteria. Where the wastes are different, such as the potential increased volume of metals, this does not impact the preclosure, or operational considerations of the DGR. Waste package off-gassing during operations is not expected to be materially different than that of operational and refurbishment waste. Air quality requirements and monitoring are expected to remain the same as for the current proposed DGR, however further assessments will be performed prior to applying for an expansion licence. The current design of the ventilation systems uses the ALARA principles to keep the workers in the fresh air supply and minimizes exposure to workers through the ventilation return tunnels. Waste packages will be required to meet the waste acceptance criteria ensuring that packages are covered and there is no loose contamination. **(b.2) Postclosure Disruptive Scenarios** The response to IR EIS-12-512 (OPG 2014) provides preliminary, qualitative information on the implications of wastes arising from decommissioning on the Normal Evolution Scenario and on Disruptive Scenarios based on preliminary waste characteristics. This information is preliminary and would need to be further assessed with more detailed waste characterization data for waste arising from decommissioning in advance of a future expansion application. Further information on the Disruptive Scenarios is provided below. Table 1 below summarizes the calculated maximum doses to an adult and the dominant radionuclides (i.e. those that contribute more than 95% of the maximum dose) for each of the Disruptive Scenarios assessed for the DGR containing operational and refurbishment wastes (Section 8.7 of OPG 2011a).

Table 1. Calculated Maximum Doses to an Adult for Disruptive Scenarios for Operational and Refurbishment Wastes

Disruptive Scenario	Calculation Case	Maximum Calculated Dose (mSv/a)	Dominant Radionuclide
Human Intrusion	HI-BC	1	Nb-94
	HI-GR2	30	C-14
Severe Shaft Seal Failure	SF-BC	1	C-14
	SF-ED	80	C-14
Poorly Sealed Borehole	BH-BC	$< 10^{-6}$	Zr-93
Vertical Fault	VF-BC	$< 10^{-6}$	Zr-93
	VF-AL	$< 10^{-6}$	Zr-93

The waste types from decommissioning are similar to wastes arising from operations and refurbishment, but different in amounts and key radionuclides (see response to EIS-12-512, OPG 2014). The main differences in sources of risk are likely to be from the increased total DGR radionuclide inventory, the increased repository footprint, and the increased gas generation from metal.

As noted in the response to EIS-12-512 (OPG 2014), the inventories of Ni-59, Ni-63, Fe-55, Co-60, Cl-36 and Ca-41 are expected to be significantly higher in wastes from decommissioning than in operational and refurbishment wastes. However, as the above table shows, these radionuclides are not significant contributors to the dose impacts from the Disruptive Scenarios and so an increase in their inventory is not expected to increase maximum calculated doses.

It is anticipated that the inventory in wastes arising from decommissioning for other radionuclides will be broadly similar to that for operational and refurbishment wastes. Thus, assuming a factor of two increase in the total Zr-93 inventory including decommissioning wastes, the maximum calculated dose for the Poorly Sealed Borehole and Vertical Fault Scenarios can be expected to increase by a factor of two. It would still remain several orders of magnitude below the 1 mSv/a dose criterion for disruptive events for these scenarios.

Similarly, based on estimates that the wastes arising from decommissioning are expected to have approximately similar amounts of C-14 and Nb-94 to that in the current licence application for wastes arising from operations and refurbishment (see response to EIS-12-512, OPG 2014), it can be expected that the maximum calculated doses associated with the Human Intrusion and Severe Shaft Seal Failure Scenarios would increase by around a factor of two for an expanded DGR. Thus the 1 mSv/a dose criterion for disruptive events would be exceeded for both these

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		scenarios. Therefore the acceptability of results from these two scenarios needs to take into account their probability and be compared with a reference health risk value of 1 x10^{-5}/a (Section 8.1.2 of OPG 2011a). For the Human Intrusion Scenario, a probability of occurrence of 10^{-5}/a was estimated for the DGR based on the arguments presented in Section 8.7.1.3 of OPG 2011. Increasing the DGR footprint by about a factor of 2 to accommodate L&ILW from decommissioning will also increase the probability of accidental intrusion by the same factor to around 2x10^{-5}/a. Combined with the increased inventory, the expanded DGR would have around a factor of four increase in risk from Human Intrusion compared to that for the DGR without L&ILW from decommissioning. However, the estimated risks remain more than two orders of magnitude below the reference health risk value of 1x10^{-5}/a (e.g. 2x10^{-5}/a (probability) × 60 mSv (dose) × 5.7x10^{-5}/mSv (dose health risk) = 7x10^{-8}/a for the HI-GR2 case that assumes the intruding borehole penetrates through the repository and continues into the pressurized Cambrian Formation and is not appropriately sealed). For the Severe Shaft Seal Failure Scenario, the risk would increase by about a factor of two due the increased C-14 inventory for the expanded DGR, assuming the design maintained the same gas pressure basis. However, the risk from this scenario would remain below the reference health risk value of 1x10^{-5}/a as long as the likelihood of the scenario remained less than around 0.09 per year (1x10^{-5}/a (risk criterion) / [2 mSv (dose) × 5.7x10^{-5}/mSv (dose health risk)]). The probability of the base case Severe Shaft Seal Failure Scenario (i.e., the 500 m composite shaft seal permeability increasing by a factor of 100 to 1000, combined with a house positioned directly above one of the DGR shafts, can sensibly be reasoned to be much lower than 0.09 per year. For the even more conservative, and less likely, extreme degradation calculation case which assumes the entire shaft seal degrades to a hydraulic conductivity of fine silt/sand, the associate scenario likelihood must be 0.001 or less per year for an expanded DGR (1 x10^{-5}/a (risk criterion) / [160 mSv (dose) × 5.7x10^{-5}/mSv (dose health risk)]). **(b.3) Gas Generation Implications** Preliminary projections for wastes arising from decommissioning indicate that these wastes will contain a larger proportion of metals than in the wastes from operations and refurbishment. This would result in more gas generated from anaerobic metal corrosion within the repository in the long-term. The metal would be primarily LLW, and thus likely largely surface contaminated. In principle, the metal can be accommodated by either increasing the excavated volume of the repository, or alternatively by disposing the LLW metal in a surface disposal facility. However the preferred option would be to minimize the amount of metal through decontamination and recycling, and then placement of the remaining amount in an expanded DGR. For example, based on preliminary estimates, separation of the clean carbon steel from steam generators could reduce the steam generator metal inventory by as much as 90%. Also, replacing all the metal containers with concrete

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		containers would reduce the decommissioning metal inventory by about 10%. Emerging decommissioning techniques are showing good potential, with some suppliers suggesting 90% metal decontamination is achievable. Since an OPG decision to emplace decommissioning waste into the DGR would not be made until 20-40 years from now (see c) below), it is reasonable to assume that advancement in technology will contribute to a meaningful reduction in the large volume of the LLW metals currently anticipated to result from decommissioning activities. Therefore the design, integrity and sequencing based on a doubling of the repository capacity, as outlined in the EIS and in the response to EIS-12-512, remains a reasonable conceptual basis. **(c) Relative Timelines** For clarity of the relative range of timelines associated with potential DGR expansion, OPG is providing Figures 1 and 2 in a similar format to that of EIS Figure 4.2-1 (OPG 2011b). However, Figures 1 and 2 reflect the latest assumptions about key near-term milestones in the DGR project. These figures are intended to illustrate the large range in time in which OPG may make the business decision, if necessary, to expand the DGR to accommodate additional volumes of L&ILW. Note that similar to the original Figure 4.2-1, the timescale across the top of each figure is truncated as necessary to best illustrate the relationship and sequence of the assumed activities with the early and late scenarios provided. Figure 1 illustrates an early scenario where an OPG decision to expand the DGR is made near the end of 2035. Assuming that it would take 4 years for the design/regulatory approvals process and 4 years for construction, the repository would be available to receive decommissioning L&ILW starting in 2044 which is the earliest start date for Pickering NGS decommissioning. In this scenario, decommissioning waste would not require sustained interim waste storage either at the reactor site or the Western Waste Management Facility. Figure 2 illustrates a late scenario where an OPG decision to expand the DGR is made in the 2060’s at the end of the proposed DGR operations period. Before any work would begin on the decommissioning and closure of the DGR, OPG would consider various options for long-term management of decommissioning L&ILW and then make a decision on whether to send decommissioning wastes to the DGR. In this scenario, prior to the expansion of the DGR, Pickering decommissioning L&ILW would be placed in interim storage or alternative means for disposal identified. The two scenarios provided show that OPG has a broad range of time from the mid 2030’s to the mid 2060’s in which to make a business decision for the potential expansion to the DGR. Figure 3 shows the layout of the repository after expansion, as previously presented. Figures 4 and 5 provide illustrations for the sequencing for the above two expansion decision options. In all cases, the intent is to minimize the time that rooms remain open to avoid the need to replace ground support systems, and to

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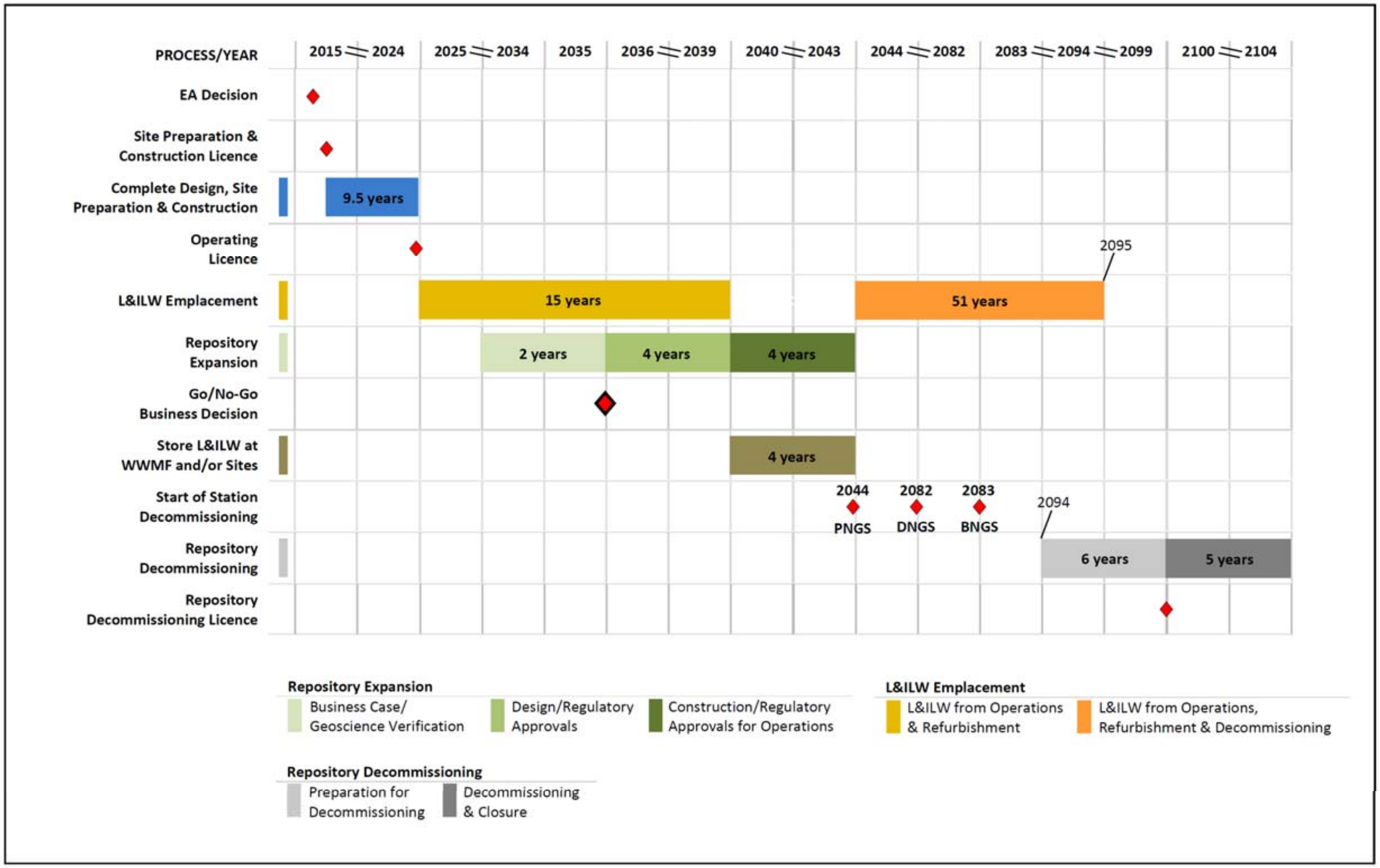
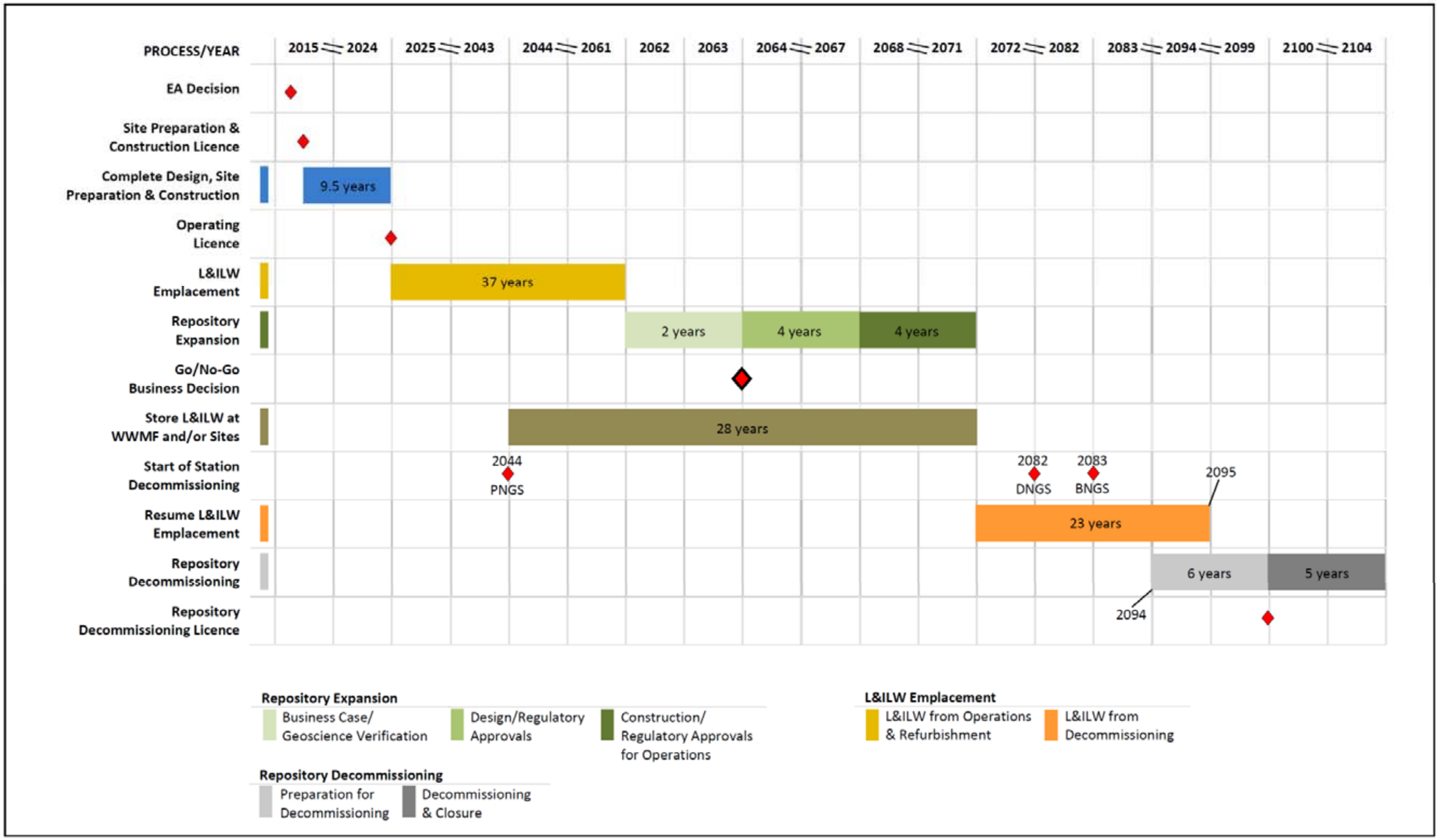
<tr><td></td><td></td><td>isolate waste-filled emplacement rooms before expansion excavations begin. For illustrative purposes, construction periods are shown in green and operational periods shown in yellow.
Figure 4 shows the possible sequencing of activities for the early scenario. Panel 2 is filled with operational and refurbishment L&ILW from the WWMF and isolated with closure walls. This timing corresponds with the planned timing for a business decision to expand the DGR. Waste placement ceases and Panels 3 and 4 are constructed. Upon re-initiation of waste placement following regulatory approval, L&ILW operational, refurbishment and decommissioning waste could be placed concurrently and not segregated to specific areas of the DGR where the waste type and packaging permits. The initial rooms of Panel 1 could remain available for rail-based wastes and the remainder of the repository filled to minimize the time emplacement rooms remain open (i.e. starting in Panel 1). Waste filled panels would be closed or isolated with closure walls following completion of emplacement within the panel. These considerations are illustrated in Figure 4, however, the final arrangement of emplacement would need to be reviewed as part of the expansion decision process.
Figure 5 shows the sequencing for the late scenario. This option does not provide the opportunity for concurrent emplacement as the timing for the decision is not made until the proposed DGR is full of waste arising from operations and refurbishment. All waste filled panels would be isolated by closure walls prior to the initiation of construction. As with the proposed DGR, following construction, the waste arising from decommissioning would fill from the farthest rooms and work back towards the shafts, with closure walls following panel completion.
References:
ASTM D4435-13. Standard Test Method for Rock Bolt Anchor Pull Test, ASTM International, United States.
BS 8081:1989. Code of Practice for Ground Anchorages, British Standards Institution, Great Britain.
NWMO. 2014. Geoscientific Verification Plan. Nuclear Waste Management Organization document NWMO DGR TR-2011-38 R001. Toronto, Canada. (CEAA Registry Doc# 1792)
OPG. 2011a. OPG’s Deep Geologic Repository for Low and Intermediate Level Waste – Preliminary Safety Report. Ontario Power Generation report 00216-SR-01320-00001 R000. Toronto, Canada. (CEAA Registry Doc# 300)
OPG. 2011b. OPG’s Deep Geologic Repository for Low and Intermediate Level Waste – Environmental Impact Statement. Ontario Power Generation report 00216-REP-07701-00001 R000. Toronto, Canada. (CEAA Registry Doc# 298)
OPG. 2014. Attachment A to OPG’s response to Information Request EIS-12-512 in OPG Letter, A. Webster to S. Swanson, “Deep Geologic Repository Project for Low and Intermediate Level Waste - Submission of Response to Information Request EIS-12-512”, CD# 00216-CORR-00531-00219, January 22, 2014. (CEAA Registry Doc# 1788)</td></tr>
</table>



Note: All dates are nominal.

Figure 1 (associated with response to IR-EIS-12a-512): Timeline for Project Implementation - Estimated Early Business Decision on Expansion Scenario



Note: All dates are nominal.

Figure 2 (associated with response to IR-EIS-12a-512): Timeline for Project Implementation - Estimated Late Business Decision on Expansion Scenario

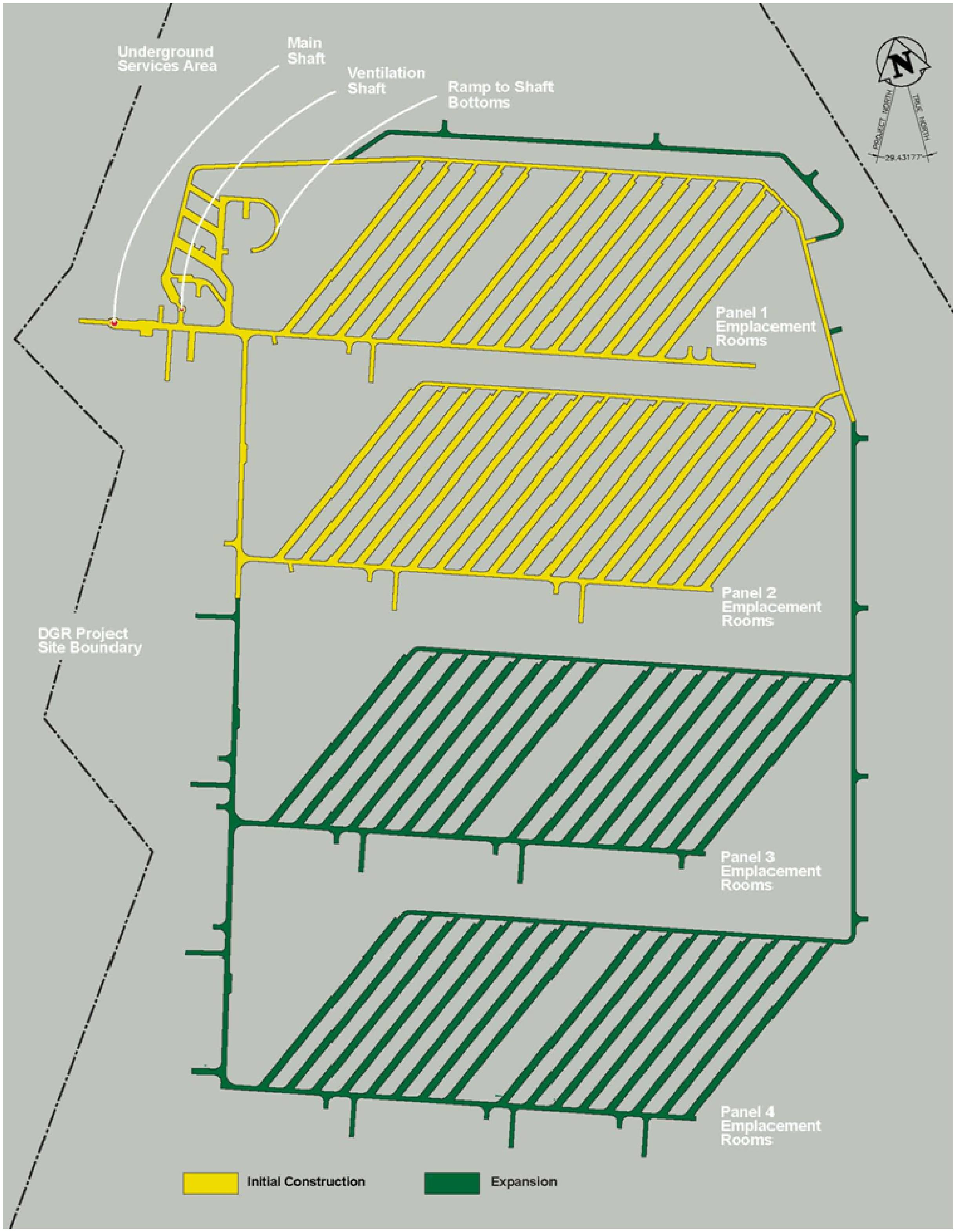
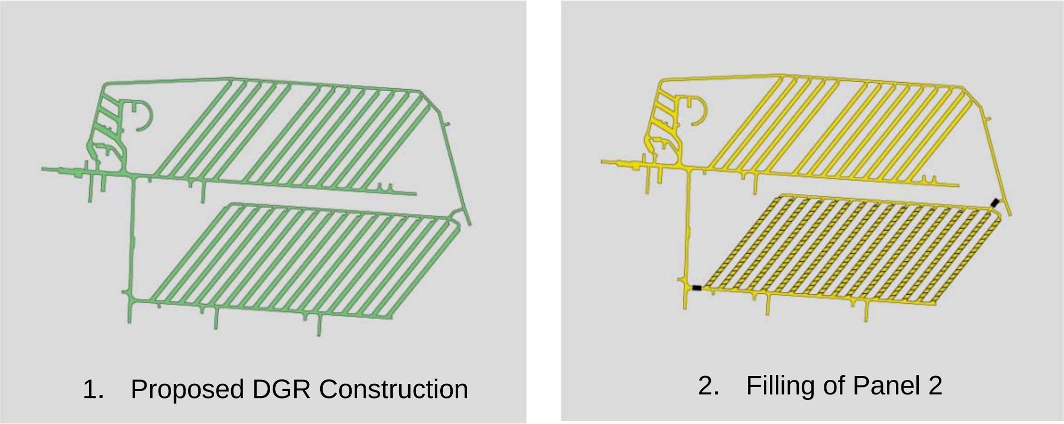
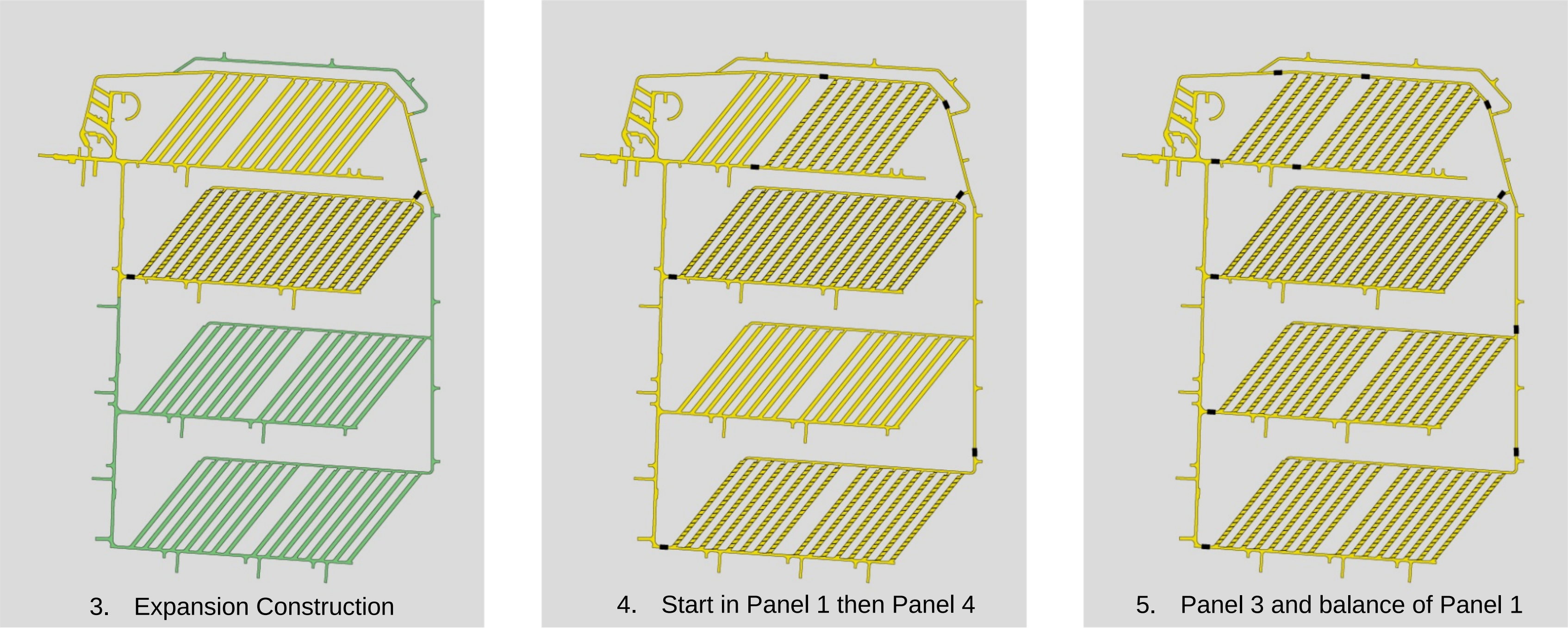


Figure 3 (associated with response to IR-EIS-12a-512): OPG's Deep Geologic Repository for L&ILW – Conceptual Expansion Layout



1. Proposed DGR Construction

2. Filling of Panel 2

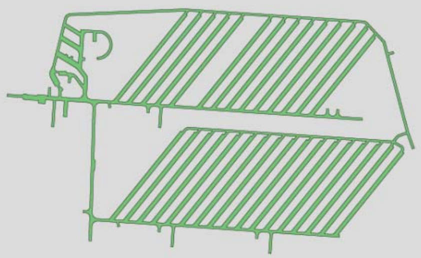


3. Expansion Construction

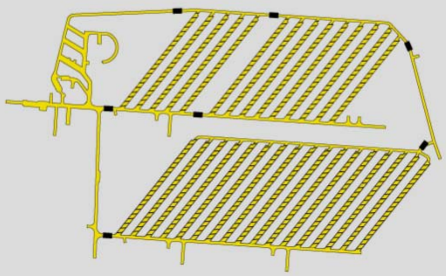
4. Start in Panel 1 then Panel 4

5. Panel 3 and balance of Panel 1

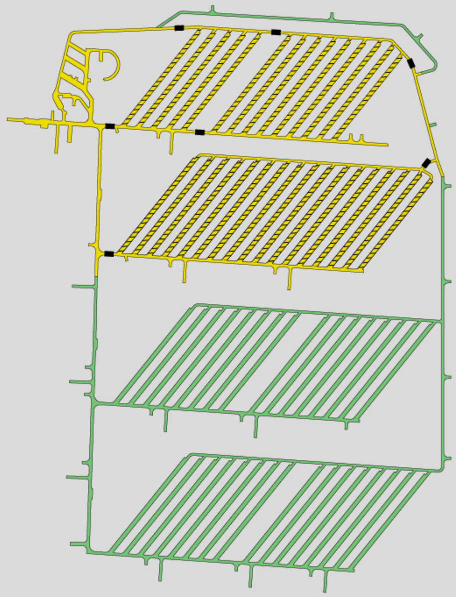
Figure 4 (associated with response to IR-EIS-12a-512): Early Expansion Decision Emplacement Sequencing



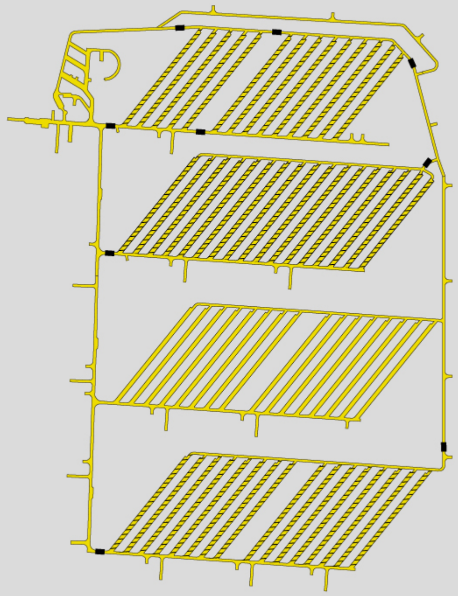
1. Proposed DGR Construction



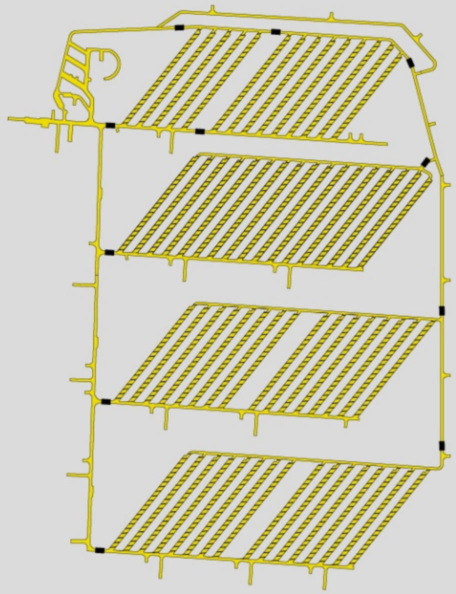
2. Filling of Panel 1 and Panel



3. Expansion Construction



4. Fill Panel 4

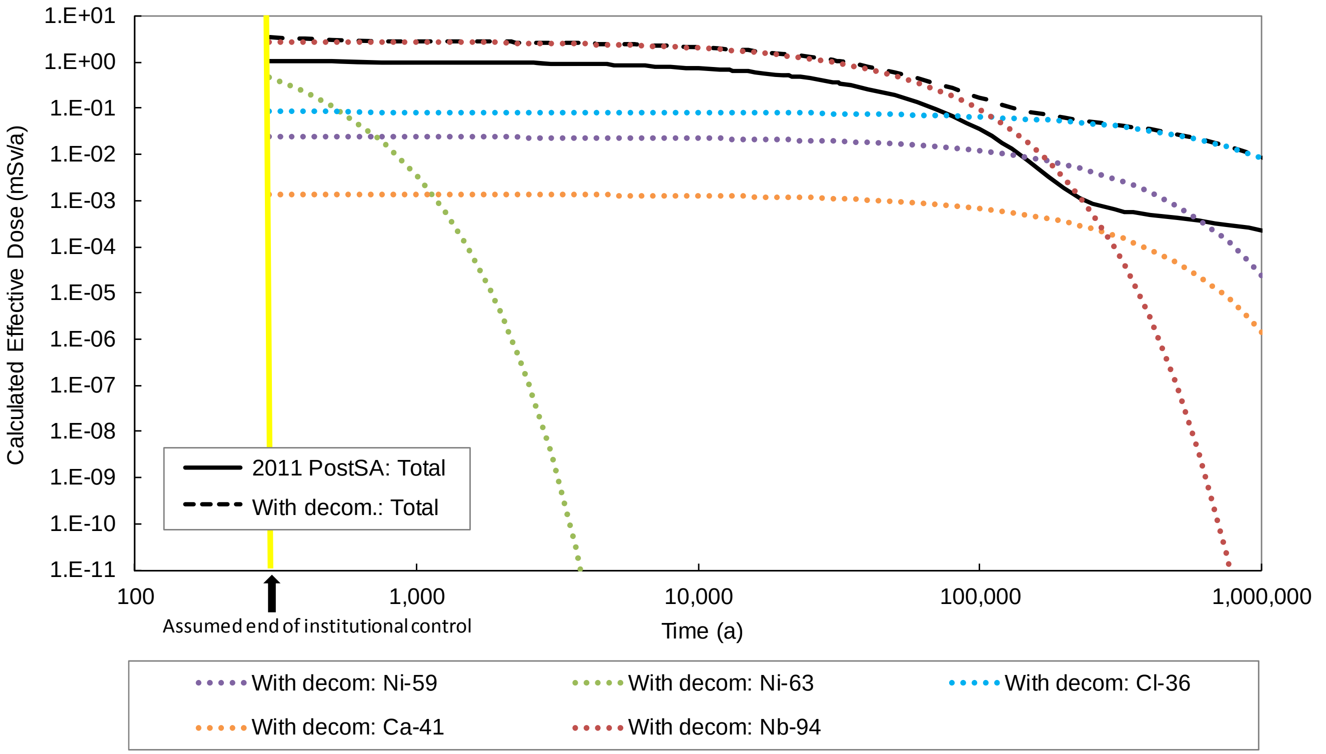


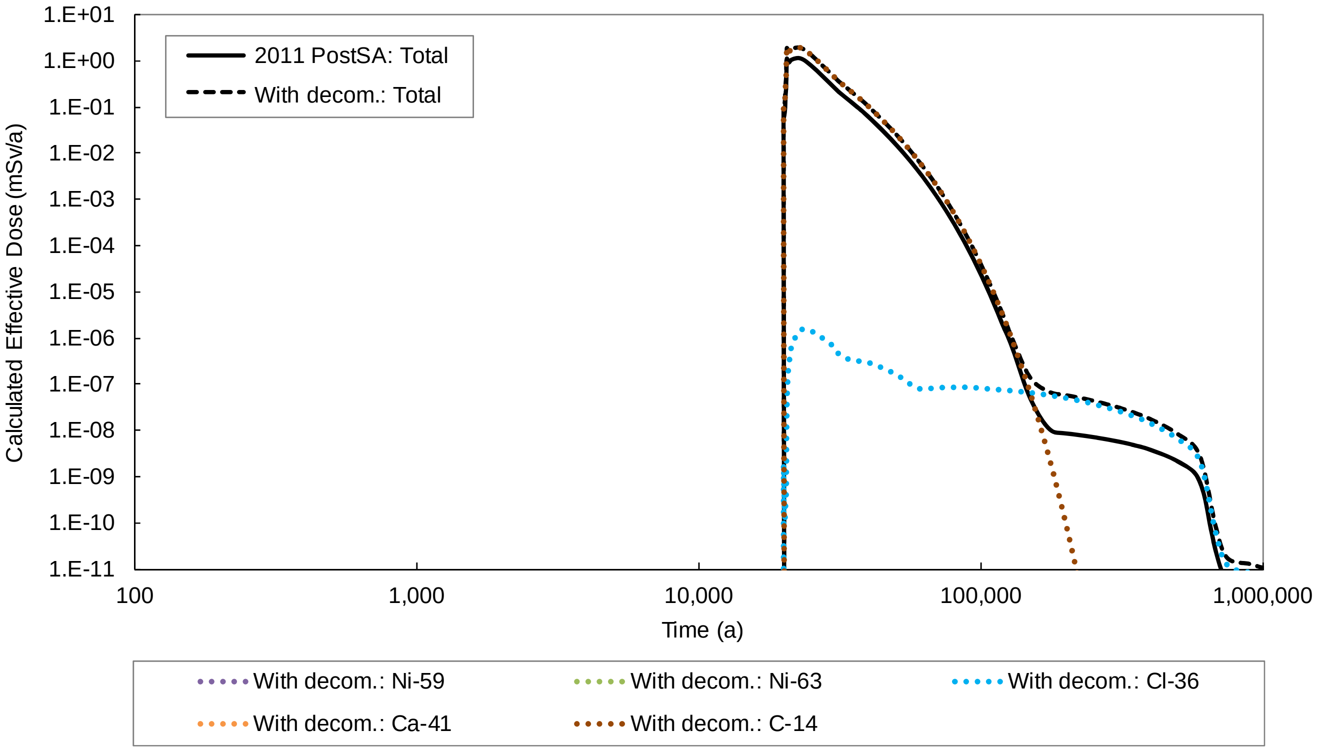
5. Completion with filling Panel 3

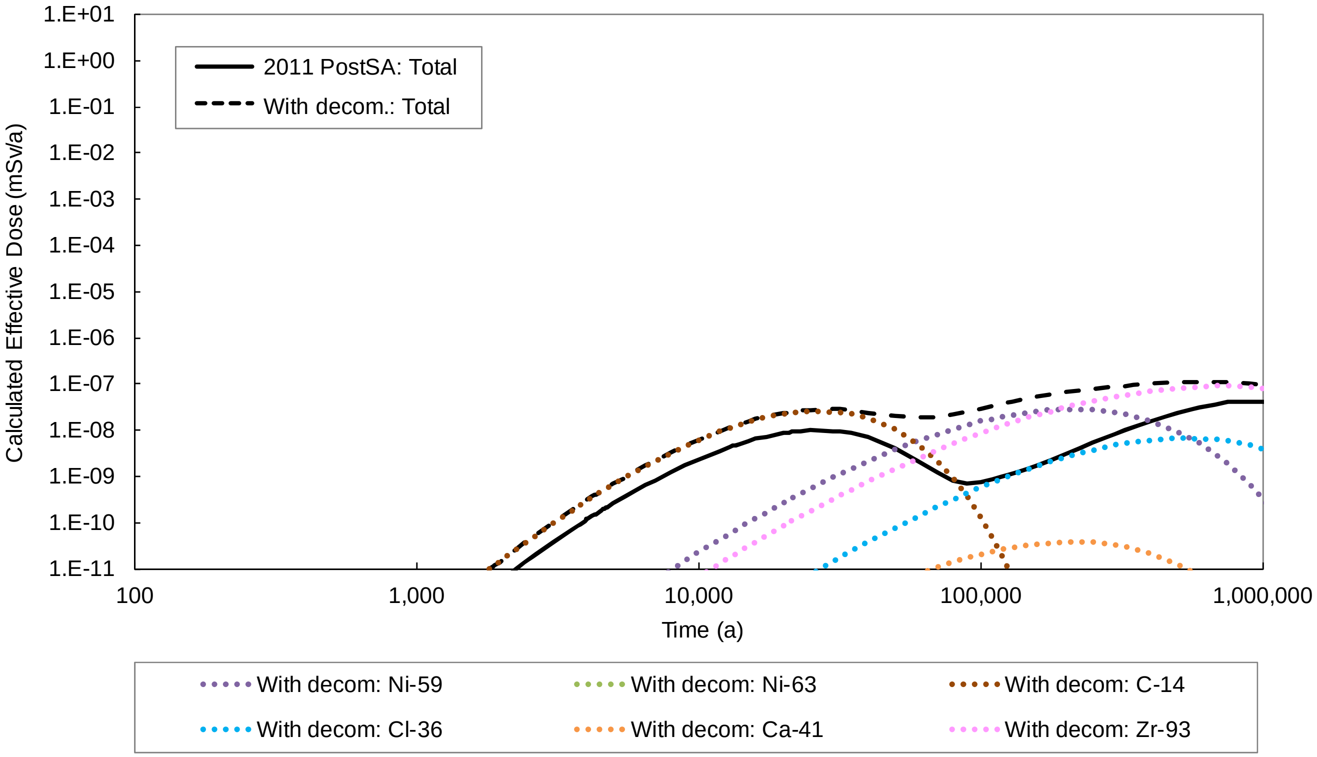
Figure 5 (associated with response to IR-EIS-12a-512): Late Expansion Decision Emplacement Sequencing

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
EIS-12b-512	- Section 14, Cumulative Effects	***Information Request:*** *Provide a more detailed evaluation of the contribution of the radionuclides “expected to be significantly higher in wastes from decommissioning than in operational and refurbishment wastes” to the maximum doses for each of the Disruptive Scenarios for an expanded repository than was provided in the response to information request EIS 12a-512.* ***Context:*** *In Section (b.2) - Postclosure Disruptive Scenarios - of the response to EIS 12a-512, OPG addresses the anticipated impact of decommissioning waste on the maximum dose rates to an adult for disruptive scenarios. It is stated that "The waste types from decommissioning are similar to wastes arising from operations and refurbishment, but different in amounts and key radionuclides..." and that "...the inventories of Ni-59, Ni-63, Fe-55, Co-60, Cl-36 and Ca-41 are expected to be significantly higher in wastes from decommissioning than in operational and refurbishment wastes." Some of the significantly more abundant radioisotopes have long half-lives (e.g., Ca-41 at $1x10^5$ years).* *While the response notes that "... these radionuclides are not significant contributors to the dose impacts from the Disruptive Scenarios and so an increase in their inventory is not expected to increase maximum calculated doses," a fuller evaluation of their contribution to maximum doses for each of the Disruptive Scenarios for an expanded repository was not provided.*

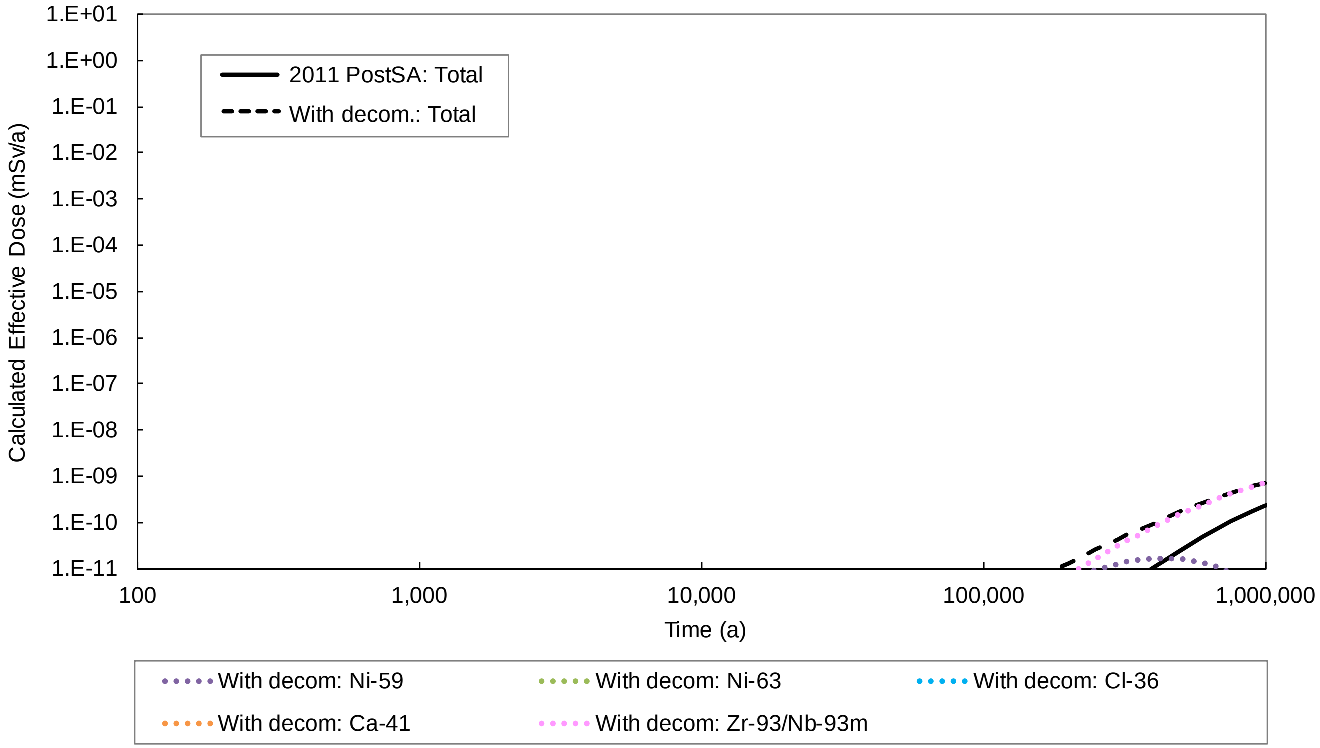
OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		OPG Response: In response to this Information Request, the following figures (i.e., Figure1 through Figure 4) show the potential contribution of the requested radionuclides Ni-59, Ni-63, Cl-36 and Ca-41 to the postclosure dose rate as a function of time for different Disruptive Scenarios. These figures also include the dominant radionuclide, if different than the requested radionuclides. The short half-lives of Fe-55 (2.7 a) and Co-60 (5.3 a) mean that these are not significant in postclosure safety despite the additional inventory. The postclosure safety assessment results shown in the figures indicate that, when including the estimated additional decommissioning inventory, the identified radionuclides contribute to the peak dose rate, but are not expected to dominate the maximum doses for each of the Disruptive Scenarios. The increases in the peak dose rates in these figures are primarily due to the increased amount of C-14, Nb-94 and Zr-93 from the wastes arising from decommissioning, as previously noted in the response to EIS-12a-512. These results must be considered as illustrative because: • The inclusion of wastes arising from decommissioning within the DGR would be subject to a future decision and a licensing process, and would require a detailed analysis. • The amount of wastes are based on conceptual plans for decommissioning methods, waste segregation and volume reduction. • The detailed characterization of the wastes arising from decommissioning will not be completed for 20-30 years until after the units have been shutdown; these results are based on an early estimate. • A detailed repository expansion design for wastes arising from decommissioning has not been completed. • The postclosure safety assessment results presented here were simply obtained by adding the estimated decommissioning inventory to the reference 2011 DGR postclosure inventory, rather than by a detailed model of the expanded repository.

IR#	EIS Guidelines Section	Information Request and Response
		 **Figure 1. Human Intrusion Base Case scenario results for 2011 safety assessment and with decommissioning wastes, showing the contribution of the specified decommissioning radionuclides.**

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		 **Figure 2. Severe Shaft Seal Failure Base Case scenario results for 2011 safety assessment and with decommissioning wastes, showing the contribution of the specified decommissioning radionuclides.**

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		 **Figure 3. Poorly Sealed Borehole scenario results for 2011 safety assessment and with decommissioning wastes, showing the contribution of the specified decommissioning radionuclides.**

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13

IR#	EIS Guidelines Section	Information Request and Response
		 **Figure 4. Vertical Fault Base Case scenario results for 2011 safety assessment and with decommissioning wastes, showing the contribution of the specified decommissioning radionuclides.**

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13

IR#	EIS Guidelines Section	Information Request and Response
EIS 12-513	• Section 7.3, Alternative Means of Carrying out the Project	***Information Request:*** ***Alternative Means Risk Analysis*** *Provide a renewed and updated analysis of the relative risks of siting alternatives under alternative means requirements of the EIS Guidelines. This analysis should be undertaken by independent risk assessment experts. The analysis is to be qualitative, transparent, defensible, and repeatable.* *Options to be analyzed:* *1. "As is" facility at the WWMF (the status quo)* *2. Enhanced surface storage at the WWMF (“hardened” storage)* *3. Proposed DGR in the Cobourg Formation at the Bruce Power site* *4. A conceptual DGR in granitic bedrock of the Precambrian Canadian Shield. Information required for the qualitative analysis of a conceptual DGR in granite bedrock should be based primarily upon the extensive data and analyses available within the environmental assessment performed by Atomic Energy of Canada Limited (AECL) for the Environmental Assessment Panel for Nuclear Fuel Waste Management and Disposal Concept (known as the Seaborne Panel).* *Analysis of risks to socio-economic factors (such as physical, social and financial assets) is not required because the conceptual DGR in granite is not located in a specific geographic location.* *The relative risk of each alternative should be assessed for normal operations and for selected accidents, malfunctions and malevolent acts. The accidents, malfunctions and malevolent acts that were assessed in the EIS can be used for the risk analysis.* *Effects of the environment on relative risk must also be included; specifically, the relative risk associated with severe weather events – particularly under climate change scenarios.* *The relative risk analysis should include the following:* • *Worker Health and Safety: construction, operation and decommissioning* • *Public Health and Safety: construction, operation, decommissioning and post-closure* • *Risks to Safety Case:* o *Advective water flow around and through the facility* o *gas generation* o *physical disruption*

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13

IR#	EIS Guidelines Section	Information Request and Response
		▪ *seismic* ▪ *structural failures* ▪ *major fracturing* o *chemical/physical degradation of waste containers (assuming containers are as described in the EIS and further described in IR responses and during the Hearing)* ▪ *seepage* ▪ *release rates* ▪ *microbial activity* o *transport of released radionuclides* ▪ *sources* ▪ *travel times to nearest receptor (radionuclides and other constituents of concern such as metals)* · *near-field and far-field risks (including Lake Huron)* ▪ *air emissions* · *sources* · *near-field and far-field risks (including Lake Huron)* o *waste transportation to and on the site* o *requirement for institutional controls, short and long term* ▪ *passive and active* o *contribution to sustainability* ▪ *add the conceptual granite bedrock location to the results of Table 1 in the OPG response to IR EIS-06-273 and Table 1 of OPG response to IR EIS-06-278* o *community acceptance* ▪ *in the Local and Regional Study Area* ▪ *Outside of the Regional Study Area* ***Context:*** *The analysis of alternative sites in Section 3.4.2 of the EIS was limited to locations within the Bruce Nuclear site and a very generic "off the Bruce nuclear site" location.* *The comparison of alternatives in the assessment was based upon a simple binary scoring system that involved a significant amount of professional judgment. The rationale for the scores assigned to the alternatives was not presented in the EIS. The reliability and defensibility of the score assigned to the "off the Bruce nuclear site" alternative, for example, cannot be assessed with confidence (the off-site alternative was assigned a score of 11 versus a score of 6 for the proposed on-site DGR), despite OPG responses to Information Requests such as EIS-03-49 which asked for a*

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		detailed description of the alternative means options analysis. *Previous OPG responses to information requests related to alternative sites placed emphasis on the importance of the results of the Independent Assessment Study (Golder 2004) and the Municipality of Kincardine's willingness to host the facility. OPG Response to EIS-02-40 relates that, "Based on the results of this assessment, and because the Municipality of Kincardine had approached OPG to initiate the study of the WWMF as a long-term L&ILW waste management facility and is therefore a willing host, OPG did not actively solicit other potential host communities or undertake geoscientific studies at other sites. The feasibility studies for the Independent Assessment Study (GOLDER 2004) were a very public process and during this process, no other municipalities approached OPG seeking to be considered as a potential host for a long-term L&ILW facility. Canadian and international experience at the time also showed that existing nuclear communities are more receptive to hosting waste management facilities. Recent experience shows that without a willing host municipality the siting of a deep geologic repository for nuclear waste is not feasible."*
		OPG Response: The updated analysis of the relative risks associated with the four options identified in the Information Request is presented in the enclosed report (IEG 2014a). This analysis has been undertaken by an Independent Expert Group retained by OPG. The correspondence from the Independent Expert Group to OPG is also enclosed (IEG 2014b). Further information addressing the Panel's follow-up comments (JRP 2014) on the comparison of risk perception among the four options will be submitted separately. **References:** IEG. 2014a. Report of the Independent Expert Group on Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario. Submitted by M. Dusseault, T. Isaacs, W. Leiss (Chair), G. Paoli to the Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR), March 25, 2014. (enclosed) IEG. 2014b. IEG letter from Dr. W. Leiss to Laurie Swami, March 28, 2014. (enclosed) JRP. 2014. JRP letter from Dr. Stella Swanson to Laurie Swami, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Independent Risk Assessment Expert Group Comments on Relative Risk Analysis of Community Acceptance in IR EIS-12-513", March 6, 2014, CD# 00216-CORR-00531-00228. (CEAA Registry Doc# 1806)

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
EIS 12-513a	▪ *N/A*	*[OPG provided further information addressing the Panel's clarification comments on the relative risk analysis of community acceptance in Information Request EIS-12-513. The attachment to the letter to JRP contains the report prepared by the independent risk assessment experts retained by OPG, providing the requested clarifications.]*
EIS 12b-513	▪ Section 7.3, Alternative Means of Carrying out the Project	***Information Request:*** *a) Provide an indication of the log-log scale on the risk assessment plots, both Relative Risk and Absolute Risk, for the 12 key features (or pathways of harm) for comparison among the 4 alternatives for the near term (<100 years) and long term (>100 years) in order that the reader may distinguish negligible, low, moderate, high or very high risk assessments on these scales.* *b) Provide a table and/or figure with accompanying explanatory narrative that summarizes the overall relative risks of the four identified options for the long-term management of low and intermediate level waste, over both timeframes (<100 years and >100 years). Include this summary in OPG's separate submission to address the Panel's follow-up comments on the comparison of risk perception among the four options.* ***Context:*** *a) In Section 3.3.1 (Visualizing Relative and Absolute Risk) of the response to EIS 12-513, potential pathways of harm are discussed for both Relative Risk and Absolute Risk. It is stated that "… judgements were made as to the relative likelihood of harm (along the horizontal dimension), and the relative magnitude or severity of the consequences (along the vertical dimension) … it should be noted that the scales are considered to be of a logarithmic nature in that the probabilities involved span many orders of magnitude …"* *As an example, for the Worker Health and Safety pathway case (page 37), in the short term (<100 year) timeframe analysis for absolute risk, the surface storage (status quo + enhanced) case and both underground storage cases appear to have equivalent relative consequence (on a linear rating scale) and similar likelihood of occurrence (on a logarithmic rating scale).* *For the Public Health and Safety pathway analysis (page 38), and for the same short term interval (<100 years), a similar absolute risk pattern to that expressed for workers appears to be shown, although all case conditions appear to have lower consequence ratings.* *In these and all other pathway analyses, slight differences in consequence, on a linear scale basis, result. For the two example cases described above, the three storage options shown appear to have similar or close likelihoods of occurrence. However, because the option position along the logarithmically-scaled Likelihood axis may represent widely-varying values, the position shown and absolute likelihood values may be significantly different. The relative*

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		position of options on the risk assessment plots have positions differentiated by terms such as "More likely" and "Much more likely", but positions on the Absolute Risk assessment plots have no similar differentiating terms or other indicated scaling factors, either linear or logarithmic, that quantify the risk elements. *b) The report in OPG's response to EIS 12-513 includes several figures illustrating relative risk for the 12 key features for the near term (<100 years) and long term (>100 years). However, no overall risk summary table or figure was included. Summary tables or figures for both timeframes would provide a clearer portrayal of the overall relative risk of the four identified options. In its response to EIS 12-513, OPG stated that it would be submitting a separate response addressing the Panel's follow-up comments on the comparison of risk perception among the four options.*
		OPG Response: The Independent Expert Group's response addressing the Panel's follow-up information request is included in the enclosed report (IEG 2014a). The correspondence from the Independent Expert Group to OPG is also enclosed (IEG 2014b). **References:** IEG. 2014a. Report of the Independent Expert Group on Additional Figures and Interpretation in Support of Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario. Submitted by M. Dusseault, T. Isaacs, W. Leiss (Chair), G. Paoli to the Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR), May 29, 2014. (enclosed) IEG. 2014b. IEG letter from Dr. W. Leiss to Laurie Swami, May 29, 2014. (enclosed)
EIS 13-514	▪ Section 8.1, General Information and Design Description	***Information Request:*** *Provide the following:* • *The results and evaluations of the re-runs of postclosure safety assessment models at a similar level of detail and clarity as that provided in NWMO DGR-TR-2011-25 "Postclosure Safety Assessment";* • *An assessment of how the revised inventories will affect the pre-closure safety evaluation of the DGR, with special emphasis on the occupational health and safety of the workforce, as well as radiation protection requirements. This assessment should also address the impact of the revised inventories on the possible future expansion of the DGR;* • *An assessment of how the revised inventories would affect the environmental effects of accidents, malfunctions and malevolent acts, with emphasis on the pre-closure phase;*

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		• *A Waste Inventory Verification Plan, similar to the Geoscientific Verification Plan, which provides clear objectives, activities, and time-lines of future endeavours to improve the accuracy of the Reference Waste Inventory. The response should also include any plans for an independent expert evaluation of the methodology and verification procedures; and* • *Clarification of the methodology used to determine radioisotope concentrations and activity levels in filter resins.* ***Context:*** *Recent correspondence between Dr. Frank Greening and the NWMO (See CEAR numbers 1777, 1808, 1809, 1810 and 1811) has raised questions regarding the accuracy of OPG's 2010 Reference Waste Inventory of L&ILW that would be emplaced into the proposed DGR. These questions concern radionuclide concentrations in CANDU pressure tubes and garter springs for which the concentrations of some radioisotopes appear to have been significantly underestimated or not estimated at all. The underestimates appear to be due to the use of calculated values and scaling factors, rather than measured values.* *In its February 20, 2014 response to Dr. Greening, the NWMO stated that:* • *the estimated tritium content of the PT waste is approximately 300 times higher than in the 2010 Reference Waste Inventory.* • *an inventory estimate of Cm-244 is not included in the 2010 Reference Waste Inventory. Cm-244 is the dominant PT transuranic radionuclide in terms of activity at reactor shutdown.* • *for the pressure tube wastes, the values for Cs-134 and Sb-125 are low by a factor of 3-4, and Cs-137 is significantly underestimated by a factor of 2300.* • *the garter spring activity was not included in the 2010 Reference Waste Inventory. Although the garter spring mass is small, the total amounts of Co-60, Ni-63 and Ni-59 in the garter springs are significant compared to the amounts in the pressure tubes in part because the garter springs are primarily nickel. The ratio change in total DGR inventory at 2062 is 1.5 for Ni-59 and 2.2 for Ni-63.* *The NWMO has also noted that some of the radioisotopes that were underestimated (H-3, Cs-137, and Cm-244) have short half-lives and would not impact the long-term safety case. The NWMO also stated that it has re-run DGR postclosure assessment models using revised pressure tubes inventories for several key scenarios and calculation cases. It concluded that the changes in the waste inventories did not change the safety case conclusions for the DGR.* *While the waste inventory is a work in progress and cannot be finalized at this stage of the Project, additional quality assurance would be provided by a Waste Inventory Verification Plan.*

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		OPG Response: The response is provided in three parts: postclosure safety, preclosure safety and inventory verification. Postclosure Safety The postclosure safety assessment models as presented in NWMO DGR-TR-2011-25 "Postclosure Safety Assessment" have been rerun with revised inventories. These revisions are as noted in the Information Request. The revised radionuclide inventories are primarily due to surface deposit from coolant on the pressure tubes. Therefore they are assumed to be located in the surface layer of the pressure tubes, and assumed to be quickly released on contact with water. Other than this change, the revisions have no effect on the other postclosure safety assessment assumptions or models. Attachment A provides the results of the revised postclosure safety assessment. It shows that the changes have no significant effect on the long-term safety. This is because these changes do not significantly affect the total repository inventory, the affected radionuclides have relatively short half-lives, and the DGR design and site provide a large safety margin. Preclosure Safety All waste packages are required to meet the DGR Waste Acceptance Criteria. This sets limits on the gamma dose rates outside of waste packages. Pressure tube wastes (including garter springs) are handled in steel-and-concrete containers, with sufficient shielding and/or decay time to ensure that dose rate waste acceptance criteria are met. Compliance with these dose rates is part of ensuring the health and safety of the workers, and in meeting radiation protection requirements. The change in inventory does not affect the ability to meet the waste acceptance criteria. The revised inventories would affect the releases from pressure tube containers in the event of an accident, malfunction or malevolent act resulting in breach of a container. These are robust steel-and-concrete containers, so such a breach is very unlikely. The consequences of assumed breach accidents are described in Attachment B. The dose consequences for accidents and malfunctions remain well below 1 mSv. For most malevolent acts, the dose also remains below 1 mSv. In one specific malevolent scenario the dose increased from 2 mSv to 3 mSv, for a person at the nearest Bruce nuclear site boundary. In addition, OPG has security programs in place to guard against any malevolent acts at the Bruce Nuclear Site. These increases in dose do not affect the conclusions of the preclosure safety case. The revised inventories for pressure tube wastes from refurbishment would have no significant effect on the possible future expansion of the DGR. After these wastes have been emplaced in the DGR, the relevant panels would eventually

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
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		be closed off, and therefore isolated from the expansion activities. And, as discussed in the Postclosure Safety section above, these revised inventories have no effect on the postclosure safety assessment so do not constrain the ability of the DGR to accept additional wastes. <ins>Inventory Verification</ins> Attachment C provides the requested Waste Inventory Verification Plan. The purpose of this document is to summarize the activities underway and planned at OPG to continue to measure and verify the properties of the L&ILW arising from operations and refurbishment of OPG-owned or operated nuclear generating facilities and intended for disposal in the proposed DGR. This document has been prepared in response to Information Request EIS-12-514. The work is implemented by more specific work programs and plans within the OPG management system. The plan includes an external third party review of the waste characterization program. The plan includes a description of the main methods used for waste characterization, including measurement of radioisotopes on ion exchange resins.
EIS 13-515	▪ Section 12, Accidents, Malfunctions and Malevolent Acts	***Information Request:*** *Provide a brief description of the recent incidents at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Include an explanation of the relevance of these incidents to worker and public health and safety (both occupational health and safety and radiation protection requirements) at the proposed DGR under normal and accident conditions.* *Describe how the consequences of such incidents might or might not fall within what OPG modeled for its analysis of accidents, malfunctions, and malevolent acts.* ***Context:*** *Recent events at the WIPP have received media attention and raised concerns with interested parties. The requested information will provide context for the Panel's review of the proposed DGR.*
		OPG Response: There have been two recent incidents at the United States Department of Energy (US DOE) Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico: 1) the February 5, 2014, mine fire, and 2) the February 14, 2014, radiological release. The events are considered by the US DOE to be independent as they occurred in different sections of the facility. OPG and NWMO are carefully reviewing the information that the US DOE is publishing with respect to these two events on their website (http://www.wipp.energy.gov/wipprecovery/recovery.html).

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<tr><th colspan="3">OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13</th></tr>
<tr><th>IR#</th><th>EIS Guidelines Section</th><th>Information Request and Response</th></tr>
<tr><td></td><td></td><td>The WIPP facility is managing disposal of transuranic radioactive wastes arising from the nuclear weapons program in the United States. Some of the wastes that are being placed in the WIPP are therefore substantially different in character than the wastes that are proposed to be placed in the OPG DGR.

OPG, as a nuclear facility operator, and NWMO both engage in the ongoing process of seeking operational experience from other nuclear facility operators, including the United States DOE and other radioactive waste facility operators worldwide. Consistent with our established management system, we carefully review the available information provided by these operators and consider its direct and indirect application to our facility designs and processes.

To the extent information is available on the events at the WIPP, we have reported on it below. When additional information becomes available, it will also be assessed for applicable lessons for the DGR facility, in accordance with our management system.

<u>Mine Fire Event</u>

The US DOE Office of Environmental Management publicly released an Accident Investigation Report of the February 5, 2014, mine fire event on March 13, 2014 (DOE 2014a). In summary, at approximately 10:45 Mountain Standard Time (MST), a fire initiated in a salt haulage truck (EIMCO Haul Truck 74-U-006B) as a result of engine fluids (hydraulic oil or diesel fuel) coming into contact with hot surfaces on the truck and igniting. Upon noticing the flames, the operator attempted to extinguish the fire, both with a portable extinguisher and with the on-board fire suppression system, and when unsuccessful, notified maintenance and his supervisor of the fire. A series of activities were undertaken to notify underground personnel to evacuate to the surface via the waste hoist. By approximately 11:35 MST, all underground personnel had been accounted for and medical attention provided.

The Accident Investigation Report provides a full description of the event and the results of the investigation. The investigators determined that the incident was preventable and a full listing of observations and conclusions is provided in the US DOE Accident Investigation Report. The key findings were related to:
Inadequate preventative and corrective maintenance of equipment, including safety related equipment;
Inadequate follow through of fire protection program standards into training, field procedures and re-inforcement of acceptable field conditions by management;
Inadequate training and qualifications of operations staff for their documented emergency roles;
Elements of the emergency preparedness program were not maintained and/or tested for adequacy through simulated drills; and
Ineffectiveness of various oversight groups in identifying weaknesses and correcting identified deficiencies associated with the root cause.
An underground fire such as occurred at WIPP is considered a credible event at the proposed OPG L&ILW DGR during</td></tr>
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OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
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		both construction and operations phases and has been considered in the design and processes including: • Fire prevention (e.g. minimize use of combustible materials); • Fire detection equipment; • Fire suppression equipment (e.g. on-board automatic fire suppression equipment); • Communication equipment and notification systems (e.g. use of stench gas); • Use and location of portable refuge stations; and • Egress and emergency response. Although the WIPP fire event occurred on construction equipment, the potential for a fire on equipment transporting waste packages was considered in the design and safety assessment for the OPG DGR operations phase. The potential impacts to worker and public safety were assessed to be below criteria. The proposed management systems, and more specifically the project health, safety and environmental management and emergency response plans, have been described in detail in OPG's response to IR LPSC-04-66 and discussed at the hearings October 30, 2013 (IRI 2013). A list of OPG's responses addressing emergency response plans was provided in response to IR EIS-08-354. For completeness, OPG's responses to the following information requests addressed various aspects of the emergency response plans: LPSC-01-09, LPSC-01-15, LPSC-01-37, LPSC-01-41, LPSC-01-45, LPSC-03-59, LPSC-03-60, LPSC-03-61, EIS-01-04, EIS-03-53, EIS-03-76, EIS-05-186, EIS-06-269, EIS-06-271. OPG's responses to the following information requests addressed various aspects of the proposed fire detection and protection systems, as well as the assessment of fire events: LPSC-01-02, LPSC-01-10, LPSC-01-15, LPSC-01-15a, LPSC-01-16, LPSC-01-20, LPSC-01-21, LPSC-01-22, LPSC-01-26, LPSC-01-36, LPSC-01-41, LPSC-01-43, EIS-04-135, EIS-06-248, EIS-06-270, EIS-06-275, EIS-07-279, EIS-07-280, EIS-07-281, EIS-08-354, EIS-09-402, EIS-09-430, EIS-09-466, EIS-10-499. OPG has committed to the development of detailed Fire Protection Programs prior to the start of site preparation and construction, and future operations phase activities. This includes the development of Fire Hazard Analyses (FHA) which support specific fire protection plans for the DGR activities. Plans include required elements such as roles and responsibilities, fire response, fire assessments, managing changes that affect fire protection, work practice and procedures, fire planning, inspection and maintenance of fire protection systems, quality assurance, housekeeping, storage and handling of hazardous goods, control of ignition sources, transient material, reporting and drills. The fire protection measures and processes developed for the DGR project will be subject to regulatory oversight by the CNSC and other regulating bodies. The Fire Protection Program and Emergency Response Plan are licensing requirements and identified by the CNSC in their response to Undertaking No. 67 (CEAA 1739) as hold points for

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regulatory review and acceptance prior to the start of site preparation and construction.

OPG is confident that the measures and processes we have established will prevent or mitigate a similar event at the proposed OPG DGR. Documented programs will be translated thoroughly into training, field procedures and management expectations. Implementation of a common Project Management System to all staff and contractors, and continued monitoring and improvement (i.e. Plan-Do-Check-Act), will help to ensure common understanding and testing of processes.

Radiological Release Event

At approximately 23:14 Mountain Standard Time (MST) on February 14, 2014, there was an event/incident in the underground repository at WIPP that resulted in a radiological release (americium and plutonium). The release was detected by a continuous air monitor located underground and the exhaust was directed through a high-efficiency particulate air filter at the surface exhaust building. Some exhaust air by-passed the filters as a result of ineffective dampers and was discharged directly to the environment. The DOE has confirmed that there were no personnel underground at the time of the incident, no worker injuries resulting from the event, the monitoring system detected the release, and the mitigation systems responded to reduce surface emissions. The radioactivity concentrations measured at the surface were well below regulatory limits for public and worker exposure and they quickly decreased to around historic background levels.

The US DOE Office of Environmental Management publicly released a Phase 1 Accident Investigation Report of the Radiological Release Event at the Waste Isolation Plant on April 24th (DOE 2014b). The report presents valuable insight and information surrounding the root and contributing causes specific to the surface release of radioactive material from underground. The findings of this report are quite similar to those from the vehicle fire event. There is a common theme that is largely related to a degraded safety culture, ineffective programs and program implementation as well as training. The following highlights the key aspects of the report and provides an OPG perspective of our practices in these same areas:

- Effectiveness of the WIPP Nuclear Safety Program, specifically related to the reduction in conservatism in the Documented Safety Analysis and corresponding Technical Safety Requirements;
  - OPG has maintained an effective nuclear safety program which has ensured safe reactor operations for several decades. The program is well guarded against degradation by OPG’s programmatic controls which not only monitor and measure its effectiveness, but seeks opportunities for improvement. OPG expects this level of nuclear safety program rigour will continue into future DGR operations.
- Implementation of the Emergency Management System related to adequately recognize, categorize and implement protective actions in a timely manner;
  - Prior to the DGR receiving its operating licence, OPG will have demonstrated to the CNSC that it has a
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		strong and sustainable emergency management system. This program will not only be reflective of those developed for our safe operations, but will consider the unique potential hazards of being deep underground. OPG has a strong performance history in this area and is confident it will further improve with time as we enter into DGR operations.
		• The site Safety Culture and lack of a questioning attitude, reluctance to report issues to management, and an acceptance of degraded equipment and conditions;
		  • This is an area where OPG's overriding priority of safety is routinely monitored and measured for effectiveness, not only by ourselves but also by our industry peers (e.g., WANO/INPO) and the CNSC. This safety culture is company wide and not limited to the large nuclear fleet. For example, this was demonstrated through the safe construction of the recently competed Niagara Tunnel project. It is expected this will continue and be pervasive throughout all phases of the DGR project as well.
		• Implementation of the Conduct of Operations to DOE requirements;
		  • OPG is well regarded for its strong conduct of operations program. The strength of this program is not only demonstrated through decades of safe reactor and waste facility operations but also by OPG's history of regulatory compliance. OPG will transfer all relevant aspects of these programs into the DGR operations programs prior to receiving its operating licence. To further ensure a robust conduct of operations program, OPG will review and incorporate the appropriate lessons learned from WIPP operations as well as other key repository and mining related operating experience.
		• Ineffective maintenance program, specifically related to the critical equipment and components contributing to the radiological detection and release;
		  • OPG has long recognized the value in proper maintenance of its critical equipment and components. Maintaining this equipment not only contributes to reliable generation of power, but more importantly to the safety of its workers and the public. OPG has an active maintenance program and will apply this to the DGR.
		• Ineffective Radiation Protection Program to Federal requirements, including training, qualifications, equipment, instruments, and auditing;
		  • OPG recognizes that a robust radiation protection program is at the center of assuring worker and public safety. Similar to OPG's programs noted above, OPG has a long history of maintaining an effective and regulatory compliant radiation protection program. This is accomplished through a commitment to regulatory compliance, well trained and qualified staff, staying current with advancements in technology and practices and by a continuous view to the industry to learn and improve from operating experience. Prior to placing the DGR into operations, OPG will have demonstrated to the CNSC that it has established an effective radiation protection program which meets all applicable regulatory requirements.
		• Ineffective execution of DOE oversight, both from the Carlsbad Field Office and DOE Headquarters.
		  • OPG's company wide operations depend heavily on the expertise and skill of a large number of contractors.

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		OPG recognizes that any breakdown in its oversight of contractors can lead to risk of worker, environment and public safety. Therefore OPG builds strong terms and conditions into its contracts and provides the necessary level of oversight to ensure predictable, safe outcomes. Moreover, and unlike the DOE, OPG conducts its contracted work under regulatory oversight. Should a contractor fail in its duty to safety, the regulating body will hold OPG ultimately accountable for a failure in oversight. Conversely, the DOE has no regulatory oversight in its control of contractors. In summary, OPG is accountable for its oversight of contractors in the design, construction and operations of the DGR facility. This accountability will be managed through rigorous management of contracts and direct oversight and auditing of our contractors approved programs. OPG's culture of safety, in its many forms, values the experience of the industry and continually seeks to learn and improve from it. This has been fundamental to OPG's long history of high standards, performance and regulatory compliance in its nuclear operations. It is this deep rooted safety culture that OPG expects will continue to guide and develop the programs and processes for safe DGR construction and operations. There is still more to be learned from the experiences at WIPP and OPG remains committed under our current programs which assure they are evaluated and opportunities for improvement are sought. In summary, the DGR will be operated through a system of OPG governance including appropriate management systems, programs and plans, and subject to independent regulatory oversight. As demonstrated through its current reactor and waste facility operations, OPG has well developed programs in the areas of emergency management, safety culture, human performance, radiation protection, operations and maintenance. As many of the Phase 1 Report findings are directly related to radiological operations, future operating plans and procedures specific to the DGR will consider the WIPP findings in their development. OPG has conducted a preliminary review of the recently released Phase 1 report and has made an initial determination that no design changes, including to the ventilation system, are required at this time. Further, some of the findings related to emergency management processes are similar to those described above for the fire event. OPG will continue a detailed review of the Phase 1 report to identify opportunities to incorporate specific findings into the future planning for the DGR project consistent with our management system and the regulatory process. The L&ILW DGR preclosure safety analyses (Section 7.5, OPG 2011) included the evaluation of a number of credible underground accident scenarios, including waste package breach. The consequences were determined to be well below the regulatory criteria for worker and public protection. The US DOE Phase 2 investigation will address the specific root cause of the release from the waste package(s). As with the Phase 1 report, OPG will review it for potential lessons when it becomes available.

OPG Responses to Joint Review Panel EIS Information Request Packages 12, 12a, 12b, and 13		
IR#	**EIS Guidelines Section**	**Information Request and Response**
		References: DOE. 2014a. U.S. Department of Energy, Office of Environmental Management – Accident Investigation Report, Underground Salt Haul Truck Fire at the Waste Isolation Pilot Plant February 5, 2014, March 2014. DOE. 2014b. U.S. Department of Energy, Office of Environmental Management – Accident Investigation Report, Phase 1 Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014, April 2014. IRI. 2013. DGR Hearing Transcript Volume 25, October 30, 2013. International Reporting Inc. to the Joint Review Panel. (CEAA Registry Doc# 1741) OPG. 2011. OPG's Deep Geologic Repository for Low and Intermediate Level Waste - Preliminary Safety Report. Ontario Power Generation report 00216-SR-01320-00001 R000. Toronto, Canada. (CEAA Registry Doc# 300) CNSC. 2013. Deep Geologic Repository Project Joint Review Panel – Undertaking Response No. 67 (CEAA Registry Doc# 1739)

ATTACHMENT A

TO

OPG RESPONSE TO IR-EIS-12-510

NARRATIVE EXPLAINING SIGNIFICANCE ASSESSMENTS FOR OPG'S DEEP GEOLOGICAL REPOSITORY PROJECT FOR LOW & INTERMEDIATE LEVEL WASTE

ABSTRACT

The Environmental Impact Statement (EIS) for the Deep Geologic Repository (DGR) Project identified residual adverse effects for air quality, noise, hydrology, the aquatic and terrestrial environments, and Aboriginal interests. Reasoned argument narratives that describe the significance assessments for each identified residual adverse effect are provided in this response. Both the EIS and the enclosed reasoned argument narratives reach the same conclusion, that the DGR Project will not result in any significant adverse environmental effects.

The *Canadian Environmental Assessment Act* contains no legislative direction on what constitutes a significant adverse environmental effect. Section 11.3 of the EIS Guidelines (CEAA and CNSC 2009) required that each residual adverse effect be considered in the categories of the magnitude of the effect, the geographic extent of the effect, the timing and duration of conditions causing the effect, the frequency of the effect, the degree to which the effect is reversible, the social and ecological context, and the probability of occurrence.

In this response, for each residual adverse effect, a hypothesis statement was formulated identifying the conditions that would make a residual adverse effect significant. Following the reasoned narrative, the effect was then judged against these hypotheses. The evidentiary basis for the detailed narratives are contained in the EIS and summarized in this response.

Table A-1 summarizes the residual adverse effects identified, the hypothesis statement, and the overall determination of significance.

Table A-1: Summary of Residual Adverse Effects and Their Significance

Residual Adverse Effect	Hypothesis	Significance Assessment
Hydrology – Section 2		
Reduction in surface water quantity and flow in the existing North Railway Ditch prior to the confluence with Stream C (31%)	For an effect on an existing engineered channel (e.g., a ditch) to be assessed as a significant adverse effect*, a decrease in flow must be sufficient to alter the capacity of the engineered channel through excessive sediment deposition.*	Not significant. The current flow in the North Railway Ditch is already low and the decrease is not expected to increase the amount of sediment deposition such that it will affect the design capacity enough to cause flooding. Additionally, the sediment deposition can be readily addressed through maintenance.
Increase in surface water quantity and flow in the existing drainage ditch at Interconnecting Road (114% during the site preparation and construction phase and 61% during the operations phase)	For an effect on an existing engineered channel (e.g., a ditch) to be assessed as a significant adverse effect, *an increase in flow must exceed the design capacity of the channel sufficiently to cause flooding and/or erosion.*	Not significant. While the predicted increase in flow has the potential to exceed the existing design capacity of the ditch, the flow capacity will be assessed and the ditch re-sized during the final design process, if necessary, to ensure that increases in flow will not cause flooding and/or erosion.
Terrestrial Environment – Section 3		
Loss of eastern white cedar caused by the removal of 8.9 ha of mixed woods	For the loss of eastern white cedar in the Local Study Area to be considered a significant adverse effect, one or more of the following would be required: • *the sustainability and productivity of the local population of eastern white cedar would be compromised;* • *woodland attributes (e.g., edge-area ratio, stand size, shape and age), species or ecological functions that are unique in the Local Study Area would be affected;* • *habitat connectivity and movement within the ecosystem would be disrupted; and/or* • *sustainability in the Local Study Area of other species that have dependence on the specific areas affected (or dependence on the Local Study Area communities containing the VEC) would be*	Not significant. The removal of 8.9 ha of mixed woods is not large enough to affect the sustainability or productivity of eastern white cedar in the Local Study Area and is reversible with time following closure of the DGR Project. The three small, fragmented stands of mixed woods that will be removed are comprised of regenerating common species with no notable age or size characteristics, do not support any sensitive species or provide unique ecological functions that would be lost, and adjacent woodland populations and communities will not be compromised. The loss of the three mixed wood stands will have no measurable effect on regional connectivity or biophysical processes, and will not cause or contribute to fragmentation in the Local Study Area.

Residual Adverse Effect	Hypothesis	Significance Assessment
	compromised by the loss (i.e., they have an obligate dependence).	There are no sensitive wildlife species or wildlife habitat use patterns that could be compromised by the loss.
Aquatic Environment – Section 4		
Removal of burrowing crayfish habitat present in the North Railway Ditch, other drainage ditches and ephemerally wet low areas during site preparation activities	For an effect on aquatic VECs to be considered a significant adverse effect, one or more of the following would be required: • *habitat that is critical to the sustainability and productivity of the aquatic VECs is removed and there is no suitable habitat found elsewhere in the Site Study Area;* • *removal and/or alteration of habitat causes changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area; and/or* • *aquatic habitat connectivity and movement of aquatic VECs within the Site Study Area is disrupted.*	Not significant. The area of aquatic habitat loss is not large enough to affect the sustainability or productivity of the local populations of affected aquatic VECs in the Site Study Area. The habitat loss is not expected to cause changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area. The habitat loss is not expected to affect watercourse habitat connectivity or disrupt flow movement or migration within the study areas.
Alteration of aquatic habitat for redbelly dace, creek chub, burrowing crayfish, variable leaf pondweed and benthic invertebrates in the South Railway Ditch caused by construction of the rail bed crossing	For an effect on aquatic VECs to be considered a significant adverse effect, one or more of the following would be required: • *habitat that is critical to the sustainability and productivity of the aquatic VECs is removed and there is no suitable habitat found elsewhere in the Site Study Area;* • *removal and/or alteration of habitat causes changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area; and/or* • *aquatic habitat connectivity and movement of aquatic VECs within the Site Study Area is disrupted.*	Not significant. The affected habitat is of marginal (non-critical) quality for the aquatic VECs when compared to the quality and availability of habitat elsewhere in the Site and Local Study Area. The habitat alteration is not expected to cause changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area. The habitat alteration is not expected to affect watercourse habitat connectivity or disrupt flow movement or migration within the study areas.
Air Quality – Section 5		
Increase in calculated maximum ambient concentrations of 1-hour NO_2, 24-hour NO_2, annual NO_2, 1-hour CO, 24-hour	To have a significant effect on the air quality VEC, *the DGR Project would need to result in ambient air concentrations beyond the Site Study Area that exceed relevant established ambient air quality criteria more than 10% of the time*.	**Site Preparation and Construction and Decommissioning Phases:** Not significant. The predicted maximum ambient concentrations of SO_2, NO_2 and CO do not exceed the relevant ambient air quality criteria beyond the Site Study Area (i.e., the Bruce nuclear site fenceline). The maximum 24-hour ambient

Residual Adverse Effect	**Hypothesis**	**Significance Assessment**
CO, 24-hour SPM, annual SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$		concentrations of $PM_{2.5}$, PM_{10} and SPM were predicted to exceed relevant criteria less than 0.5% of the time, in a relatively small area immediately adjacent to, but beyond, the Site Study Area. **Operations Phase:** Not significant. None of the predicted maximum ambient concentrations exceed the relevant ambient air quality criteria.
Noise – Section 6		
Increase in noise levels at four residences near receptor R2 (Baie du Doré) during the quietest hour.	For a noise effect to be considered a significant adverse effect, *the change in ambient noise would need to be disturbing (i.e., >10 dB change in the quietest hour)*.	Not Significant. Noise effects would not be perceived as disturbing as the predicted change in ambient noise levels at the four residences near Baie du Doré is 5 dB or less. Adverse effects were predicted only during the site preparation and construction and decommissioning phases and only in areas immediately adjacent to the Site Study Area, a short distance into the Local Study Area.
Aboriginal Interests – Section 7		
Diminishment of the quality or value of activities undertaken by Aboriginal peoples at the Jiibegmegoong burial site located within the Bruce	For an effect on Aboriginal heritage resources, specifically the Jiibegmegoong burial site, to be considered a significant adverse effect, *the Project would need to prevent or interfere with the performance of ceremonies at, or observation of, the burial site.*	Not significant. The DGR Project is not anticipated to further restrict access to the burial site for ceremonial purposes or prevent or interfere with ceremonies at the burial site. While the waste rock pile and other Project-related structures will be visible at the burial site, they are not expected to prevent or interfere with ceremonial activities. In addition, indirect effects from noise and dust are expected primarily during the site preparation and construction and decommissioning phases of the project, and would be reversible with time
Radiation and Radioactivity – Section 8		
No residual adverse effects on radiation and radioactivity identified	For a significant adverse effect of radiation and radioactivity to occur, *the DGR Project would need to cause radiological releases that result in doses to human or non-human biota in excess of the relevant Canadian Nuclear Safety Commission (CNSC) regulatory requirements.*	As all predicted doses are less than established dose criteria, no residual adverse effects as a result of radiological releases from the DGR Project were predicted to occur, and no significance assessment was performed.

Residual Adverse Effect	**Hypothesis**	**Significance Assessment**
Near-surface Geology and Hydrogeology – Section 9		
No residual adverse effects on near-surface geology and hydrogeology identified	For an effect to near-surface groundwater to be considered a significant adverse effect, the following would be required: • *migration of contaminants of potential concern in excess of established criteria and/or guidelines relevant to human or ecological health, on a frequent and/or continuous basis; or* • *alteration of the shallow groundwater flow regime to an extent that it would alter sensitive or critical habitats on a frequent and/or continuous basis.*	The Project will not have an effect on the overall site groundwater regime or sensitive ecological features located near the site, therefore, OPG concluded that there would be no measurable change to the near-surface geology and hydrogeology that would result in an adverse environmental effect, and thus no residual adverse effects were identified and no significance assessment was performed.
Surface Water Quality – Section 10		
No residual adverse effects on surface water quality identified	For an effect to surface water quality to be considered a significant adverse effect, the following would be required: • *releases of indicator compounds at concentrations in excess of the relevant Provincial Water Quality Objectives or Canadian Environmental Quality Guidelines protective of human or ecological health in receiving waters; or* • *alteration of the surface water quality regime to an extent that it would adversely affect sensitive or critical habitats on a long-term or continuous basis.*	The project design and the commitments made by OPG provide for water treatment where required to meet applicable criteria (OPG 2012, EIS 04 130). The parameters that may need treatment are well understood, common in industrial environments and are easily managed with common treatment technologies. Ensuring that the discharge criteria are met prevents adverse effects on surface water quality. Therefore, OPG concluded that the DGR Project will not result in residual adverse effects to surface water quality and no significance assessment was performed.

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1. BACKGROUND

The response to this Information Request presents the narrative describing the assessment of significance for the residual adverse effects identified through the environmental assessment (EA) for OPG's Deep Geologic Repository (DGR) Project for Low and Intermediate Level Waste and presented in the DGR Project Environmental Impact Statement (EIS) (OPG 2011).

The Information Request asked for a detailed narrative to explain how the significance of each residual adverse effect on the biophysical environment, and on Aboriginal interests, was determined. The EIS identified residual adverse effects for air quality, noise, hydrology, the aquatic and terrestrial environments, and Aboriginal interests. Reasoned argument narratives that support the significance assessments presented in the EIS for each identified residual adverse effect are provided in this response. Although no residual adverse effects were identified for radiation and radioactivity, shallow groundwater and surface water quality, an overview is provided in Sections 8, 9 and 10 respectively to respond to additional direction from the JRP (JRP 2013). For context and completeness, information on what would have been required for identification of a significant adverse effect and a discussion of the potential effects of the DGR Project are provided.

The *Canadian Environmental Assessment Act* contains no legislative direction on what constitutes a **significant** adverse environmental effect. OPG assessed significance for each predicted residual adverse effect according to the categories set out in Section 11.3 of the EIS Guidelines (CEAA and CNSC 2009), including the magnitude of the effect, the geographic extent of the effect, the timing and duration of conditions causing the effect, the frequency of the effect, the degree to which the effect is reversible, the social and ecological context, and the probability of occurrence. In general terms, in the context of existing guidance (FEARO 1994), an adverse effect may be considered significant if it is major or catastrophic, widespread, long-term and/or frequent, or irreversible. Conversely, adverse effects that are inconsequential or minor, localized, infrequent or of short duration, or reversible, may be considered not significant.

A number of methods have been developed to determine significance – technical, collaborative, and reasoned argument (Lawrence 2005). All of the methods incorporate an element of professional judgement (Sippe 1999). Another common feature of the assessment methods is the use of Valued Ecosystem Components (VECs) to represent important ecological features, or features important to stakeholders, consistent with common EA practice (Beanlands and Duinker 1983, CEAA and CNSC 2009). The evidentiary bases for the following detailed narratives are contained in the EIS and corresponding Technical Support Documents (TSDs), and are summarized and cited where appropriate throughout this response. Additional support for the reasoned judgements is taken from available scientific literature, applicable government standards and guidelines and past EAs, including the results of follow-up monitoring programs confirming the conclusions reached in those EAs.

The remainder of this response is organized by environmental component. Each of Sections 2 through 7 begins with a hypothesis statement that states the conditions that would make a residual adverse effect significant, summarizes the significance assessment. Each section outlines the overall approach to the assessment, describes the existing conditions and the potential residual adverse effects, presents a reasoned argument narrative that assesses the significance of the residual adverse effects against the hypothesis statement and discusses OPG's confidence in the conclusions. Sections 8, 9 and 10 each present a brief overview of the assessment for those components where no residual adverse effects were predicted.

1.1 References

Beanlands G.E. and P.N. Duinker. 1983. An Ecological Framework for Environmental Impact Assessment in Canada. Institute for Resource and Environmental Studies, Dalhousie University and Federal Environmental Assessment Review Office. Hull, Canada.

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Federal Environmental Assessment Review Office (FEARO). 1994. A Reference Guide for the Canadian Environmental Assessment Act – Determining Whether a Project is Likely to Cause Significant Adverse Effects. Federal Environmental Assessment Review Office. Hull, Canada.

Joint Review Panel (JRP). 2013. Chair, Deep Geologic Repository Joint Review Panel Letter, S. Swanson to L. Swami, “Ontario Power Generation (OPG) Scope of Work and Proposed Response Dates for Information Request (IR) Package #12”, December 6, 2013. (CEAA Registry Doc# 1767).

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Sippe, R. 1999. Criteria and Standards for Assessing Significant Impact. In J. Petts (ed). Handbook of Environmental Impact Assessment. Blackwell Science. Malden, USA. p. 74-92.

2. HYDROLOGY

This section provides a detailed narrative that explains the significance assessment for surface water quantity and flow (i.e., hydrology). Based on the literature reviewed, and taking into consideration experience from other projects, OPG's hypothesis was that, for an effect on a natural stream to be assessed as a significant adverse effect, *a change to the magnitude of high flow events must be sufficient to alter the geomorphological conditions of the stream, or to alter habitat for sensitive aquatic species on a long-term or continuous basis*. For an effect on an existing engineered channel (e.g., a ditch) to be assessed as a significant adverse effect, *an increase in flow must exceed the design capacity of the channel sufficiently to cause flooding and/or erosion, or a decrease in flow must be sufficient to alter the capacity of the engineered channel through excessive sediment deposition.* Additional information explaining the reasoning behind this hypothesis, including the literature reviewed, is presented in Section 2.1.

The detailed assessment of the potential effects presented in the Hydrology and Surface Water Quality TSD (Golder 2011a, Sections 6, 7, and 8) identified three residual adverse effects of the DGR Project on the hydrology of existing engineered channels. None of those effects were assessed to be significant. No residual adverse effects on the hydrology of natural streams were identified.

2.1 Approach to Assessment

Surface water quantity and flow was chosen as a VEC because surface water features of ecological importance and stakeholder interest (Golder 2011a, Section 4) are present in the Local Study Area.

Changes to surface water quantity and flow in a natural stream can change the rate at which geomorphology, which is the natural process of gradual change to a stream, occurs. Changes to surface water quantity and flow can also alter the channel shape, depth and velocity, which are all components of habitat for aquatic species in rivers and streams (Leopold et al 1964). The "bankfull" flow conditions of a stream are the conditions that are responsible for the bulk of shaping the channels and establishing their location (Leopold et al 1964), the frequency of which can be altered by changing flow in the natural stream. Seasonal flow variations reflect a time period that is consistent with changes to habitat and hydrologic conditions, and maintaining typical seasonal flows will maintain the habitats in and around natural streams (Golder 2011a, Section 4). Changes in the rate of geomorphology or changes that affect habitat for sensitive aquatic species could trigger the need for an authorization under the *Fisheries Act* (Government of Canada 2013) and were therefore classified as being significant effects.

Increases in surface water quantity and flow in an existing engineered channel have the potential to exceed the original design capacity during storm events. If such an increase were to occur, it is possible that flooding and erosion could occur at downstream structures (e.g., culverts) resulting in potential damage and a safety hazard. If surface water quantity and flow were to decrease in an existing engineered channel, it is possible that excessive sediment deposition could occur because the velocities required to prevent sedimentation are not maintained. Excessive sediment deposition would ultimately reduce the capacity of the engineered channel such that flooding could occur under higher flows. Such changes were considered to be significant adverse effects. Engineered channels are typically designed and maintained to have sufficient capacity and resist erosion during storm events (e.g., 25-year return flow) to prevent erosion and/or flooding.

For both natural streams and engineered ditches, the changes in flow were calculated as being directly proportional to the change in drainage area (i.e., it is assumed that there is a linear correlation to the contributing drainage area). The assumption that runoff flow is directly proportional to drainage area is the basis for the Rational Method, which is the most common method to estimate runoff for small urban and rural watersheds (Viessman 1989), and has been used in North America since 1889 (Kuichling 1889). Annual average flow was estimated at the DGR Project site by pro-rating long-term data from other local gauged watersheds.

For the purposes of the assessment, any predicted change in flow as a result of the DGR Project was considered to be a measurable change. For changes in flow to be considered adverse, the change would need to be sufficiently large to be accurately detected using standard stream flow measurement techniques. For streams within the study area, a change of ±15% in stream flow was sufficient to be accurately measured, and thus considered an adverse effect (Golder 2011a, Appendix C).

2.2 Existing Conditions

Figure 2-1 shows the location of the existing surface water features in the Site Study Area. The figure illustrates the natural feature (i.e., Stream C) potentially affected, as well as the various man-made ditches, including the drainage ditch at Interconnecting Road and the North Railway Ditch that extend beyond the DGR Project site.

The Site Study Area is primarily drained by a network of constructed ditches and drains that have been divided into several drainage areas, as shown on Figure 2-2. The DGR Project site is largely located within the MacPherson Bay South Drainage Area, and its runoff drains into MacPherson Bay via the drainage ditch at Interconnecting Road. The remaining portion of the DGR Project site is currently drained by the North Railway Ditch and Stream C, which eventually discharge to Baie du Doré. The DGR Project site is isolated from receiving flows from other parts of the Bruce nuclear site by the existing ditch system (OPG 2012a, EIS-07-299). The only drainage areas receiving flows from the DGR Project Area are the MacPherson Bay South and Stream C catchments.

Stream C is a former tributary of the Little Sauble River that was diverted to Baie du Doré during the initial development of the Bruce nuclear site. The stream enters the Site Study Area via a culvert under Tie Road and transects the southeast corner of the Project Area. The existing drainage area of Stream C is 1,042.4 ha with an average annual flow of 144.6 L/s (Golder 2011a, Table 5.4.3-2). The existing 2-year return (bankfull) flow for Stream C is estimated to be 2,090 L/s (OPG 2000).

The North Railway Ditch (Figure 2-1) flows eastward towards Stream C adjacent to the abandoned rail bed and South Railway Ditch. The North Railway Ditch is similar in size to the South Railway Ditch, which has a wetted channel width of 3 m and top of the bank width of 5 m (OPG 2005). The North Railway Ditch is a straight channel filled with thick stands of cattails. The ditch drains 26.1 ha but is often dry, only conveying water after large rainfall events and during the spring snow melt. The average annual flow of the North Railway Ditch is 3.6 L/s.

The drainage ditch at Interconnecting Road drains a portion (41.3 ha) of the MacPherson Bay South Drainage Area. The ditch is approximately 1.5 m deep near Interconnecting Road and the depth gradually increases as it nears MacPherson Bay. Further upstream, the ditch is barely distinguishable from the surrounding terrain. Most of the ditch bottom is either grass lined (swale) or filled with cattails. The section immediately downstream of Interconnecting Road has been lined with cobbles to reduce erosion during large rainfall events. This ditch conveys an average flow of 5.7 L/s under Interconnecting Road via three culverts that were observed to be partially

Drainage Ditch at Interconnecting Road blocked with sediment and aquatic plants during a site visit in 2007.

The marsh located in the northeast portion of the Project Area is likely the result of precipitation being retained in a shallow depression. There are no inflows to the marsh other than surface runoff from a small catchment of approximately 3 ha. The only outflow of the marsh is intermittent discharge over a sill located in the northwestern area. It is expected that marsh drainage only occurs when the water levels in the marsh exceed the sill elevation. This outfall connects to the drainage ditch at Interconnecting Road.

2.3 Description of Potential Effects

The project was determined to affect the surface water quantity and flow VEC as a result of the drainage area diversion from the Stream C watershed to MacPherson Bay (approximately 8 ha, shown as a hatched area on Figure 2-2), increasing the flow to the existing drainage ditch at Interconnecting Road. Flow in the North Railway Ditch and Stream C will decrease as a result of the diversion. A further increase in the average annual flow to the drainage ditch at Interconnecting Road is predicted to occur as a result of shaft excavation and sump pumping during construction and operations. The predicted changes in flow were calculated by pro-rating flows with change in drainage area and adding discharges from shaft excavation and sump pumping (see Table 2-1). There will be no changes in flow in the South Railway Ditch from the DGR Project.

Table 2-1: Predicted Flow Change from Drainage Diversion and Sump Pumping

Surface Water Feature	Existing Average Annual Flow (L/s)	Change in Flow from Drainage (L/s)	Change in Flow from Pumping (L/s)	Total Predicted Flow (L/s)	Total Change in Flow (%)	Adverse
Stream C at point of discharge from the Bruce nuclear site	144.6	–1.2	0	143.4	-0.8	No
North Railway Ditch at Stream C	3.6	–1.1	0	2.5	-31	Yes
Drainage Ditch at Interconnecting Road	5.7	+1.2	+5.3 [a]	12.2 [a]	+114 [a]	Yes [a]
			+2.3 [b]	9.2 [b]	+61 [b]	Yes [b]

Source: From Table 8.2.3-1 in the Hydrology and Surface Water Quality TSD (Golder 2011a)
Notes: [a] During site preparation and construction; [b] During operations

The decrease in the drainage area of Stream C is calculated to be 0.8%, decreasing the average annual flow to 143.4 L/s. This predicted change is not considered to be adverse as it is less than ±15%.

A decrease in flow in the North Railway Ditch of 31% is predicted as a result of the drainage diversion. As this change is greater than ±15%, it is considered to be an adverse effect.

When the effect of shaft dewatering is combined with the change in flow from drainage diversion, a 114% increase in flow in the existing drainage ditch at Interconnecting Road is predicted to occur during the site preparation and construction phase, and a 61% increase in flow is predicted to occur during the operations phase (see Table 2-2). As these changes are both greater than ±15%, they are considered to be adverse effects.

The potential for the DGR Project to affect the surface water quantity and flow VEC also considered indirect effects through changes to groundwater flow (Golder 2011a, Section 7.2.2). It was predicted that changes in groundwater levels would not be measureable at any of the surface water features, as the estimated zone of influence during dewatering to support shaft construction will not approach any surface water features (OPG 2012b, EIS-03-55; OPG 2012a, EIS-07-298). As discussed in Section 9, there are no adverse effects on surface water quantity and flow as a result of changes to near-surface groundwater.

Since the drainage diversion that redirects flows from the Stream C catchment towards the drainage ditch at Interconnecting Road does not include the local catchments surrounding the northeast marsh, no effects on the surface water quantity in the marsh (inflow) are anticipated as a result of the project (OPG 2013a, EIS-09-413; OPG 2013b, EIS-10-491). There are no aspects of the DGR Project that will encroach on the marsh, nor are there any discharges to the marsh. As described in Section 9 of this response, weathered/fractured tills that could increase vertical connectivity to groundwater are not expected at the site; however, OPG would line the stormwater management pond should such conditions be encountered (OPG 2011, Section 4.4.1.5). This would prevent increased infiltration and decrease in available water in the northeast marsh. Therefore, no adverse effects on hydrology in the marsh were identified.

The North Railway Ditch also provides marginal/secondary habitat for burrowing crayfish that do not rely on open water. As described in Section 4, the aquatic environment assessment determined that the decrease in flow in the North Railway Ditch is not expected to adversely affect the habitat for burrowing crayfish in the Site Study Area (Golder 2011b, Section 7.5.2.1).

In summary, adverse effects to surface water quantity and flow of the existing drainage ditch at Interconnecting Road and North Railway Ditch were predicted to occur during all project phases. Several mitigation measures to avoid or minimize surface water quantity and flow effects were included in the design of the project.

- The project footprint and stormwater management system (drainage ditches and stormwater management pond) were designed to minimize changes in drainage areas, specifically the potential of the project to divert flows to and from Stream C.
- The project includes lining of the shafts to reduce the quantity of water pumped to the stormwater management pond. Lining of the shafts and underground operation as a dry facility will minimize the flow increase predicted in the drainage ditch at Interconnecting Road.

In addition, any increased sediment deposition caused by the decrease in flow predicted in the North Railway Ditch can be readily addressed through ongoing maintenance practices, although no credit was taken in the assessment for such maintenance.

Because the likely adverse effects predicted in the drainage ditch at Interconnecting Road and the North Railway Ditch remain after consideration of mitigation measures, they were classified as residual adverse effects.

2.4 Significance of the Residual Adverse Effects

Based on the categories set out in the EIS Guidelines, the residual adverse effects of the DGR Project on the surface water quantity and flow VEC can be described as follows:

- **Magnitude**: Changes in flows are predicted as follows:
  - A 31% decrease in the flow in the North Railway Ditch.
  - A 114% increase in the flow in the existing drainage ditch at Interconnecting Road during site preparation and construction.

  - A 61% increase in the flow in the existing drainage ditch at Interconnecting Road during operations.
- **Geographic Extent**: The effects are restricted to the Site Study Area, which comprises only a small portion of the local watershed area. The effects do not extend into Stream C or Lake Huron beyond the point of discharge.
- **Timing and Duration**: The changes in flow are predicted to occur throughout all project phases.
- **Frequency**: Effects of the above magnitude will occur during high flow events caused by storms and snowmelt runoff.
- **Reversibility**: The changes in flow can be reversed. Following decommissioning, water will no longer be pumped from the repository; however, at this time the flow diversion is expected to remain in place.
- **Probability**: The changes in flows will occur should the project proceed.
- **Context**: There were no adverse effects predicted in Stream C (a natural stream); adverse effects are only predicted in engineered ditches.

The North Railway Ditch is often dry, only conveying water after large rainfall events and during the spring snow melt. The predicted 31% decrease in annual average flow (from 3.6 L/s to 2.5 L/s) has the potential to result in some increase in sediment deposition over time in the North Railway Ditch. This increase in the rate of sediment deposition would not be sufficient to rapidly alter the capacity enough to cause flooding. Although no credit was taken in the assessment for maintenance, excessive sedimentation will be addressed through ongoing maintenance practices, if necessary.

The increase in flow predicted in the drainage ditch at Interconnecting Road is considered an adverse effect that could exceed the carrying capacity of the present ditch. Although not part of the project design assessed in the EIS, OPG has committed (OPG 2013a) to undertake a detailed design study to evaluate whether the design capacity of the drainage ditch at Interconnecting Road could be exceeded. The ditch will be modified in accordance with accepted practices (e.g., Ministry of Transportation drainage management manual [MTO 1997]), and undergo regular maintenance if current ditch conditions cannot convey the predicted flows (e.g., control of unwanted vegetation) (OPG 2013a). With design modifications, if necessary, the increased flow will not result in flooding or erosion. Therefore, with the OPG commitment to mitigative actions, the effects of increased flows in the drainage ditch at Interconnecting Road are considered to be not significant.

Several past and existing projects/activities and one reasonably foreseeable project (Bruce B refurbishment, continued operations, decommissioning and safe storage) were identified as having potential to act cumulatively with the DGR Project on hydrology. None of these projects or activities were predicted to affect surface water quantity and flow in the drainage ditch at Interconnecting Road or the North Railway Ditch. The DGR Project will not act cumulatively with other projects/activities to affect surface water quantity and flow.

Consideration was also given to whether the effects assessment conclusions on surface water quantity and flow are sensitive to changes in climate conditions (OPG 2011, Section 7.14). Since changes in current flows are proportional to drainage area, changes in future flows, regardless of changing climatic conditions would also be proportional. Therefore, it was concluded that changing climate would not alter the predicted adverse effects of the project. While future climate conditions may result in storm events that exceed the current design capacities, such changes in climate are expected to be gradual. This provides time to modify the engineered drainage features such that they will continue to serve their design purpose.

In summary,

- Residual adverse effects were only predicted for two existing engineered channels, the North Railway Ditch and the drainage ditch at Interconnecting Road. No residual adverse effects were predicted for any natural streams.
- For the North Railway Ditch, the predicted adverse effect was assessed against a hypothesis that, in order to be significant, *a decrease in flow must be sufficient to alter the capacity of the channel through excessive sediment deposition*. The current flow in the North Railway Ditch is already low and the decrease is not expected to increase the rate of sediment deposition such that it will rapidly alter the capacity enough to cause flooding. Excessive sediment deposition can be readily addressed through maintenance.
- For the drainage ditch at Interconnecting Road, the predicted adverse effects were assessed against a hypothesis that, in order to be significant, *increases in flow must exceed the design capacity of the channel sufficiently to cause flooding and/or erosion*. While predicted increases in flow have the potential to exceed the existing design capacity of the ditch, the flow capacity will be assessed and the ditch re-sized during the final design process, if necessary, to ensure that increases in flow will not cause flooding and/or erosion.

Therefore, OPG concluded that the residual adverse effects of the DGR Project on hydrology (i.e., surface water quantity and flow) are not significant.

2.5 Confidence

OPG has a high degree of confidence in the conclusion that the changes in flows predicted to occur as a result of the DGR Project are not significant. The significance conclusion is founded on well-established methods for determining the potential change to surface water flow arising from the changes to the site topography that are planned to occur.

The predicted increases in flow are conservatively estimated in accordance with the precautionary principle. The estimated flows from dewatering during excavation and sump pumping during operation are the maximum flows used to size the pumps. The actual flows are expected to be lower, resulting in a smaller increase of flow in the drainage ditch at Interconnecting Road.

From a hydrological perspective, change of flow for surface water features in small drainage areas can be reasonably estimated by pro-rating the existing flow by the anticipated change in drainage area (Viessman 1989, Kuichling 1889). This method has some inherent uncertainty, mostly attributed to the drainage areas calculated for the existing and future cases. However, the margin of error can be calculated to confirm prediction confidence. A potential error on the order of ±2 m × [perimeter] can be assumed when delineating drainage areas (OPG 2012c, EIS-05-190). Consequently, the drainage areas (existing and future) contributing flow to the North Railway Ditch at Stream C would have errors of ±0.78 ha. Based on these uncertainties, the existing drainage area could range from 17.1 to 18.7 ha and the change in drainage area between existing and future conditions could range from 6.6 to 9.8 ha. These values would imply that the decrease in drainage area is expected to be between 25% and 38%. The significance conclusion for the North Railway Ditch would remain the same (i.e., not significant). The corresponding range in predicted decrease in flow in Stream C is expected to be between 0.6% and 0.9% which would also not change the conclusions reached.

2.6 References

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2.7 Figures

Figures are provided on the following pages.

Figure 2-1: Key Surface Water Features of the Bruce Nuclear Site

LEGEND

- 🟩 Project Area (OPG-retained lands that encompass the DGR Project)
- 🟧 Site Study Area [1]
- ← Drainage Ditch

PROJECT

INFORMATION REQUEST EIS-12-510

TITLE

KEY SURFACE WATER FEATURES OF THE BRUCE NUCLEAR SITE

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

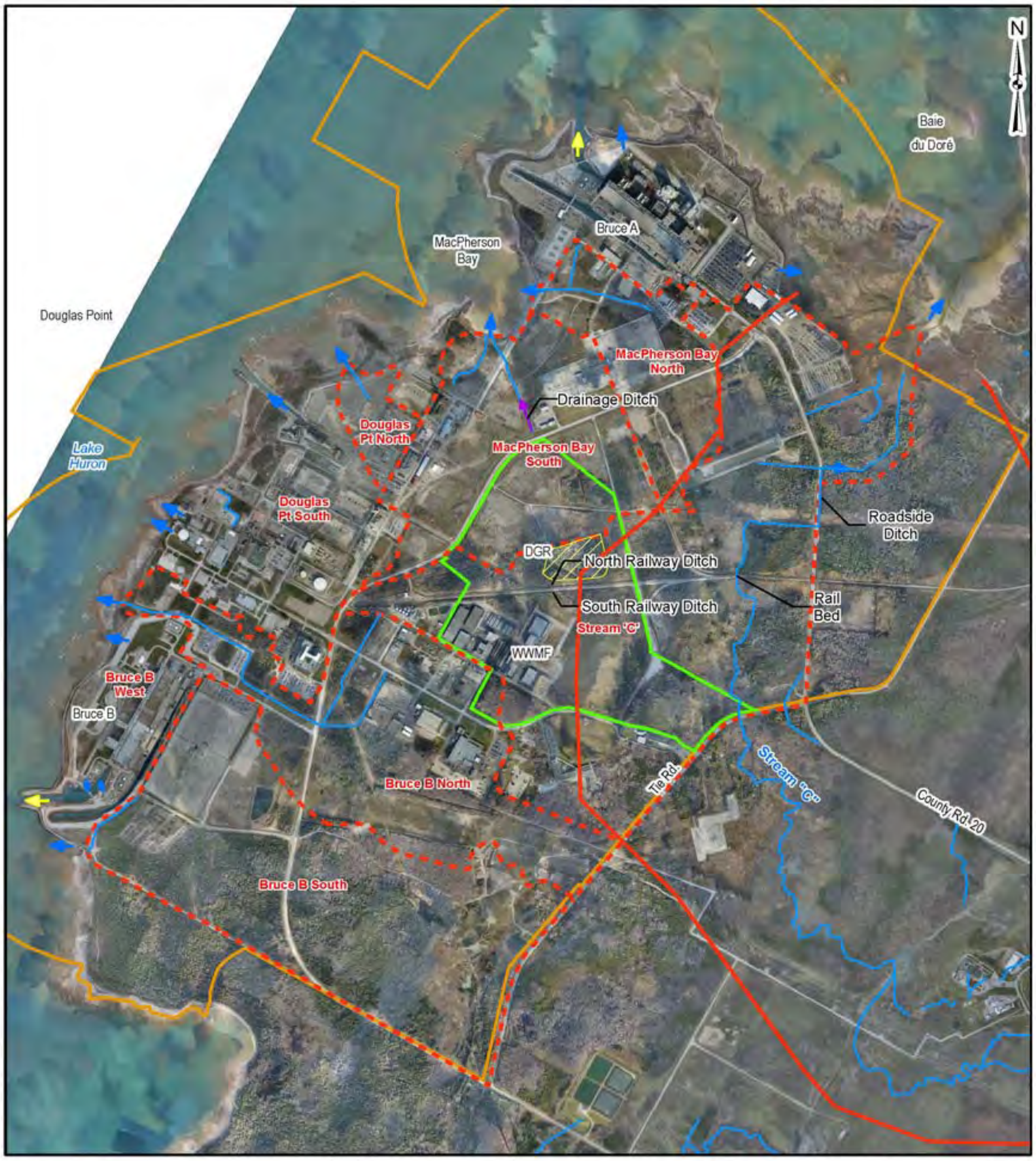
REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

Golder Associates
Mississauga, Ontario

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 2-1**	
GIS	SC	28 Feb. 2014		
CHECK	KC	28 Feb. 2014		
REVIEW	AB	28 Feb. 2014		

Figure 2-2: Site Drainage Areas



LEGEND

- 🟥 Approximate Catchment Boundary
- 🟥 Little Sauble and Stream C Watershed Divide
- 🟨 Drainage Diversion
- 🟩 Project Area (OPG-retained lands that encompass the DGR Project)
- 🟧 Site Study Area [1]
- ← Drainage Outfall
- ← Plant Discharge Channels
- ← Drainage Ditch

Drainage Area	Historic Catchment Area [12]
Bruce A	M, N, O
Bruce B	B, C, D
Bruce B North	E
Bruce B South	A
Douglas Point	H, G, F
Douglas Point North	I
MacPherson North	L, part of K
MacPherson South	J, part of K
Stream C	part of K

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007. Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

INFORMATION REQUEST EIS-12-510

TITLE

SITE DRAINAGE AREAS

Golder Associates
Mississauga, Ontario

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 2-2**	
GIS	SC	28 Feb. 2014		
CHECK	KC	28 Feb. 2014		
REVIEW	AB	28 Feb. 2014		

3. TERRESTRIAL ENVIRONMENT

This section provides a detailed narrative that explains the significance assessment for the terrestrial environment, specifically a loss of eastern white cedar. Based on the literature reviewed and taking into consideration experience from other projects, OPG's hypothesis was that, for the loss of eastern white cedar in the Local Study Area to be considered a significant adverse effect, one or more of the following would be required:

- *the sustainability and productivity of the local population of eastern white cedar would be compromised;*
- *woodland attributes (e.g., edge-area ratio, stand size, shape and age), species or ecological functions that are unique in the Local Study Area would be affected;*
- *habitat connectivity and movement within the ecosystem would be disrupted; and/or*
- *sustainability in the Local Study Area of other species that have dependence on the specific areas affected (or dependence on the Local Study Area communities containing the VEC) would be compromised by the loss (i.e., they have an obligate dependence).*

The reasoning behind the above hypothesis, including the literature reviewed, is presented below in Sections 3.1, 3.3 and 3.4.

The detailed assessment of potential effects presented in the Terrestrial Environment TSD (Golder 2011) identified only one residual adverse effect of the DGR Project on the terrestrial environment VECs; the removal of mixed wood forest containing eastern white cedar. This effect was assessed to be not significant.

3.1 Approach to Assessment

A detailed assessment of the potential effects was presented in the Terrestrial Environment TSD (Golder 2011, Sections 6, 7 and 8). Eastern white cedar was one of thirteen VECs identified for the terrestrial environment. These VECs were chosen using factors such as presence and abundance in the study areas, ecological importance, expressions of stakeholder interest, and past precedents in other EAs conducted on the Bruce nuclear site (Golder 2011). These VECs also represent indicators of ecosystem functions or important receptors in the ecosystem, which may be affected by the project.

Consideration of ecological context is important in determining the nature of any effect on the terrestrial environment. One purpose of the effects assessment is to establish the effects of the project on the maintenance of self-sustaining and ecologically functional populations and communities. Self-sustaining plant populations (and communities) can be considered as healthy, robust populations capable of withstanding environmental change and accommodating random population processes (Reed et al. 2003). The potential effects of the DGR Project on the eastern white cedar VEC were examined both from the perspective of sustainability of the individual populations of eastern white cedar, and within the context of other woodlands in the larger system as it relates to habitat diversity, connectivity and wildlife habitat utilization. For example, eastern white cedar dominated woodlands are preferred by white-tailed deer for shelter in the winter.

Consideration of ecological resiliency, or the capacity of the system to absorb disturbance and reorganize and retain the same structure, function and feedback responses (Holling 1973, Gunderson 2000), is also important in determining the nature of any effect on the terrestrial environment. Population resilience can be considered to share similar features as ecological resilience. This is because adaptability influences the ability of the population to absorb or recover from change. Eastern white cedar in the Regional Study Area is generally resilient and tolerant of a broad range of environmental conditions including changing climate and anthropogenic disturbance in the Regional Study Area, partially because it is in the middle of its range (Farrar 1995; McKenney et al. 2007). It is also a hardy species that expanded northward very rapidly after the last glacial period, is known to rapidly take over burned alvar habitats or barrens in the Great Lakes ecosystem (Riley 2013), and recovers quickly after disturbances on relatively shallow soil over limestone bedrock.

There are few absolute effects thresholds for plants and animal species available in literature or established guidelines, and biological parameters are typically subject to large amounts of natural variation. Consequently, the classification of effects for terrestrial VECs is based on quantitative and qualitative analyses, relevant information from the scientific literature on life history characteristics and known effects thresholds, experience from previous EAs and monitoring programs, and professional judgement. For the purposes of the EIS, an effect was considered to be a measurable change if it could be quantified through air photo overlays of the footprint of the project on Ecological Land Classification (ELC) community mapping boundaries.

3.2 Existing Conditions

To understand the importance of changes in the abundance and distribution of plant populations and communities, and their ability to remain self-sustaining, the local terrestrial ecological features need to be put into context with the landscape ecosystem.

Eastern white cedar is a prominent component of conifer and mixed woods throughout the Regional Study Area (and generally throughout southern Ontario) and contributes to a number of ecological functions in the surrounding landscape. For example, it provides a large portion of the tree canopy cover in conifer and mixed woods in all of the forest stands that are present in the immediate vicinity of the DGR Project, as well as in many of the forest stands on Douglas Point, in Kincardine Township[1], major stretches of the Lake Huron Shoreline and in the area occupied by Bruce and Grey Counties (S.L. Ross Environmental Research et al. 1990). It has a broad ecological amplitude, occurring on both dry and wet sites and on organic and mineral soils, particularly shallow soils over carbonate bedrock (Farrar 1995).

The Local Study Area, shown on Figure 3-1, represents the scale where regional ecological processes interact with the natural features and wildlife using the Bruce nuclear site. With the exception of Douglas Point (including the Bruce nuclear site and Inverhuron Provincial Park), which extends into Lake Huron on a peninsula, the Local Study Area is dominated by two major landscape elements. The first includes the Lake Huron shoreline and adjacent relatively contiguous terrestrial corridor comprised of forests (which are dominated by eastern white cedar), wetlands and valley features. The terrestrial corridor varies in width, from less than 0.5 km (particularly south of the Bruce nuclear site) up to approximately 1 to 2 km in and around the Douglas Point Peninsula, and up to approximately 4 km in the vicinity of MacGregor Point Provincial Park to the north. The remainder of the Local Study Area (approximately 75% to 80%) comprises open farmland, interspersed with infrastructure corridors (transmission and road), rural settlement areas and isolated patches of forest cover associated primarily with stream corridors.

The Site Study Area, shown on Figure 3-2, corresponds to the Bruce nuclear site and its exclusion zone. From an ecological perspective, this area contains the extent of potential direct effects from the project on the terrestrial environment. The Site Study Area is characterized as a fragmented and disturbed landscape, dominated by industrial facilities associated with the Bruce nuclear site, with barrens, regenerating wooded areas (which include eastern white cedar) and wetland patches. The habitat composition of the Project Area (OPG-retained land within the centre of the Bruce nuclear site, also shown on Figure 3-2) is similar except it is less diverse and does not include the Lake Huron shoreline.

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[1] Kincardine Township amalgamated with the Town of Kincardine and Township of Bruce in 1999.

Mixed Wood Forest Containing Eastern White Cedar in the Project Area

The wooded areas in the DGR Project Site, (the footprint of all facilities associated with the project within the Project Area), comprise three small separate stands (total area of 8.9 ha) of regenerated mixed woods, dominated by common, resilient species such as eastern white cedar, balsam poplar, white birch and trembling aspen. The understory is dominated by choke cherry and dogwood. Each stand is less than 4 ha in area, within which eastern white cedar is co-dominant. These stands are not a part of the Lake Huron Fringe Deer Yard, which is located to the southeast of the Project Area, and they are also peripheral to a Natural Heritage System identified for the surrounding area (North-South Environmental and Dougan and Associates 2009). No plant species of conservation concern have been identified within the DGR Project site (Golder 2011, Section 5.4.1).

3.3 Description of Potential Effects

The assessment concluded that clearing of the DGR Project site during site preparation is likely to cause an adverse effect to the eastern white cedar VEC (Golder 2011, Sections 6, 7, 8). Likely adverse effects on the eastern white cedar VEC were assessed through changes to the indicators and measures, including the area of vegetation communities and the presence, distribution and abundance of plant species. Multiple pathways of effect, based on project infrastructure and activities, were evaluated to determine which have the potential to adversely affect the eastern white cedar VEC (Golder 2011, Sections 6, 7, 8).

The project will affect eastern white cedar through direct removal of 8.9 ha of mixed woods, which include eastern white cedar. The 8.9 ha of mixed woods to be removed represents the only woodland affected by the DGR Project. This loss was considered to be a measurable change as it is readily quantifiable and detectable. The 8.9 ha represents 77.4% of the 11.5 ha of mixed wood in the total DGR footprint, 11.3% of mixed wood in the Site Study Area, and much less than 1% of the woodland in the Local Study Area. Even though the area of mixed wood forests removed (8.9 ha) was relatively small in the context of the Site Study Area, this was considered a potential adverse effect because the removal could potentially interrupt local wildlife habitat use patterns.

The Local Study Area represents the geographic scale at which the functions of sustainability, continuity, wildlife movement and abundance of the mixed woods containing the eastern white cedar population can be interpreted. For instance, one of the broadest scale ecological functions of eastern white cedar in mixed woodlands is the provision of movement corridors for larger, wider ranging wildlife species. The Local Study Area was selected as the appropriate scale to consider major elements of the woodland corridor along the Lake Huron shoreline because, if interrupted, it would have measurable effects on larger wildlife such as white-tailed deer. This scale is also important for maintenance of plant and wildlife species diversity and for local populations of smaller wildlife that require linked home ranges for genetic viability. Residual adverse effects at this scale are considered to influence woodland ecosystem sustainability throughout the region.

Although not extensive, there is some support in literature for a loss of 10% of plant populations as the threshold of measurability at a local scale, such as the Local Study Area for the DGR Project

(Krebs 1972, Cohen cited in Munkittrick et al. 2009). The project represents a loss of much less than 1% of the forest cover (containing eastern white cedar) in the approximately 21,700-ha Local Study Area. The implications of this loss on population sustainability, and other ecological functions such as wildlife habitat provision, are likely to be marginal. However, as it is a loss of forest habitat, and because subtle changes in ecological functions may be difficult to detect (Osenberg et al. 1994), the loss was conservatively considered to be an adverse effect.

In addition to the loss of eastern white cedar during site preparation and construction, the potential for the DGR Project to affect other eastern white cedar through changes to air quality, groundwater, surface water and soil quality, individually and in combination, was also assessed. These changes are not considered likely to cause any additional or combined loss in the quantity or quality of eastern white cedar in the Local Study Area, and therefore, will not have an adverse effect on the remaining eastern white cedar (Golder 2011, Sections 7.2.2 and 8.2.2.2, OPG 2013).

The only identified adverse effect on the eastern white cedar VEC was the direct removal of 8.9 ha of mixed wood forest. Several suitable mitigation measures to minimize the loss of both species and habitat associated with the mixed woods clearing were considered. Opportunities to retain tree cover will be investigated where possible. Where retention is not possible, exclusionary fencing to prevent additional loss of or effect on specimens and habitat during construction will be installed surrounding the DGR Project site within the Project Area. These mitigation measures, however, do not avoid the loss of 8.9 ha of mixed woods on the project site, resulting in a residual adverse effect on the eastern white cedar VEC.

Rehabilitation after decommissioning of the DGR Project may include both active and passive naturalization of the Project Area to provide additional suitable habitat, similar to that currently provided by the eastern white cedar. OPG chose to consider rehabilitation of the project site as a characteristic of reversibility in the significance assessment instead of as a mitigation measure.

3.4 Significance of the Residual Adverse Effects

Based on the categories set out in the EIS Guidelines, the residual adverse effects of the DGR Project on eastern white cedar can be described as follows:

- **Magnitude**: The predicted loss of mixed wood forest containing eastern white cedar is estimated to be 8.9 ha.
- **Geographic Extent**: The extent of the mixed wood forest containing eastern white cedar to be lost is measured in terms of area. In terms of location and condition, it is isolated and fragmented inside a large industrial complex (limited to the Site Study Area).
- **Timing, Duration and Frequency**: The effect will begin immediately and fully at commencement of project construction and remain in full effect until rehabilitation following project closure. Thus, the effect is continuous from the beginning of the site preparation and construction phase through to the end of the operations phase.
- **Reversibility**: Upon completion of the project, rehabilitation plans include re-establishment of high-quality mixed wood habitats containing large portions of eastern white cedar on the site.
- **Probability**: The effect is certain to occur if the project proceeds as planned.
- **Context**: Within the ecologically meaningful context of all the woodland in the Local Study Area, the mixed woods to be lost represent much less than 1% of the total woodland.

The removal of 8.9 ha of mixed woods is not large enough that the population of eastern white cedar in the Local Study Area would no longer remain sustainable and productive. As noted in Section 3.3, for an effect at the scale of the Local Study Area, some literature supports a 10% reduction as being the smallest level of loss that would be considered to have a measurable effect on plant populations

(Krebs 1972, Cohen cited in Munkittrick et al. 2009). Based on additional literature, losses of vegetation communities (e.g., mixed wood forest) of greater than 20% to 30% are high in magnitude and could be significant effects (Suter et al. 1995, Lande 1987, Flather and Bevers 2002) and may influence long term stability, sustainability and productivity of the ecosystem. The magnitude of the predicted residual adverse effect from the DGR Project, the loss of 11% of the mixed woods ecotype in the 1,034 ha Site Study Area, which amounts to less than 1% of the forest cover in the approximately 21,700 ha Local Study Area, would not affect plant population sustainability and productivity.

For the DGR Project, the extent of the loss is restricted to the Project Area, which is a small portion of the Site Study Area. While the loss of the mixed wood forest in that location extends for the duration of the DGR Project, eastern white cedar is a resilient species and the communities in the Site Study Area have been sustained through a number of human related disturbances followed by regeneration in idle or newly created landscape elements. Relatively few individual specimens (less than 100 in a stand) of eastern white cedar are required for minimum population viability and genetic conservation (Lemieux 2010). This suggests that the effect of removing 8.9 ha of mixed woods in the Project Area will not affect the sustainability of the eastern white cedar in the Local Study Area as there is sufficient area of mixed woods remaining and the effect will be reversible with time.

Support for the conclusions on sustainability and productivity may be found in the planning framework used in Ontario. For most industrial and residential land use approvals in southern Ontario, woodlands are assessed through municipal and provincial criteria in environmental impact studies. Ontario’s Provincial Policy Statement (PPS) and the Natural Heritage Reference Manual, which guides its implementation, deals with the identification of significant woodlands, and encroachments or disturbances to significant woodlands (OMNR 2010). The potential for woodlands to be considered significant is related to minimum size criteria based on the amount of forest cover in a given region or watershed (e.g., if the woodland is about 15% to 30% of the land cover in a region, woodlands 20 ha or larger could be considered for significance). If potentially significant, a certain level of removal or encroachment may still be allowed, subject to an environmental impact analysis that considers specific ecological attributes of the woodland, the surrounding area and other values such as wildlife use. Using this framework, the mixed woods to be removed as a result of the DGR Project would not be considered significant, nor would any of its related attributes constrain the proposed land use (i.e., the woodlots affected are not part of a >20 ha woodlot).

The affected area does not contain unique features, species or ecological functions within the Local Study Area. In Nova Scotia, where eastern white cedar is rare, conservation priority is placed on large contiguous stands as opposed to more numerous but smaller stands (Lemieux 2010). In Ontario, where eastern white cedar is common, unique woodland attributes such as edge-area ratio, stand size, shape, age, species and connectivity are important in determining the significance of a loss or disturbance, as well as the sensitivity of a population (OMNR 2010, Noss 1995, Diamond and May 1981). At the DGR Project site, the wooded area lost comprises immature regenerating mixed woods that contain no unique or significant tree species. At the Site, Local and Regional Study Area scales, these three stands of mixed woods are small, young, isolated, and contribute no genetic or movement corridor functions north-south along the shoreline forest communities, nor between the shoreline and inland areas (the three patches that will be lost are shown in brown on Figure 3-1). The affected areas are marginal to the core of the natural heritage system, which are already affected by adjacent anthropogenic activities, their utilization by wildlife is low and their functional contribution to the system is small. The largest and least fragmented forests in the Site Study Area are located approximately 1 to 2 km south of the Project Area, contiguous with Inverhuron Provincial Park (EC 2013, and as shown on Figure 3-2). The stands to be removed are already fragments from the larger system. The removal therefore does not contribute to additional fragmentation, including any cumulative fragmentation effects, which are known to affect population viability (Aguilar et al. 2006).

The affected area is not positioned in the landscape such that its loss may affect habitat connectivity and disrupt flow and movement within the ecosystem. No species are dependent on the affected areas such that their sustainability in the Local Study Area could be compromised by the loss (i.e., they have no obligate dependence). Although eastern white cedar can be an important species for some birds and as winter refuge for white-tailed deer, it does not provide preferred habitat to many wildlife species relative to other tree species (Martin et al. 1951). There are no expected negative effects to area sensitive breeding bird species or migratory bird species of conservation concern resulting from the loss of the mixed woods (EC 2013). Neither the white-tailed deer nor wild turkey VECs have habitat limitations or strong dependencies on the 8.9 ha of mixed woods at this location that would make its loss more significant or consequential. The three isolated stands of mixed woods to be removed contain no forest interior habitat and provide no critical links in regional woodland corridors for wildlife.

In addition, no cumulative effects on eastern white cedar as a result of other projects, past, existing or future were identified. The effects assessment inherently gives consideration to effects of other regional land uses or sources of stress on eastern white cedar, given that projected losses of regional forest cover would raise greater concern with respect to the loss of the stands in the Project Area. No such future land uses were identified at a scale that cumulatively would compromise the sustainability of eastern white cedar (i.e., there are no likely cumulative effects on the eastern white cedar VEC).

The assessment also considered whether the conclusions about the terrestrial environment are sensitive to changes in climate conditions (OPG 2011, Section 7.14). It was concluded that the future environment effect by climate change will not influence the conclusions of the assessment.

In summary:

- The only predicted residual adverse effect of the DGR Project on the terrestrial environment was a loss of eastern white cedar caused by the removal of 8.9 ha of mixed woods.
- The predicted adverse effect was assessed against a hypothesis that, in order to be significant, one or more of the following would be required:
    - *The sustainability and productivity of the local population of eastern white cedar would be compromised.* The removal of 8.9 ha of mixed woods is not large enough to affect the sustainability or productivity of eastern white cedar in the Local Study Area and is reversible with time following closure of the DGR Project.
    - W*oodland attributes (e.g., edge-area ratio, stand size, shape and age), species or ecological functions that are unique in the Local Study Area would be affected.* The three small, fragmented stands of mixed woods that will be removed are comprised of regenerating common species with no notable age or size characteristics, do not support any sensitive species or provide unique ecological functions that would be lost, and adjacent woodland populations and communities will not be compromised.
    - *Habitat connectivity and movement within the ecosystem would be disrupted.* In combination with the local abundance of mixed woods, and the poor habitat connectivity of the stands on the project site, the loss of the three mixed wood stands will have no measurable effect on regional connectivity or biophysical processes such as nutrient and energy pathways, and will not cause or contribute to fragmentation in the Local Study Area.

- *Sustainability in the Local Study Area of other species that have dependence on the specific areas affected (or dependence on the Local Study Area communities containing the VEC) would be compromised by the loss (i.e., they have an obligate dependence).* There are no sensitive wildlife species or wildlife habitat use patterns that could be compromised by the loss.

Therefore, OPG concluded that the residual adverse effect of the DGR Project on the terrestrial environment is not significant.

3.5 Confidence

OPG has a high degree of confidence in the conclusion that the removal of 8.9 ha of mixed wood forest at the DGR Project Area is not significant. The significance conclusion is founded on the precautionary principle. A conservative approach was used to identify measurable effects, which were assessed in an ecosystem context. The mixed wood forest containing eastern white cedar would generally be assessed at the Local Study Area scale for broader considerations of population viability and effects on other ecological functions. Relative changes (percent loss) typically applied at the Local Study Area scale were applied at the Project Area scale, which effectively lowered the thresholds for further analysis. This provided an additional level of conservatism in the analysis.

As noted above, the literature generally indicates that losses of receptor vegetation communities of greater than 20% to 30% are high magnitude and/or potentially significant effects (Suter et al. 1995; Lande 1987; Flather and Bevers 2002). Recent EAs, such as the New Prosperity Gold-Copper mine in British Columbia, used sustainability based thresholds with similar magnitudes at the regional scale for significance of forest losses (e.g., a 10-20% reduction in the availability of non-pine old forest in the Regional Study Area was considered to be of a moderate magnitude [Taseko Mines Limited 2012]). There is a high degree of confidence that the removal of 3% of the forest cover in the Site Study Area (or 1% of the forest cover in the Local Study Area), particularly in light of the isolated location of the stands of mixed woods to be removed, is not significant.

The potential risks associated with unforeseen ecological events in the future are also low because if broader blocks of mixed woods are suddenly lost, the stands in the Project Area will not play a significant role in sustaining or rehabilitating ecological functions.

3.6 References

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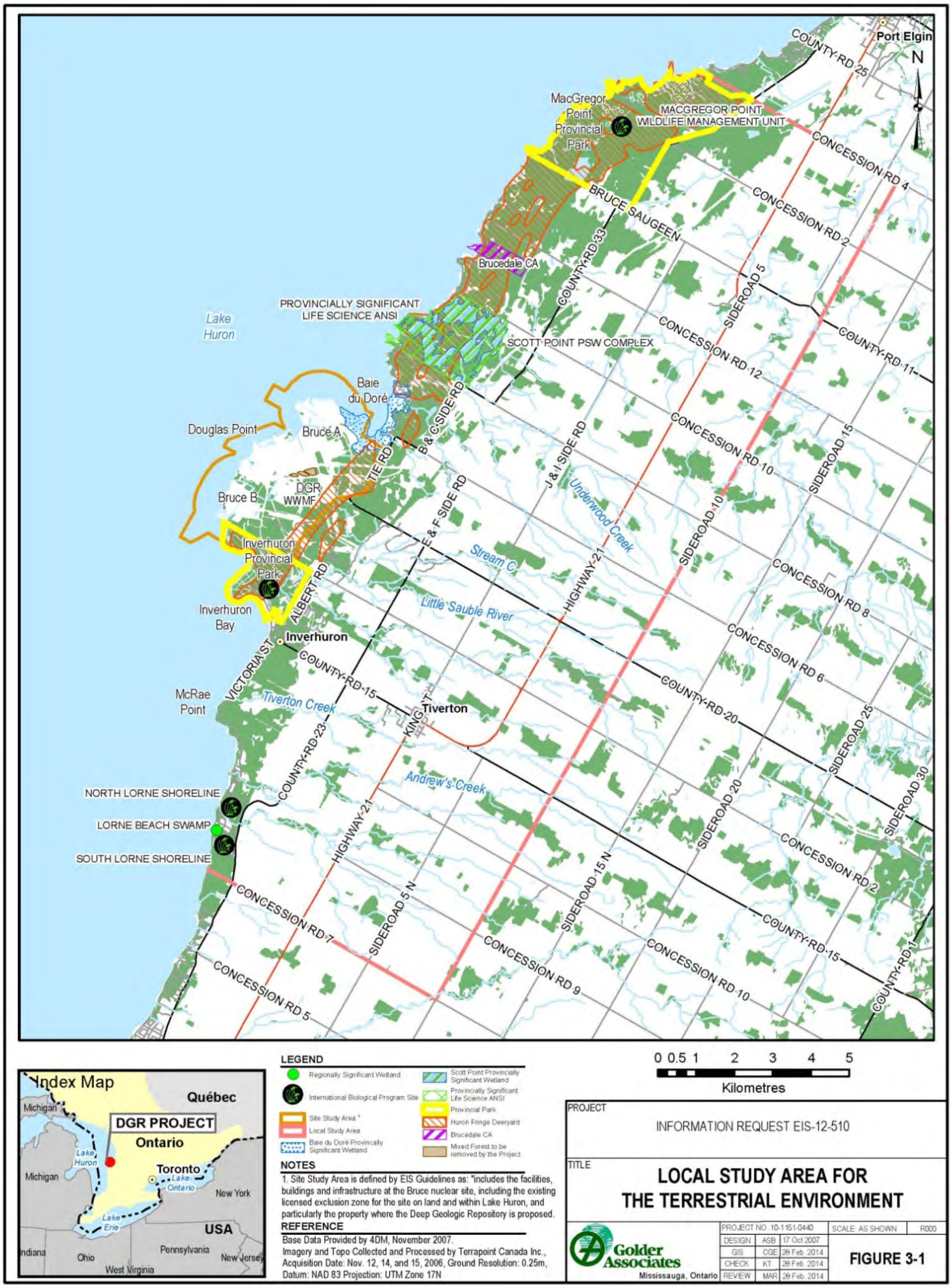
3.7 Figures

Figures are provided on the following pages.

Figure 3-1: Local Study Area for the Terrestrial Environment



NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

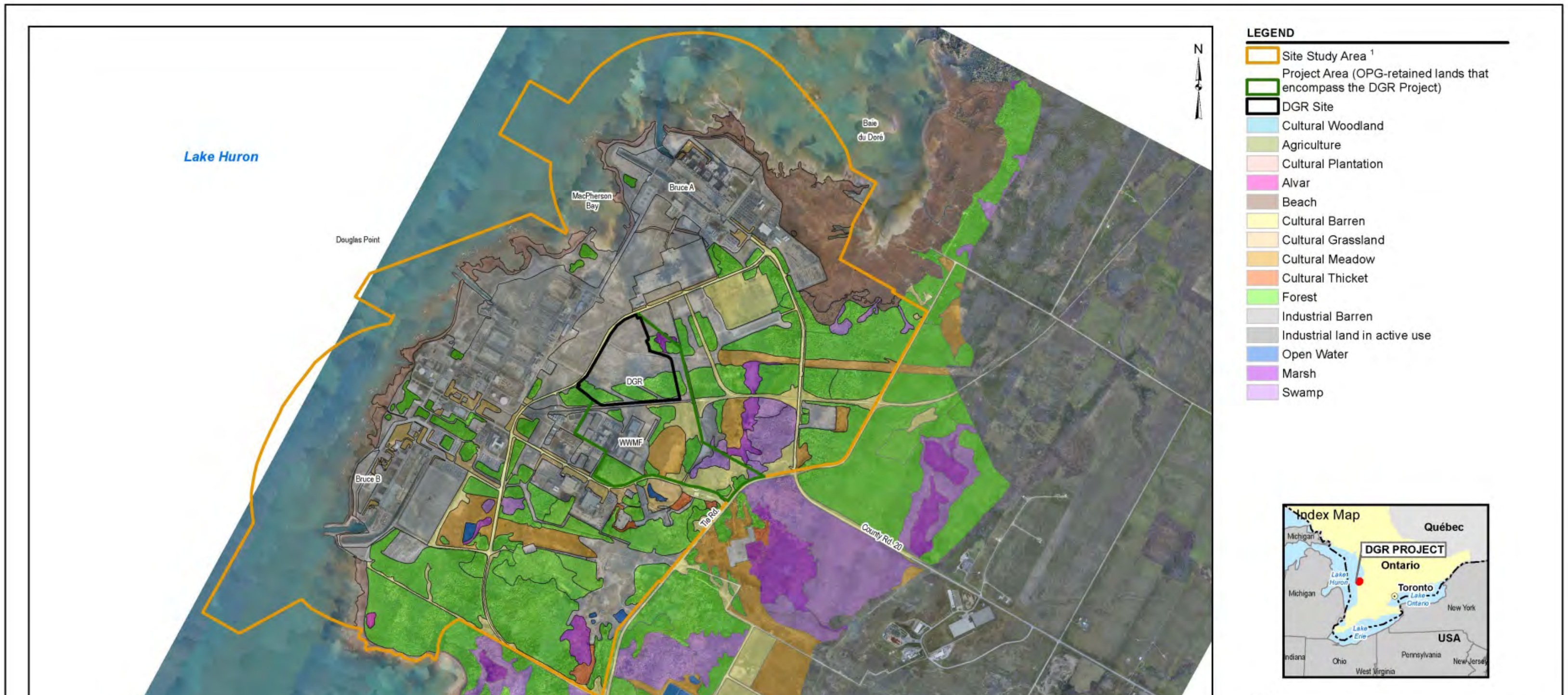
Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT: INFORMATION REQUEST EIS-12-510

TITLE: LOCAL STUDY AREA FOR THE TERRESTRIAL ENVIRONMENT

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN
DESIGN	ASB	17 Oct 2007	R000
GIS	CGE	28 Feb. 2014	FIGURE 3-1
CHECK	KT	28 Feb. 2014	
REVIEW	MAR	28 Feb. 2014	

Figure 3-2: Vegetation Communities



NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

The ELC data within the Site Study Area was collected during 2007. The ELC data within Project Area was updated during 2009 survey.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750 1,000
Metres

PROJECT
INFORMATION REQUEST EIS-12-510

TITLE
VEGETATION COMMUNITIES

Golder Associates
Mississauga, Ontario

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	FIGURE 3-2	
GIS	CGE	28 Feb. 2014		
CHECK	KT	28 Feb. 2014		
REVIEW	AB	28 Feb. 2014		

4. AQUATIC ENVIRONMENT

This section provides a detailed narrative that explains the significance assessment for the aquatic environment. Based on the literature reviewed and taking into consideration experience from other projects, OPG's hypothesis was that, for an effect on aquatic VECs to be considered a significant adverse effect, one or more of the following would be required:

- *habitat that is critical to the sustainability and productivity of the aquatic VECs is removed and there is no suitable habitat found elsewhere in the Site Study Area;*
- *removal and/or alteration of habitat causes changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area; and/or*
- *aquatic habitat connectivity and movement of aquatic VECs within the Site Study Area is disrupted.*

The basis for the above hypothesis, including literature reviewed, is provided below in Sections 4.1, 4.3 and 4.4.

The detailed assessment of the potential effects presented in the Aquatic Environment TSD (Golder 2011a) identified two residual adverse effects of the DGR Project on the aquatic environment. Neither of those effects was assessed to be significant.

4.1 Approach to Assessment

A detailed assessment of the potential effects was presented in the Aquatic Environment TSD (Golder 2011a, Sections 6, 7 and 8). Nine aquatic VECs were chosen using factors such as presence and abundance in the study areas, ecological importance, expressions of stakeholder interest, and past precedents in other environmental assessments conducted on the Bruce nuclear site (Golder 2011a). These VECs also represent indicators of ecosystem functions or important receptors in the ecosystem, which may be affected by the project. The effects on the identified VECs can also be used to describe the effects to other species that share habitat, behaviours and trophic characteristics with the VECs.

Any removal and/or alteration of aquatic habitat, regardless of the size of the area affected, was considered to be both a measurable change and an adverse effect to the VECs inhabiting that habitat. Five of the aquatic VECs are predicted to be affected by the DGR Project through the removal and/or alteration of aquatic habitat: burrowing crayfish, redbelly dace, creek chub, benthic invertebrates and variable leaf pondweed.

Consideration of ecological context is important in determining the nature of any effect on the aquatic environment. One purpose of the effects assessment is to establish the effects of the project on the maintenance of self-sustaining and ecologically functional populations and communities. Self-sustaining populations (and communities) can be considered as healthy, robust populations capable of withstanding environmental change and accommodating random population processes (Reed et al. 2003). The potential effects of the DGR Project on the aquatic VECs were examined both from the perspective of sustainability of the individual populations, and within the context of other aquatic communities in the larger system relating to habitat diversity, connectivity and aquatic habitat utilization. For example, production (e.g., nutrients, benthic invertebrates) from the warm water aquatic community in the South Railway Ditch can be washed downstream and contribute to the foraging opportunities for aquatic species in Stream C.

Consideration of ecological resiliency, or the capacity of the system to absorb disturbance and reorganize and retain the same structure, function and feedback responses (Holling 1973, Gunderson 2000), is also important in determining the nature of any effect on the aquatic environment. Population resilience can be considered to share similar features as ecological resilience. This is because adaptability influences the ability of the population to absorb or recover from change. For example, the South Railway Ditch is a man-made intermittent drainage feature. It supports a resilient aquatic community that is relatively tolerant to a broad range of environmental conditions, including habitats that are anthropogenic in nature. The aquatic habitat in the South Railway Ditch is likely to have the potential to recover more quickly than sensitive aquatic habitats (e.g., permanent coldwater trout streams) after a disturbance. These aquatic VECs, with the exception of burrowing crayfish, are common and widespread throughout the Regional Study Area and beyond, and occur in a wide range of habitat types.

Fisheries and Oceans Canada (DFO) applies the Risk Management Framework (DFO n.d.) to decision-making under the habitat protection provisions of the *Fisheries Act*. This approach uses pathways of effect in relation to the sensitivity of the fish habitat being affected. In a similar way, the approach in this assessment used the scale of residual adverse effects in relation to the sensitivity of the aquatic habitats being affected.

Other than acute toxicological thresholds, there are few absolute effects thresholds for aquatic species available in literature or established guidelines, and biological parameters are typically subject to large amounts of natural variation. There is interest in identifying disturbance thresholds for establishing regulatory criteria for aquatic systems on the part of stream ecologists, watershed managers and policy makers (Wang et.al. 2007). It is anticipated that disturbance thresholds being developed will correspond to meaningful changes in ecosystem function or aquatic communities (Brenden et.al. 2008). The classification of effects on aquatic VECs for the DGR Project is based on quantitative and qualitative analyses supported by relevant information from the scientific literature on life history characteristics, taking into consideration experience from other projects and professional judgement.

4.2 Existing Conditions

The DGR Project is predicted to affect redbelly dace, creek chub and variable leaf pondweed VECs in the South Railway Ditch, and burrowing crayfish and benthic invertebrates in both the South Railway Ditch and other aquatic habitats in the Project Area. These VECs are common and widespread in the Local Study Area and are more fully discussed in the Aquatic Environment TSD (Golder 2011a, Section 5).

To understand the importance of changes in the abundance and distribution of aquatic communities and their ability to remain self-sustainable, as well as the ecological function of the communities the various aquatic habitats support, the aquatic habitat present in surface water features potentially affected by the DGR Project need to be put into context.

The Local Study Area, shown on Figure 4-1, corresponds to the Stream C and Underwood Creek watersheds for the on-land (non-lake) portion. The Local Study Area also extends approximately 2 km offshore into Lake Huron, from MacGregor Point Provincial Park in the north and approaches McRae Point in the south. The watercourses and lake habitats in this study area have been historically influenced by land uses in watersheds comprised of open farmland, interspersed with infrastructure corridors (transmission and road), rural settlement areas and the Bruce nuclear site.

The Site Study Area, shown on Figure 4-2, corresponds to the Bruce nuclear site and the nearshore waters of Lake Huron (small embayment immediately south of Bruce A known as MacPherson

Stream C in the Site Study Area

Bay), which receive the surface water runoff from catchment areas draining water from portions of the Project Area.

The Site Study Area also includes the lower section of the Stream C watershed, which drains the remainder of the Project Area. Effects at the Site Study Area level are focused on the individual species and habitats within the Bruce nuclear site and the potential receiving waterbodies (e.g., on-site ditches, Stream C). The land use in the Site Study Area is dominated by industrial facilities associated with the Bruce nuclear site, characterized as a fragmented and disturbed landscape, as well as a portion of Inverhuron Provincial Park to the south and Baie du Doré to the north.

The surface water features potentially affected by the DGR Project consist of the South and North Railway Ditches, the northeast wetland, other ephemeral aquatic features, including drainage ditches along roadways and the railway spur, and the portion of Stream C downstream of the abandoned rail bed.

Burrowing crayfish habitat (i.e., moist clay soils) occurs in all of the surface water features potentially affected by the DGR Project, and throughout the Site Study Area (Golder 2007).

Redbelly dace, creek chub, variable leaf pondweed and benthic invertebrates use aquatic habitat in the South Railway Ditch and Stream C and are common and widespread in the study areas and throughout Ontario. The South Railway Ditch is choked with cattails and the banks are covered with a mix of grasses, trees and shrubs. Stream C is described fully in the Aquatic Environment TSD (Golder 2011a, Section 5.3.2.2).

4.3 Description of Potential Effects

The only identified adverse effect on the aquatic VECs in the South Railway Ditch results from the construction of the rail bed crossing for waste transfer from the Western Waste Management Facility to the DGR Project site. Construction of the rail bed crossing will cause a change in habitat in a localized area of the South Railway Ditch. The crossing consists of the placement of a culvert in-stream, which will cover a small area of in-stream habitat. Appropriate in-design features (e.g., embedded culvert for fish passage), specific mitigation measures (e.g., management of surface water runoff) and best management practices (e.g., erosion and sediment control) both during and after construction were assessed as having a mitigating effect on the habitat alteration. However, these measures do not avoid the alteration of aquatic habitat in the South Railway Ditch, resulting in a residual adverse effect on the aquatic VECs using this habitat.


South Railway Ditch

Similarly, site preparation and decommissioning activities are identified as resulting in an adverse effect on burrowing crayfish habitat in other aquatic habitats on the DGR Project Site, specifically the North Railway Ditch, other drainage ditches and ephemerally wet low areas. The footprint of the project avoids most of the identified crayfish habitat in the Project Area, including protection of the marsh in the northeast portion of the Project Area. The construction of the crossing over the abandoned rail bed and other surface infrastructure will result in the loss of a small portion of burrowing crayfish habitat in the North Railway Ditch, as well as other ditches in the western portion of the Project Area. Rehabilitation after decommissioning of the DGR Project may include both active and passive naturalization of the Project Area to provide additional suitable habitat, similar to that currently provided on the site. Rehabilitation of the project site was considered as a characteristic of reversibility in the significance assessment instead of as a mitigation measure.

Measurable changes predicted for surface water quantity and flow, surface water quality (see Sections 2 and 10, and Golder 2011b, Section 7.3), are not likely to create any additional or combined effects on the aquatic VECs (Golder 2011a, Section 7.3.2.2 and 7.5.2.1). Vibration effects from blasting during shaft sinking and underground development are predicted to be less than thresholds established for protecting aquatic life (Wright and Hopky 1998) and are not likely to create any additional or combined effects on the aquatic VECs (Golder 2011a, Section 7.2.2.1).

4.4 Significance of the Residual Adverse Effects

In accordance with the categories set out in the EIS Guidelines, the residual adverse effects of the Project on the aquatic VECs can be described as follows:

- **Magnitude**: A loss/alteration of <1% of non-critical habitat in the Project Area.
- **Geographic Extent**: The extent of the habitat loss/alteration effect is localized and limited to the Project Area.
- **Timing and Duration**: The burrowing crayfish habitat loss will begin immediately at the commencement of site preparation and remain in full effect until rehabilitation begins. The habitat alteration caused by the rail bed crossing will begin during the construction phase and remain throughout operations. The rail bed crossing and the ditches would re-naturalize following operations (during decommissioning).
- **Frequency**: The habitat loss and alteration is continuous through the duration of the site preparation and construction, operations and decommissioning phases of the project.
- **Reversibility**: The loss and alteration of habitat was conservatively assumed to not be reversible with time.
- **Probability**: The loss/alteration of aquatic habitat will occur should the project proceed.
- **Context**: The habitat affected is common, non-critical habitat. The effect occurs within man-made, regularly disturbed aquatic features and does not extend into the more sensitive natural watercourses such as Stream C.

Removal of Burrowing Crayfish Habitat – The ecological function, sustainability and productivity of the burrowing crayfish population in the Site Study Area will be unaffected. The habitats to be removed are common in the Site Study Area and are small in proportion to available similar type habitats. Less than 1% of the available burrowing crayfish habitat identified during the baseline studies in the Project Area will be disturbed, and the proportion is smaller with respect to other available, suitable habitat throughout the Site Study Area. In addition, the type of habitat to be removed is anthropogenic, consisting of a small area of disturbed ditch bed and other disturbed seasonally wet depressions. Other burrowing crayfish habitat associated with stream margins and wetland features in the Project and Site Study Areas will not be disturbed through the DGR Project works and activities. There is suitable habitat for the burrowing crayfish in anthropogenically disturbed areas throughout the Site Study Area and the Project footprint will not interrupt any movement corridors or critical habitat connections for burrowing crayfish. For these reasons, it was concluded that the loss of aquatic habitat used by burrowing crayfish was not significant.

Alteration of Aquatic Habitat in the South Railway Ditch – While the South Railway Ditch provides habitat for fish, it is considered habitat of marginal quality (i.e., non-critical) when compared to the quality of habitat elsewhere in the Site and Local Study Areas, for instance the fish habitat in Stream C. The affected VECs are resilient species and the aquatic communities in the Site Study Area have previously been sustained through a number of human-related disturbances. The affected area does not contain unique features, species or ecological functions within the study areas. Therefore, the habitat alteration will not affect the sustainability and productivity of these habitats or the populations of aquatic species that rely on them. The affected aquatic habitat is at the upstream end of the South Railway Ditch. Therefore, the loss is not expected to affect habitat connectivity and disrupt flow or migration within the watershed. For these reasons, it was concluded that the alteration of aquatic habitat was not significant.

The existing conditions and effects assessment capture the cumulative effects of past and existing projects. There were no future projects or activities identified in the Site Study Area or Local Study Area that could contribute to cumulative effects on the VECs concurrent with the effects of the DGR Project. Additionally, the VECs are widespread and tolerant. Therefore the VECs resilience to change indicates that there are few other stressors on these species populations that could compromise their sustainability.

Consideration was also given to whether the effects assessment conclusions on the aquatic environment are sensitive to changes in climate conditions (OPG 2011, Section 7.14). It was concluded that the future environment affected by climate change will not influence the conclusions of the assessment for the aquatic VECs in the South Railway Ditch and burrowing crayfish and benthic invertebrates in the South Railway Ditch and other aquatic habitats.

In summary,

- The only predicted residual adverse effects of the DGR Project on the aquatic environment were the removal of burrowing crayfish habitat present in the North Railway Ditch, other drainage ditches and ephemerally wet low areas during site preparation activities, and the alteration of aquatic habitat for redbelly dace, creek chub, burrowing crayfish, variable leaf pondweed and benthic invertebrates in the South Railway Ditch caused by construction of the rail bed crossing.
- The predicted adverse effects were assessed against a hypothesis that, in order to be significant, one or more of the following would be required:
    - *Habitat that is critical to the sustainability and productivity of the aquatic VECs is removed and there is no suitable habitat found elsewhere in the Site Study Area.* The area of aquatic habitat loss is not large enough to affect the sustainability or productivity of the local populations of affected aquatic VECs in the Site Study Area. The affected habitat is of marginal (non-critical) quality for the aquatic VECs when compared to the quality and there is available habitat elsewhere in the Site and Local Study Area.
    - *Removal and/or alteration of habitat causes changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area.* The habitat loss or alteration is not expected to cause changes to the ecological function of the aquatic community or the aquatic habitat in the Site Study Area.
    - *Aquatic habitat connectivity and movement of aquatic VECs within the Site Study Area would be disrupted.* The habitat loss or alteration is not expected to affect watercourse habitat connectivity or disrupt flow movement or migration within the study areas.

Therefore, OPG concluded that the residual adverse effects of the DGR Project on the aquatic environment are not significant.

4.5 Confidence

OPG has a high degree of confidence in the conclusion that the removal of a small proportion of aquatic habitat within the Project Area is not significant to the affected aquatic VECs. The significance conclusion is founded on the precautionary principle. A conservative approach was used to identify measurable effects, which were assessed in a watershed context (Project Area and Site Study Area).

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4.7 Figures

Figures are provided on the following pages.

Figure 4-1: Local Study Area for the Aquatic Environment

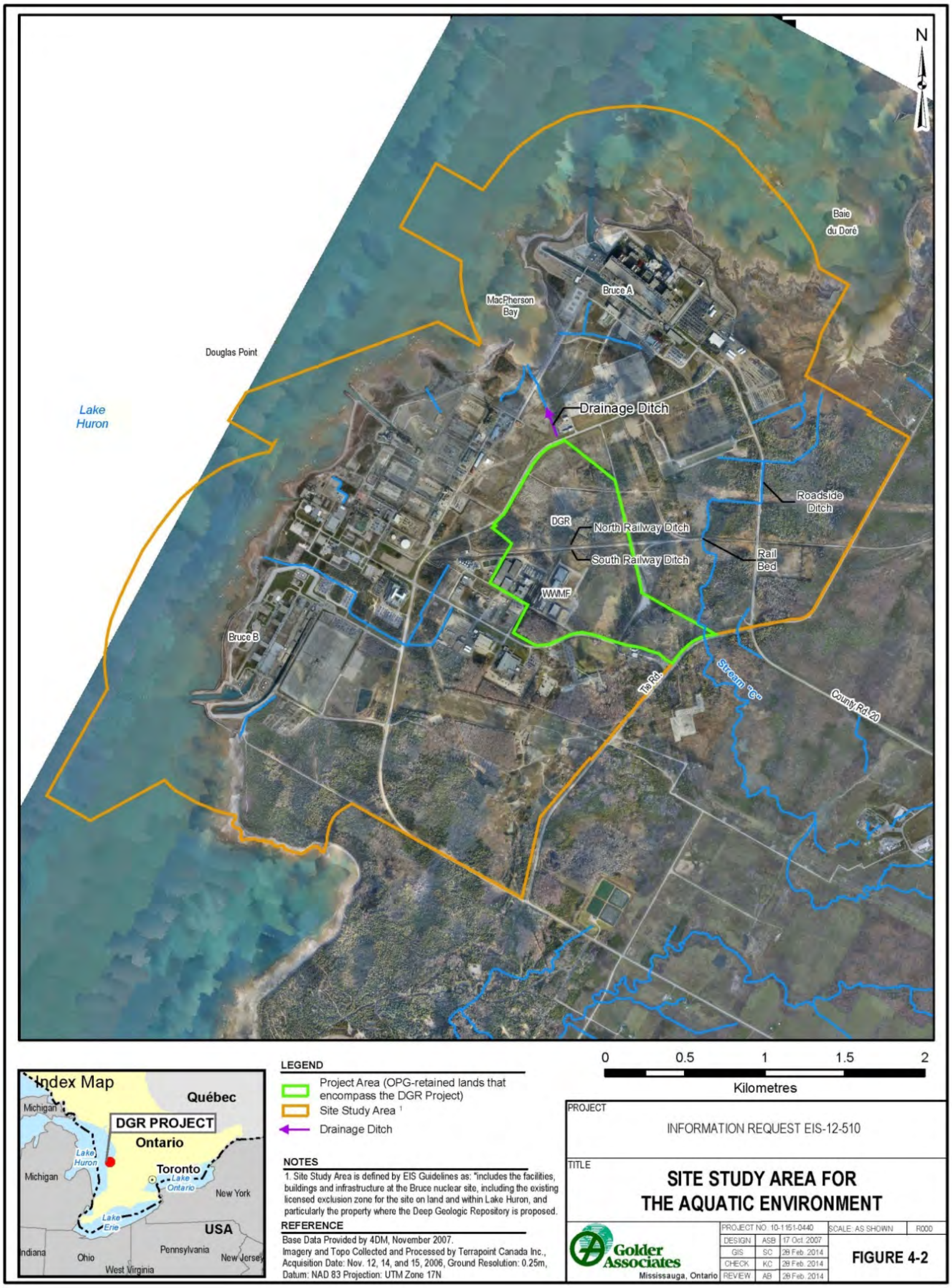
NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m; Datum: NAD 83 Projection: UTM Zone 17N

Figure 4-2: Site Study Area for the Aquatic Environment



LEGEND

🟩	Project Area (OPG-retained lands that encompass the DGR Project)
🟧	Site Study Area [1]
←	Drainage Ditch

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT
INFORMATION REQUEST EIS-12-510

TITLE
SITE STUDY AREA FOR THE AQUATIC ENVIRONMENT

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	**FIGURE 4-2**	
GIS	SC	28 Feb. 2014		
CHECK	KC	28 Feb. 2014		
REVIEW	AB	28 Feb. 2014		

5. AIR QUALITY

This section provides a detailed narrative that explains the significance assessment for air quality. Based on the literature reviewed and experience from other projects, OPG's hypothesis was that, to have a significant effect on the air quality VEC*, the DGR Project would need to result in ambient air concentrations beyond the Site Study Area that exceed relevant established ambient air quality criteria more than 10% of the time*.

The detailed assessment of the potential effects presented in the Atmospheric Environment TSD (Golder 2011) identified residual adverse effects of the DGR Project on air quality during the site preparation and construction phase, the operations phase, and the decommissioning phase. None of those effects were assessed to be significant.

5.1 Approach to Assessment

The effects assessment focussed on the following indicator compounds selected to represent compounds that will be emitted from the project in measurable amounts, have established ambient criteria, and are commonly used for describing air quality in Ontario:

- nitrogen dioxide (NO_2);
- sulphur dioxide (SO_2);
- carbon monoxide (CO);
- suspended particulate matter (SPM);
- airborne particles with nominal aerodynamic diameters smaller than 10 micrometres (µm) in diameter (PM_{10}); and
- airborne particles with nominal aerodynamic diameters smaller than 2.5 µm in diameter ($PM_{2.5}$).

Table 5-1 provides a listing of the ambient air quality criteria used in the assessment.

When establishing ambient air quality criteria in Canada, thresholds are set at levels that inherently provide a level of protection. Criteria are usually set below "no-effects" or "lowest-observed-adverse effects" levels. For example, the "acceptable" national ambient air quality objectives for exposures to carbon monoxide (CO) (i.e., 15,000 µg/m³ for 8-hour exposures; 35,000 µg/m³ for 1-hour exposures) were set at levels that would result in COHb (Carboxyhemoglobin) levels in adults less than 2%, or below the 2.5% COHb level identified as a conservative "no-effect level" (CEPA/FPAC 1994). Similarly, the "acceptable" national ambient air quality objectives for exposures to nitrogen dioxide (NO_2) (i.e., 100 µg/m³ for annual exposures; 400 µg/m³ for 1-hour exposures) were set to levels that were less than the respective "lowest observed adverse effects levels (LOAEL) of 940 µg/m³ and 156 µg/m³ (FPAC 1987). In some cases, such as SPM, the ambient air quality criteria are established for aesthetic reasons (MOE 2012a) rather than ecological or health thresholds. Therefore, occasionally exceeding the criteria values are not likely to result in significant adverse effects. . Furthermore, the Canada-Wide Standards development process has included acceptable frequency for exceeding the criteria value while still achieving the standard. For fine particulate matter ($PM_{2.5}$) the 24-hour Canada-Wide Standard is based on the 98th percentile, and for 8-hour ozone (O_3) the Canada-Wide Standard is based on the fourth highest daily value (CCME 2000). The fourth highest daily value is approximately equal to the 98th percentile.

Table 5-1: Ambient Air Quality Criteria Used in the Assessment of Effects on Air Quality

Indicators	Air Quality Criteria for Indicators (μg/m³) (Golder 2011)[a]	AAQC 2012 (μg/m³) (MOE 2012a)	MOE Standards[b] (μg/m³) (MOE 2012b)
1-hour NO_2	400	400	400
24-hour NO_2	200	200	200
Annual NO_2	100	—	—
1-hour SO_2	900	690	690
24-hour SO_2	300	275	275
Annual SO_2	60	55	—
1-hour CO	35,000	36,200	—
8-hour CO	15,000	15,700	—
24-hour SPM	120	120	120
Annual SPM	70	60[c]	—
24-hour PM_{10}	50	50	—
24-hour $PM_{2.5}$	30	30 25[d]	—

Notes:

[a] As detailed in Tables 4.2.1-1 and 11.1.1-1 of the Atmospheric Environment TSD (Golder 2011)

[b] The applicability of O.Reg. 419/05 standards are discussed in the responses to IR EIS-01-09 (OPG 2012b), EIS-01-09a (OPG 2012c), EIS-04-138 (OPG 2012a) and EIS-08-321 (OPG 2013).

[c] Geometric mean

[d] The 25 μg/m³ MOE guidelines listed in the Information Request only appears as a footnote to the AAQC table (MOE 2012a). The actual AAQC listed for $PM_{2.5}$ is 30 μg/m³. The value of 25 μg/m³ is recommended as a target for $PM_{2.5}$ resulting from a single facility.

Maximum ambient concentrations for comparison to the above criteria were predicted using a numeric dispersion model, specifically AERMOD, which is recommended for use in Ontario (MOE 2005). The model also provides information regarding the frequency of predicted values. This model was discussed and described in Technical Information Session #2 (OPG 2012d).

To ensure a conservative assessment, maximum existing ambient concentrations of the indicator compounds were predicted for the existing sources in the Local Study Area and combined with background concentrations derived from monitoring data.

All DGR Project activities for which the emissions of indicator compounds could be quantified were classified as having the potential to cause a measurable change to the air quality VEC. Maximum ambient concentrations resulting from the DGR Project were then predicted by combining background air quality, existing sources and project emissions. An adverse effect was identified in cases where the predicted maximum ambient concentrations including DGR Project emissions increased relative to the existing ambient concentrations. The emissions used in the modelling included the mitigation incorporated into the design of the project; therefore, all predicted adverse effects were also classified as residual adverse effects.

In addition to the emissions of indicator compounds, the project is expected to result in emissions of several other compounds in relatively small amounts. The ambient concentrations of all of these compounds were predicted at human receptor locations, and the results assessed as an integral part of the human health assessment (OPG 2011, Appendix C). Although predicted ambient acrolein concentrations at the off-site human receptor locations were less than ambient Ontario criteria (OPG 2012c, IR-05-223), the resulting inhalation of acrolein by local residents during the site preparation and construction phase was identified as a residual adverse effect to human health because the predicted concentrations were above health screening criteria. However, based on the results of a human health risk assessment, the resulting health risks to local residents were considered low (OPG 2011, Section 7.11). Changes in air quality were not predicted to result in adverse health effects during the operations phase. Therefore, no significant adverse effects were predicted on human health (OPG 2011, Section 7.11) as a result of changes in air quality.

5.2 Existing Conditions

Existing air quality conditions in the Local Study Area were predicted using a combination of dispersion modelling of the existing local sources and background air quality derived from air quality monitoring stations in the Regional Study Area. Existing conditions were predicted in a conservative manner.

The contribution to ambient air quality from existing sources at the Bruce nuclear site (including the incinerator at the Western Waste Management Facility) was modelled using on-site local meteorological data and conservative selection of emissions. The emissions were conservatively based on the maximum permitted emissions from all of the facilities at the Bruce nuclear site, as well as the emissions for actual vehicle traffic activity levels for those sources that do not require permits. The resulting predictions are conservative because actual emission levels at the Bruce nuclear site are considerably lower than the permitted maximum values. The resulting maximum predicted concentrations were combined with background concentrations derived from the air quality measurements taken in the Regional Study Area. The existing conditions modelled in this manner are shown in the second column on Tables 5-2 and 5-3.

The background air quality established from air monitoring data collected within the Regional Study Area represents the combined effect of emissions from sources near each of the monitoring stations, as well as the effect of the emissions transported into the region. Based on feedback from regulators (CEAA and CNSC 2009), guidance in other Canadian jurisdictions (AENV 2009) and expert judgement, the 90th percentile of the available monitoring data was considered an appropriate estimate of background air quality for combination with modelled existing sources. The use of the 90th percentile of the available monitoring data continues to be identified as appropriate for establishing background air quality in more recent guidance documents (AESRD 2013). Where data were available, concentrations measured at the nearest regional station (Tiverton) were used. In those cases where data from Tiverton were unavailable, background air quality was based on the next closest regional station in London, Ontario, or was calculated based on the available data.

Generally the monitoring data show that the existing air quality in Tiverton is good; the maximum measured concentrations for the gaseous indicators (i.e., NO_2, SO_2 and CO) are well below established criteria (Golder 2011, Section 5, Appendix E). Monitoring data for Tiverton shows that fine particulate ($PM_{2.5}$) currently exceeds the 30 µg/m³ criteria about 1.0% of the time. Monitoring data from the other communities in the Regional Study Area (i.e., Kitchener, London and Sarnia) report 24-hour $PM_{2.5}$ values higher than those in Tiverton, with maximums ranging between 45.6 and 75.5 µg/m³ (Golder 2011, Section 5, Appendix E), and the frequencies above 30 µg/m³ ranging between 2.2% and 4.7% of the time.

Ambient PM_{10} and SPM concentrations were not available in Tiverton, so values were derived based on available particulate monitoring (Golder 2011, Appendix E8). By applying the derived relationships between available $PM_{2.5}$, PM_{10} and SPM monitoring, it was concluded that there have been periods at Tiverton and the other regional monitoring stations when the maximum 24-hour PM_{10} and SPM concentrations would have exceeded the ambient criteria values of 50 and 120 µg/m³, respectively.

5.3 Description of Potential Effects

Air quality effects of the project were predicted using a dispersion model. The modelling included the conservatively determined existing conditions (described previously), and conservative project emissions that assumed all equipment were operating at their full capacity. The project emissions included all activities at the site, such as traffic, construction equipment exhaust, and fugitive dust.

The resulting calculated maximum ambient concentrations were then compared to the existing maximum ambient concentrations to determine if the emissions from the project were likely to result in an increase in the maximum concentration at, or beyond, the boundary of the Bruce nuclear site.

During the site preparation and construction phase, residual adverse effects were identified for nine of the air quality indicator compounds. Specifically, the calculated maximum ambient concentrations of 1-hour NO_2, 24-hour NO_2, annual NO_2, 1-hour CO, 24-hour CO, 24-hour SPM, annual SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$ during the site preparation and construction phase were higher than the maximum existing concentrations as shown in Table 5-2 (Golder 2011, Section 8.2.5). The concentrations of 24-hour SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$ were predicted to exceed the relevant criteria on nine of the 1,826 days modelled (i.e., <0.5% of the time).

Table 5-2: Predicted Residual Adverse Effect, Site Preparation and Construction Phase

Indicator Compound	Maximum Existing Concentration (µg/m³) in Local Study Area [a]	Maximum Site Preparation and Construction Phase Concentration (µg/m³) in Local Study Area [b]	Increase Over Existing Concentration (µg/m³) in Local Study Area [c]	Likely Adverse Effect?
1-hour NO_2	110.4	321.7	+211.3	adverse effect
24-hour NO_2	26.5	141.2	+114.7	adverse effect
Annual NO_2	6.8	18.5	+11.7	adverse effect
1-hour SO_2	318.9	318.9	0	no adverse effect
24-hour SO_2	51.3	51.3	0	no adverse effect
Annual SO_2	5.0	5.0	0	no adverse effect
1-hour CO	1,580.6	2,504.2	+923.6	adverse effect
8-hour CO	1,201.8	1,595.7	+393.9	adverse effect
24-hour SPM	71.0	276.9	+205.9	adverse effect
Annual SPM	25.1	30.7	+5.6	adverse effect
24-hour PM_{10}	26.0	75.3	+49.3	adverse effect
24-hour $PM_{2.5}$	15.4	45.7	+30.3	adverse effect

Notes:

[a] From Table 5.4.2-3 (Golder 2011). [b] From Table 8.2.3-4 (Golder 2011).

[c] The increases over existing concentrations are calculated as the difference between the calculated maximum site preparation and construction phase concentrations and the maximum existing concentrations. These maximums may not occur at the same location.

During the operations phase, residual adverse effects were identified for eight air quality indicator compounds. Specifically, the predicted maximum ambient concentrations of 1-hour NO_2, 24-hour NO_2, annual NO_2, 1-hour CO, 24-hour CO, 24-hour SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$ were higher than the existing maximum concentrations as shown in Table 5-3 (Golder 2011, Section 8.2.5). None of the predicted maximum concentrations exceed the relevant ambient air criteria.

Table 5-3: Predicted Residual Adverse Effect, Operations Phase

Indicator Compound	Maximum Existing Concentration (µg/m³) in Local Study Area [a]	Maximum Operations Phase Concentration (µg/m³) in Local Study Area [b]	Increase Over Existing Concentration (µg/m³) in Local Study Area	Likely Adverse Effect?
1-hour NO_2	110.4	151.6	+41.2	adverse effect
24-hour NO_2	26.5	67.8	+41.3	adverse effect
Annual NO_2	6.8	7.6	+0.8	adverse effect
1-hour SO_2	318.9	318.9	0	no adverse effect
24-hour SO_2	51.3	51.3	0	no adverse effect
Annual SO_2	5.0	5.0	0	no adverse effect
1-hour CO	1,580.6	1,597.8	+17.2	adverse effect
8-hour CO	1,201.8	1,202.3	+0.5	adverse effect
24-hour SPM	71.0	71.5	+0.5	adverse effect
Annual SPM	25.1	25.1	0	no adverse effect
24-hour PM_{10}	26.0	26.9	+0.9	adverse effect
24-hour $PM_{2.5}$	15.4	15.9	+0.5	adverse effect

Notes:
[a] From Table 5.4.2-3 (Golder 2011).
[b] From Table 8.2.3-5 (Golder 2011).
[c] The increases over existing concentrations are calculated as the difference between the calculated maximum site preparation and construction phase concentrations and the maximum existing concentrations. These maximums may not occur at the same location.

The residual adverse effects for the decommissioning phase were determined to be similar to, or less than, those during the site preparation and construction phase (Golder 2011, Section 8.2.3.2).

5.4 Significance of the Residual Adverse Effects

The following narrative deals with the significance of the predicted residual adverse effects by project phase.

Site Preparation and Construction Phase – In accordance with the categories set out in the EIS Guidelines, the residual adverse effect of the DGR Project on air quality during the site preparation and construction phase can be described as follows:

- **Magnitude**: The maximum ambient concentrations beyond the Site Study Area will increase for nine of the indicators. The maximum ambient concentrations exceed relevant ambient criteria for 24-hour SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$.
- **Geographic Extent**: The extent of areas where concentrations were predicted to exceed relevant criteria is limited to an area adjacent to, but beyond, the Site Study Area (i.e., the fenceline of the Bruce nuclear site).
- **Timing and Duration**: The effects are assumed to occur throughout the site preparation and construction phase.
- **Frequency**: Predicted concentrations above ambient criteria will occur infrequently throughout the site preparation and construction phase (<0.5% of the time).
- **Reversibility**: The effect on air quality will be immediately reversible when the activities that cause the emissions cease.
- **Probability**: The predicted effects on air quality during the site preparation and construction phase are expected to occur if the Project proceeds.
- **Context**: The existing air quality measured in the region is generally good, with concentrations of gaseous indicators compounds meeting all relevant ambient criteria and particulate matter (SPM, PM_{10} and $PM_{2.5}$) concentrations infrequently exceeding ambient criteria.

For assessing the effects on ambient air quality, there are absolute effects thresholds established as regulatory criteria. Regulatory ambient air criteria established in Canada were developed to ensure adequate protection for the environment and those living in it. Of the predicted residual adverse effects arising during site preparation and construction, only the maximum 24-hour SPM, 24-hour PM_{10} and 24-hour $PM_{2.5}$ increased to the point of exceeding the relevant regulatory criteria values (Golder 2011, Section 11.2.1). Elevated levels of airborne particulates (i.e., $PM_{2.5}$, PM_{10} and SPM) are not uncommon near construction sites, and can occur in many areas where human activities occur. Elevated ambient concentrations of airborne particulates (i.e., concentrations above the relevant criteria) have also been monitored at stations in the region.

Although the air quality assessment predicted that the maximum 24-hour $PM_{2.5}$, 24-hour PM_{10} and 24-hour SPM concentrations could exceed the relevant criteria during the site preparation and construction phase, such predictions were restricted to areas immediately adjacent to, but beyond, the fenceline of the Bruce nuclear site. Ambient air criteria are developed to apply at locations where a member of the public could be exposed (i.e., the criteria would apply at, or beyond, the fenceline of the property). The authors of the Canada-Wide Standards acknowledge that achievement of the standards were to be based on “community-oriented locations” (CCME 2000), with an emphasis on areas “where people live, work and play” (CCME 2000). None of the predicted maximum concentrations at human receptors exceed relevant ambient air quality criteria (Golder 2011, Appendix J).

As ambient air quality criteria in Canada are established at levels that are conservatively safe (see Section 5.1), occasionally exceeding the criteria values is not likely to result in significant adverse effects. This is consistent with the recently developed Canada-Wide Standards for ambient air that incorporate an allowable frequency above the criteria values. Occasional values in excess of the relevant ambient air quality criteria are also observed at the ambient monitoring stations in the Regional Study Area. These data show that, for fine particulate matter ($PM_{2.5}$), the monitoring data for Tiverton exceeds the 30 $\mu g/m^3$ Canada-Wide Standard criteria about 1.0% of the time, for Kitchener about 2.2% of the time, for Sarnia about 4.7% of the time and for London about 2.3% of the time. Similarly, the ambient monitoring in the Regional Study Area shows the reading from 65 parts per billion (ppb) Canada-Wide Standard criteria is exceeded 5.4% of the time in Tiverton, 4.8% of the time in Kitchener, 5.3% of the time in Sarnia and 5.0% of the time in London. For an effect to be considered significant, the frequency of exceeding the relevant ambient air quality criteria was selected as 10%. This frequency is based on professional judgement and past environmental assessments, and is an incremental contribution comparable to the current situation observed in the region. Ambient 24-hour SPM, 24-hour PM_{10} and 24 hour $PM_{2.5}$ concentrations above the relevant ambient air quality criteria were predicted to occur <0.5% of the time (Golder 2011, Section 11.2.1), which is much less than the 10% threshold.

The conservative nature of the assessment in combination with the short duration of the periods during which the criteria could be exceeded, and the point of impingement being limited to the area immediately adjacent to, but beyond, the fenceline of the Bruce nuclear site, is the basis for concluding that the residual adverse effects during site preparation and construction are not significant.

Operations Phase – In accordance with the categories set out in the EIS Guidelines, the residual adverse effect of the DGR Project on air quality during the operations can be described as follows:

- **Magnitude**: None of the predicted maximum ambient concentrations exceed relevant ambient criteria.
- **Geographic Extent**: None of the predicted ambient concentrations exceed relevant ambient criteria beyond the Site Study Area.
- **Timing and Duration**: The effects are assumed to occur throughout the operations phase.
- **Frequency**: None of the predicted ambient concentrations exceed relevant ambient criteria beyond the Site Study Area.
- **Reversibility**: The effect on air quality will be immediately reversible when the activities that cause the emissions cease.
- **Probability**: The predicted effects on air quality during the operations phase are expected to occur should the Project proceed.
- **Context**: The existing air quality measured in the region is generally good, with concentrations of gaseous indicators compounds meeting all relevant ambient criteria and particulate matter (SPM, PM_{10} and $PM_{2.5}$) concentrations infrequently exceeding ambient criteria.

Of the predicted residual adverse effects modelled to occur during operations, none exceed the relevant regulatory criteria values beyond the Site Study Area (Golder 2011, Section 11.3.1). Therefore, it was concluded that the residual adverse effects during operations were not significant.

Decommissioning Phase – The residual adverse effects for the decommissioning phase were determined to be similar to, or less than, those during the site preparation and construction phase. For the reasons presented above, it was concluded that the effects of the DGR Project on air quality during the decommissioning phase are not significant.

No additional cumulative residual adverse effects on the air quality VEC as a result of other projects were identified. The worst case existing air quality used for the assessment inherently included the effect of other existing project emissions. There were no future projects identified that would result in cumulative air quality effects that were greater than the effects predicted as part of the assessment.

Consideration was also given to whether the effects assessment conclusions for air are sensitive to changes in climate conditions (OPG 2011, Section 7.14). It was concluded that the changing climate will not affect any of the conclusions related to the air quality predictions. Therefore, the conclusion that the predicted effects to air quality are not significant remains valid.

In summary,

- Residual adverse effects of the DGR Project on air quality were identified during the site preparation and construction phase, the operations phase, and the decommissioning phase.
- The predicted adverse effects were assessed against a hypothesis that, to have a significant effect on the air quality VEC, *the DGR Project would need to result in ambient air concentrations beyond the Site Study Area that exceed relevant established ambient air quality criteria more than 10% of the time*.
- During site preparation and construction, and decommissioning, the predicted ambient concentrations of SO_2, NO_2 and CO do not exceed the relevant ambient air quality criteria beyond the Site Study Area. The maximum predicted 24-hour ambient concentrations of $PM_{2.5}$, PM_{10} and SPM were predicted to exceed relevant criteria less than 0.5% of the time, in a relatively small area immediately adjacent to, but beyond, the Site Study Area.
- None of the predicted indicator concentrations during the operations phase exceed the relevant ambient air quality criteria beyond the Site Study Area.

Therefore, OPG concluded that the residual adverse effects on air quality are not significant.

5.5 Confidence

OPG has a high degree of confidence in the conclusion that the changes in air quality resulting from the proposed activities associated with the DGR Project are not significant. As described in this section, the significance conclusion is founded on a conservative approach to predicting existing local air quality and to predicting the effect on local conditions of emissions from the DGR Project. Established and accepted air modelling systems were used for the assessment in combination with available air quality measurements for the area and available meteorological data from the site.

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OPG. 2012c. Letter, A. Sweetnam to S. Swanson, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to a Sub-set of Package #5 Information Requests. CD# 00216-CORR-00531-00145, October 24, 2012. (CEAA Registry Doc# 776).

OPG. 2012d. OPG's Written Submission for JRP's Technical Information Session #2 on October 11, 2012. Attachment to OPG letter, Albert Sweetnam to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission for the October 11, 2012 JRP Technical Information Session #2". CD#: 00216-CORR-00531-00142, October 3, 2012. (CEAA Registry Doc# 758).

OPG. 2013. Letter, A. Letter, A. Sweetnam to S. Swanson, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to Second Sub-set of Package #8 Information Requests. CD# 00216-CORR-00531-00170, February 28, 2013. (CEAA Registry Doc# 902).

6. NOISE

This section provides a detailed narrative that explains the significance assessment for noise. Based on the literature reviewed and taking into consideration experience from other projects, OPG's hypothesis was that, for a noise effect to be considered a significant adverse effect, *the change in ambient noise would need to be disturbing (i.e., >10 dB change in the quietest hour)*.

The detailed assessment of the potential noise effects presented in the Atmospheric Environment TSD (Golder 2011a, Sections 6, 7, and 8) identified one residual adverse effect of the DGR Project. The effect was assessed to be not significant.

6.1 Approach to Assessment

A detailed assessment of noise was presented in the Atmospheric Environment TSD (Golder 2011a, Sections 6, 7 and 8). Change in noise was assessed as a potential cause of nuisance beyond the Site Study Area and was identified as being important to stakeholders and regulators.

The noise effects VEC was assessed using the lowest 1-hour L_{eq}, or quietest hour which may be affected by the Project. The use of the 1-hour L_{eq} incorporates both level and dose. It follows the approach used in Ontario by the Ministry of the Environment (MOE) (MOE 1995, 2013) and more broadly by Health Canada (HC 2005) and the World Health Organization (WHO 1999), although the approach used in the DGR Project was more conservative. The DGR assessment used the lowest 1-hour L_{eq} rather than longer term average L_{eq} metrics. As a result, any predicted change in noise levels associated with the DGR Project would be greater following the approach used in the EIS (OPG 2011), and have a higher probability of being identified as an adverse effect. The assessment also conservatively assumed that noise from site activities is continuous for the duration of the site preparation and construction and decommissioning phases, even though construction type activities are not continuous in nature. The predictions did not apply equipment duty cycle (i.e., the actual amount of time the equipment will operate), which would result in lower noise predictions. All equipment or activities for which noise emissions can be quantified were considered likely to cause a measurable effect and were included as part of the noise predictions.

A change in ambient noise level of <3 dB is the generally accepted threshold for perceptibility of changes in noise levels in the environment (Hansen 2001). Changes in ambient noise levels >3 dB and ≤6 dB are considered to be noticeable, while changes that are >6 dB and ≤10 dB are considered to be readily noticeable (Hansen 2001). A change in ambient noise level of >10 dB is considered disturbing (Hansen 2001; Beranek 1988; Bies. and Hansen 2009). These thresholds can also be described as follows:

- 3 dB change in ambient noise levels means that noise from the DGR Project is equal to the existing levels at receptor locations (a doubling of the sound power);
- 6 dB change in ambient noise levels is a doubling of the sound pressure level received at receptor locations; and
- 10 dB change in ambient noise levels is perceived by humans as being twice as loud (Hansen 2001) at receptor locations.

Of the above thresholds, a 3 dB change in ambient noise levels as a result of the DGR Project was selected as the threshold above which an adverse effect was identified.

Noise predictions were also carried out, as un-weighted noise levels (i.e., dB_{Lin}) for an assessment of noise effects on wildlife. Noise levels in dB_{Lin} were considered to be more appropriate for evaluating effects on ecological receptors than A-weighted levels (dBA), which are used in describing human response to noise. The un-weighted noise levels represent the actual acoustic energy in the atmosphere, and are considered to be an unbiased representation of how ecological receptors react to noise levels in the environment. The assessment of effects of noise on wildlife was carried out in the Terrestrial Environment TSD (Golder 2011b). The DGR Project noise levels were assessed as not resulting in any residual adverse effect on terrestrial ecology.

Predicted changes in noise levels at nearby residences were evaluated for their potential to affect the use and enjoyment of private property socio-economic environment VEC. The Socio-economic assessment (AECOM 2011a) determined this effect to be not significant. Similarly, changes in noise levels were expected at the on-site burial ground, the effects of which were included in the assessment of Aboriginal Interests (AECOM 2011b) and determined to be not significant (see also Section 7 of this response).

6.2 Existing Conditions

To understand how the potential change in noise levels associated with the DGR Project will be perceived by humans, the existing noise levels were quantified using extended periods of noise monitoring. A field study was conducted to help characterize existing noise levels. The noise monitoring locations are shown in Figure 6-1. The monitored results at each location are summarized in Table 6-1.

Table 6-1: Existing Noise Levels at Off-Site Noise Monitoring Locations

Location	Minimum 1-hour L_{eq} (dBA)
R1 – Albert Street	36
R2 – Baie du Doré	37
R3 – Inverhuron Provincial Park	35

6.3 Description of Potential Effects

Noise emissions associated with the DGR Project were modelled in combination with the background noise levels. Adverse noise effects were considered likely if the modelled ambient noise levels (i.e., existing plus project) were 3 dB or more above the lowest 1-hour L_{eq} at the receptor locations. For the purpose of the noise assessment, it was assumed that activities associated with all phases of the DGR Project would occur 24-hours per day.

The only identified residual adverse effect was a 5 dB increase in noise levels at receptor R2 during the site preparation and construction phase. Table 6-2 summarizes the results of the predicted changes to the noise levels at all three receptor locations.

Table 6-2: Site Preparation and Construction Phase Adverse Effects in the Local Study Area

Receptor	Predicted Project Noise Levels (dBA)	Predicted Ambient Noise Level [a] (dBA)	Lowest 1-Hour L_{eq} (dBA)	Project-related Change Relative to Lowest 1-Hour L_{eq} (dB)	Likely Adverse Effect?
R1 – Albert Street	33	38	36	+2	No
R2 – Baie du Doré	40	42	37	+5	Yes
R3 – Inverhuron Provincial Park	32	37	35	+2	No

Note:
[a] Ambient noise levels include the combined effect of noise from the DGR Project and existing noise levels.

No adverse effects were identified during the operations phase of the DGR Project. The emissions during the decommissioning phase are bounded by the emissions from the site preparation and construction phase and therefore, the potential adverse effects are similar to those predicted for that phase, as presented in Table 6-2.

6.4 Significance of the Residual Adverse Effect

In accordance with the categories set out in the EIS Guidelines, the residual adverse effect of the DGR Project on noise can be described as follows:

- **Magnitude**: The maximum predicted increase in noise level is 5 dB at a receptor location during the quietest hour (primarily during late night/early morning hours).
- **Geographic Extent**: The effect extends only a short distance (approximately 400 m) beyond the Site Study Area.
- **Timing, Duration and Frequency**: The effect will occur only during the site preparation and construction and decommissioning phases of the DGR Project, and is predicted to occur primarily during late night/early morning hours, on a daily basis.
- **Reversibility**: The effect will be reversible immediately upon completion of the site preparation and construction and decommissioning phases.
- **Probability**: The increase is expected to occur should the Project proceed.
- **Context**: The existing area is adjacent to an established industrial site. Existing noise levels are consistent with typical rural environments, with noise from the operations at the Bruce nuclear site audible at some locations.

Although compliance with Ontario noise level limits is not required for construction type activities (MOE 1995; 2013), they were assessed as part of the EA (Golder 2011a). As identified in MOE guideline publication NPC-232 (MOE 1995), recently replaced by NPC-300 (MOE 2013), noise associated with the operations of a facility (i.e., not including existing noise levels) must not exceed the greater of the exclusionary limits or the existing quietest 1-hour L_{eq}. For the DGR Project, this limit is 40 dBA, as all of the existing quietest 1-hour L_{eq} values are less than 40 dBA (see Table 6-2). Furthermore, the conservative nature of the assessment and predictions provides confidence that noise emissions from the DGR Project will meet Health Canada and World Health Organization guidelines.

For construction noise at receptors with durations of more than one year (i.e., long-term) and where noise levels are in the range of 45 to 75 dBA, Health Canada advises that health impact endpoints be evaluated on the change in the percentage of the population (at a specific receptor location) who become highly annoyed (%HA). Health Canada suggests that mitigation be proposed if the predicted change in %HA at a specific receptor is greater than 6.5% between project and baseline noise environments, or when the baseline-plus-project-related noise is in excess of 75 dBA (HC 2005). For the DGR Project, the percentage of the population that will be highly annoyed is less than 6.5 %, and the specific impact or impulse noise indicator (HCII) is less than 75 dBA at all receptor locations.

Noise levels associated with the DGR Project inside dwellings are predicted to be below the 30 dBA level recommended by the World Health Organization to minimize sleep disturbance (WHO 1999).

The only residual adverse effect on noise levels occurs during the site preparation and construction phase and decommissioning phase, and is limited to the residences in the vicinity of Baie du Doré. No cumulative residual effects on the noise levels VEC as a result of future projects were identified. The noise assessment inherently gives consideration to the cumulative effects of existing projects and their influence on the noise levels at all receptor locations given that the monitored noise levels include all emissions present at the time of the monitoring campaign.

Consideration was also given to whether the effects assessment conclusions on noise levels are sensitive to changes in climate conditions (OPG 2011, Section 7.14). It was concluded that the changing climate will not affect noise levels.

In summary,

- The only predicted residual adverse effect of the DGR Project on noise was a predicted increase in noise level at four residences near receptor R2 (Baie du Doré) during the quietest hour during site preparation and construction and decommissioning phases.
- The predicted adverse effect was assessed against a hypothesis that, *for a noise effect to be considered a significant adverse effect, the change in ambient noise would need to be disturbing (i.e., >10 dB change in the quietest hour)*.
- Noise effects would not be perceived as disturbing as the predicted change in ambient noise levels in the quietest hour at four residences near Baie du Doré is 5 dB or less. Adverse effects were predicted only during the site preparation and construction and decommissioning phases and only in areas immediately adjacent to the Bruce nuclear site, a short distance into the Local Study Area.
- In addition, although not required for construction activities, noise levels would comply with MOE guidelines, and the effect is immediately reversible upon completion of the site preparation and construction phase of the DGR Project.

Therefore, OPG concluded that the residual adverse effects of the DGR Project on noise levels are not significant.

6.5 Confidence

OPG has a high degree of confidence in the conclusion that the increase in noise level of 5 dB at receptor R2 is not significant. The significance conclusion is founded on the precautionary principle. A conservative approach was used to identify measurable effects based on comparison to the quietest 1-hour L_{eq} rather than longer term averages. In addition, the following factors provide further support for the conclusion:

- conservative bounding assumptions with respect to emissions and activities were incorporated into the prediction model (i.e., continuous at the highest level of activity and highest noise emissions); and
- limited noise attenuating factors were used in the prediction model.

The DGR Project will comply with relevant MOE criteria, and Health Canada and World Health Organization standards and guidelines. In addition, the DGR Project will meet the requirements of the Municipality of Kincardine Noise Bylaw.

6.6 References

AECOM Canada Ltd. (AECOM) 2011a. Socio-economic Environment Technical Support Document. AECOM report to Nuclear Waste Management Organization NWMO DGR-TR-2011-08 R000. Toronto, Canada. (CEAA Registry Doc# 299)

AECOM. 2011b. Aboriginal Interests Technical Support Document. AECOM report to Nuclear Waste Management Organization NWMO DGR-TR-2011-09 R000. Toronto, Canada. (CEAA Registry Doc# 299)

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Ministry of the Environment of Ontario (MOE). 1995. Sound Level Limits for Stationary Sources in Class 3 Areas (rural). Publication NPC-232.

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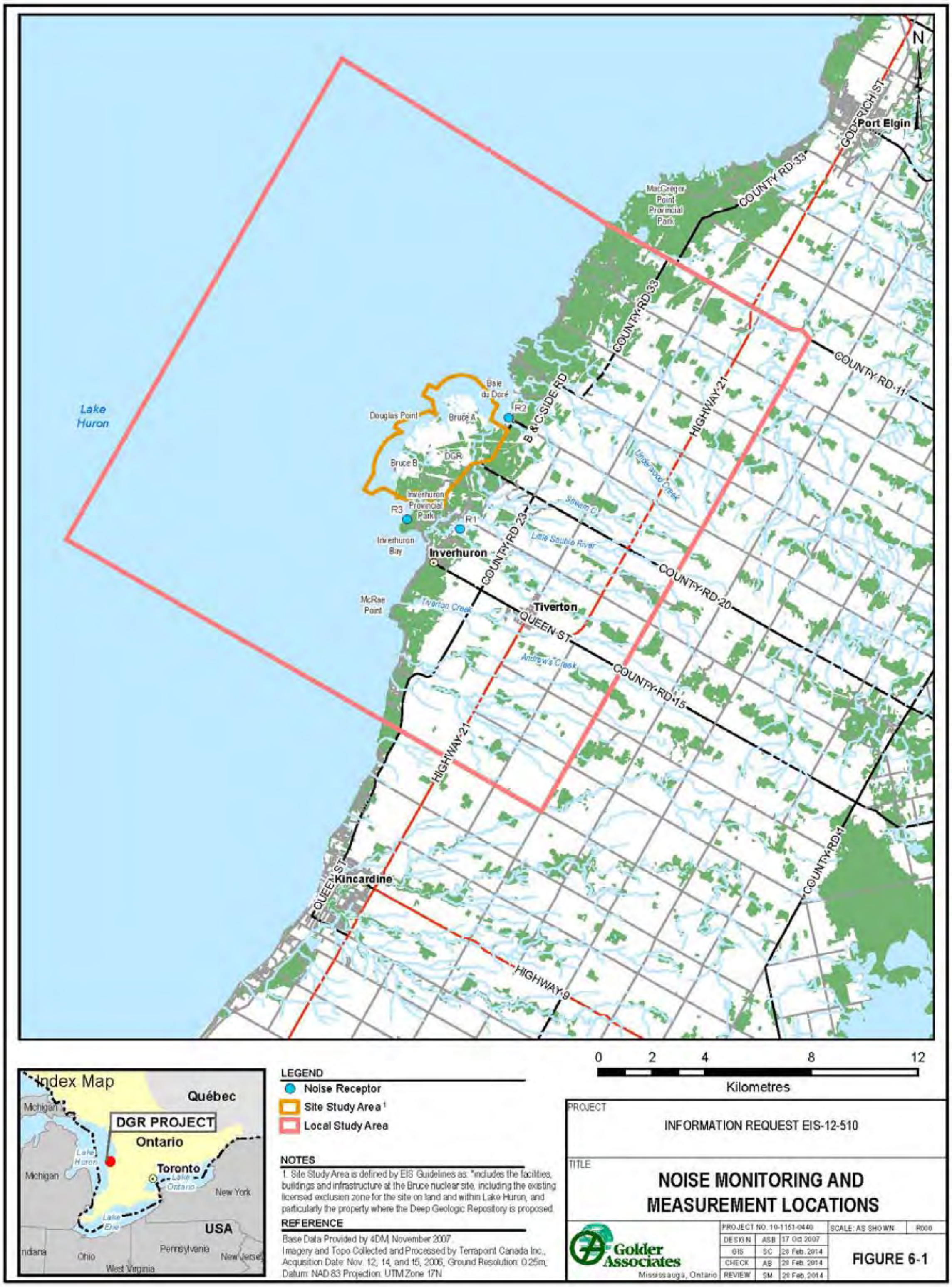
6.7 Figures

Figures are provided on the following pages.

Figure 6-1: Noise Monitoring and Measurement Locations



NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m; Datum: NAD 83 Projection: UTM Zone 17N

PROJECT
INFORMATION REQUEST EIS-12-510

TITLE
NOISE MONITORING AND MEASUREMENT LOCATIONS

Golder Associates
Mississauga, Ontario

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	FIGURE 6-1	
GIS	SC	28 Feb. 2014		
CHECK	AB	28 Feb. 2014		
REVIEW	SM	28 Feb. 2014		

7. ABORIGINAL INTERESTS

This section provides a detailed narrative that explains the significance assessment for Aboriginal interests. Based on experience from other projects at the Bruce nuclear site, OPG's hypothesis was that an effect of the DGR Project on Aboriginal heritage resources, specifically the Jiibegmegoong burial site, would only be considered a significant adverse effect if *it prevents or interferes with the performance of ceremonies at, or observation of, the burial site*. The reasoning behind this hypothesis is presented below.

The detailed assessment of the potential effects presented in the Aboriginal Interests TSD (AECOM 2011) identified one residual adverse effect of the DGR Project on the Aboriginal heritage resources VEC. The effect was assessed to be not significant.

7.1 Approach to Assessment

A detailed assessment of the potential effects of the DGR Project on Aboriginal interests was presented in the Aboriginal Interests TSD (AECOM 2011, Sections 6, 7 and 8). The assessment concluded that the Aboriginal heritage resources VEC (including the use of the burial site) was the only VEC predicted to have a residual adverse effect as a result of the DGR Project.

The project was assessed to determine whether there was a potential for it to have a measurable change to the Aboriginal heritage resources VEC, and whether that measurable change would be considered adverse. The assessment identified no potential direct effects of the DGR Project on any Aboriginal heritage resources. However, changes to the environment that might indirectly affect potential use and access to the Jiibegmegoong burial site (e.g., the on-going presence of the DGR Project and disruption from changes in noise and dust levels) were identified as both measurable and adverse.

7.2 Existing Conditions

To understand the importance of changes in Aboriginal heritage resources, it was necessary to determine the existing conditions with respect to this VEC. Traditional information from Aboriginal communities was not available during preparation of the EIS. Archaeological investigations have been completed in and around the Bruce nuclear site since the 1950s (Fitzgerald 2009; Golder 2013). Stage 1 and 2 Archaeological Assessments identified and confirmed two registered archaeological sites, Upper Mackenzie and Dickie Lake, within the confines of the Site Study Area (Fitzgerald 2009). Four culturally-sensitive areas (A, B, C and D) have been identified within the Site Study Area (Figure 7-1), three of which were related to Aboriginal interests (i.e., A, B and C) (Fitzgerald 2009). Culturally-sensitive area A is composed of a section of the sandy Nipissing Great Lakes shoreline complex and the abutting Main Lake Algonquin lakebed. The Late Archaic period Jiibegmegoong burial site is located within Area A. The remainder of the Bruce nuclear site, including the footprint for the DGR Project, was considered to be clear of further Aboriginal-related archaeological concerns.

The burial site is located within the Bruce nuclear site more than one kilometre from the DGR Project site. OPG controls access to the burial site and Aboriginal people request site access from OPG in advance when planning to visit the burial ground. OPG has a protocol in place to ensure that access is granted each time it is requested. In the past, visits have been infrequent (International Reporting Inc. 2013).

7.3 Description of Potential Effects

The assessment considered direct and indirect effects on the Jiibegmegoong burial site during all project phases. In 1998, OPG and the Saugeen Ojibway Nation (SON) established a protocol for SON to access the Bruce nuclear site to conduct ceremonies and monitoring at the Jiibegmegoong burial site. The access of the SON to this burial site will be unchanged. The burial site itself will not be physically altered by the DGR Project; however indirect effects have the potential to diminish the quality and value of Aboriginal ceremonial activities at the burial site. The visibility of the DGR structures may diminish the quality or value of activities undertaken by Aboriginal peoples at the burial site. This effect will occur during the site preparation and construction and operations phases. All surface facilities will be removed during the decommissioning phase, but the waste rock pile will remain. Therefore, an adverse effect on Aboriginal heritage resources was identified as a result of the visual presence of the DGR Project during all phases.

The activities and traffic during the site preparation and construction phase of the DGR Project are predicted to cause increased dust and noise levels at the burial site (Sections 5 and 6 of this response). The quality or value of activities undertaken by Aboriginal peoples at the burial site will be diminished because noise and dust from an industrial source are not considered compatible with the intended function of a burial ground; a place where human remains of Aboriginal ancestors have been respectfully and ceremonially laid. Therefore, an adverse effect on Aboriginal heritage resources was identified.

Mitigation measures have been incorporated into the design of the DGR Project to reduce the visual effect (e.g., berm and/or trees). In-design mitigation measures to reduce air quality and noise effects are described in the Atmospheric Environment TSD (Golder 2011, Sections 8.2.2, 8.2.4, 8.3.2, 8.3.4). OPG would have advance notice of visits to the burial site and has committed to take reasonable measures to mitigate effects while visits to the site are occurring (International Reporting Inc. 2013).

The changed aesthetics, including visual presence of DGR structures, and increased dust and noise, are expected to have a residual adverse effect on the Aboriginal heritage resource VEC.

7.4 Significance of the Residual Adverse Effect

In accordance with the categories set out in the EIS Guidelines, the residual adverse effect of the DGR Project on Aboriginal heritage resources, specifically the burial site, can be described as follows:

- **Magnitude**: No physical disturbances to Aboriginal heritage resources; however, there will be changes to the aesthetics, namely visual presence, dust and noise at the Jiibegmegoong burial site.
- **Geographic Extent**: The effect is limited to the burial site within the Site Study Area.
- **Timing and Duration**: The visual effect of structures associated with the DGR will occur during all phases. The indirect effects of noise and dust will occur during the site preparation and construction phase and decommissioning phase.
- **Frequency**: At any time the burial site is visited or used for ceremonial purposes.
- **Reversibility**: Noise and dust effects are immediately reversible when the activity ceases. The waste rock pile will remain in place.
- **Probability**: It is assumed that Aboriginal people will visit the burial site and that the predicted effect would occur.

There are no absolute effects thresholds to use when evaluating effects that diminish the quality or value of activities undertaken by Aboriginal peoples at Aboriginal heritage resources. Therefore, the results were based on the professional judgement of the experts who performed the assessment.

In summary,

- The only predicted residual adverse effect of the DGR Project on Aboriginal interests was the diminishment of the quality or value of activities undertaken by Aboriginal peoples at the Jiibegmegoong burial site located within the Bruce nuclear site.
- The predicted adverse effect was assessed against a hypothesis that an effect of the DGR Project on Aboriginal heritage resources, specifically the Jiibegmegoong burial site, would only be considered a significant adverse effect *if it prevents or interferes with the performance of ceremonies at, or observation of, the burial site.*
- The DGR Project is not anticipated to further restrict access to the burial site for ceremonial purposes. OPG has a protocol in place to accommodate access requests and to ensure safe access is granted. This practice is expected to continue. Therefore, the DGR Project is not expected to prevent or interfere with ceremonies at the burial site.
- The waste rock pile and other Project-related structures that will be visible at the burial site will not change the existing industrial character of the Bruce nuclear site. Therefore, they are not expected to prevent or interfere with ceremonial activities.
- In addition, indirect effects from noise and dust are primarily during the site preparation and construction and decommissioning phases of the project, and would be reversible with time.

Therefore, OPG concluded that the residual adverse effect of the DGR Project on Aboriginal interests is not significant.

7.5 Confidence

OPG is confident that the DGR Project will not change access to the burial site, as the burial site is located one kilometer from the project, and will not result in physical changes to Aboriginal heritage resources.

OPG's confidence in the conclusion that the indirect effects from noise and dust on the quality and value of activities at the burial site will not be significant is based on OPG being aware of the timing of these activities through providing access to the site. It is also based on the ability to manage noise and dust emissions through readily available mitigation measures during Aboriginal ceremonies. Further, the visual impacts of the DGR Project will be mitigated through constructing berms or planting trees on the DGR Project Site.

7.6 References

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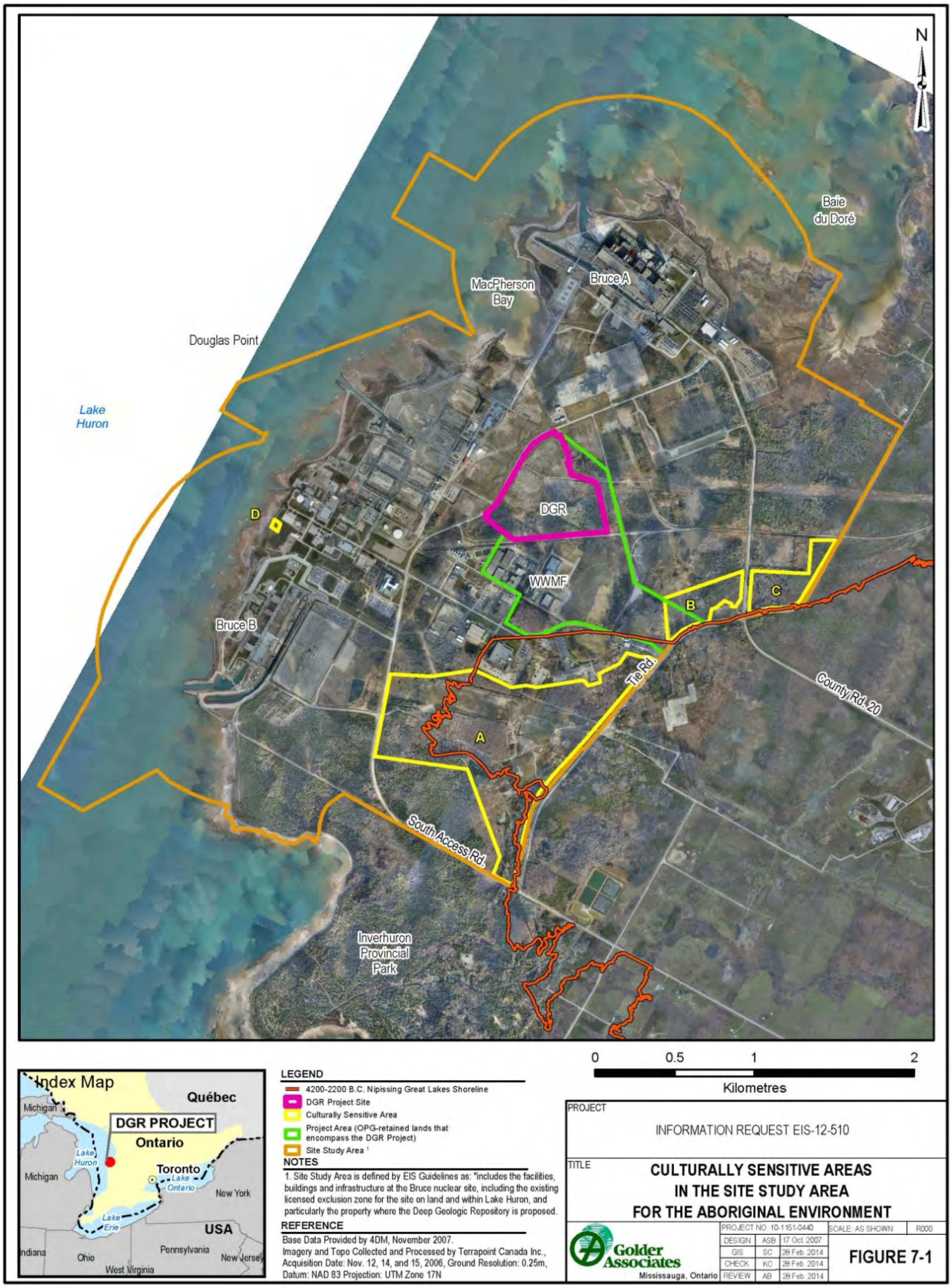
Golder. 2013. Stage 1 – 2 Archaeological Assessment OPG's Deep Geologic Repository Project for Low & Intermediate Level Waste. Part Lots 18-23, Lake Range Geographic Township of Bruce, Now Municipality of Kincardine Bruce County, Ontario. P362-044-2013.

International Reporting Inc. 2013. Deep Geologic Repository Joint Review Panel for Low and Intermediate Level Radioactive Waste Project – Monday October 7, 2013. Volume 18, page 52, lines 2-25. Deep Geological Repository for Low and Intermediate Level Radioactive Waste Project Joint Review Panel Proceedings. (CEAA Registry Doc# 1675).

7.7 Figures

Figures are provided on the following pages.

Figure 7-1: Culturally Sensitive Areas in the Site Study Area for the Aboriginal Environment



NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

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PROJECT
INFORMATION REQUEST EIS-12-510

TITLE
CULTURALLY SENSITIVE AREAS
IN THE SITE STUDY AREA
FOR THE ABORIGINAL ENVIRONMENT

Golder Associates
Mississauga, Ontario

PROJECT NO. 10-1151-0440			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007		
GIS	SC	28 Feb. 2014	FIGURE 7-1	
CHECK	KC	28 Feb. 2014		
REVIEW	AB	28 Feb. 2014		

8. RADIATION AND RADIOACTIVITY

OPG's hypothesis was that, for a significant adverse effect of radiation and radioactivity to occur, *the DGR Project would need to cause radiological releases that result in doses to human or non-human biota in excess of the relevant Canadian Nuclear Safety Commission (CNSC) regulatory requirements*.

A comprehensive assessment of radiological effects was completed using a systematic risk assessment approach (AMEC NSS 2011; OPG 2011) and predicted that there will be no residual adverse effects as a result of the DGR Project. Since no residual adverse effects were identified, a significance assessment was not completed.

Potential effects on humans included Nuclear Energy Workers (NEWs), who are expected to receive radiation doses as a result of the DGR Project, non-NEWs and members of the public including Aboriginal peoples. Non-human biota VECs were identified to capture potential effects on different trophic levels, and hence different exposure pathways.

The existing ionizing radiation and radioactivity conditions were established through a compilation and review of existing information for existing doses to humans and the results of modelling for existing doses to non-human biota. This included consideration of annual reports summarizing radiological data for the other facilities on the Bruce nuclear site, including Bruce A, Bruce B, the WWMF (Bruce Power 2002, 2003, 2004, 2005a, 2006, 2007, 2008, 2009, 2010), and previous EAs conducted on the site (OPG 2005, Bruce Power 2005b).

For the purposes of the radiation and radioactivity assessment, likely effects on humans were compared with regulatory limits for NEWs, non-NEWs and members of the public. The CNSC sets the regulatory limits on the annual dose to members of the public and to workers to ensure that the probability of occurrence of effects is acceptably low (Canada Gazette 1998). For non-human biota VECs, screening dose criteria, which are usually expressed as the Estimated No Effect dose-rate Values (ENEVs), were used to determine whether project-related changes are likely to be adverse. These benchmarks are consistent with the lowest values in various studies (NWMO 2009) and represent chronic dose rates that were observed not to produce any adverse effects upon populations of biota (CNSC 2002).

Predictive modelling was used to calculate the dose to humans as described in the Radiation and Radioactivity TSD (AMEC NSS 2011). All doses to NEWs are expected to be much lower than OPG's occupational dose target of 10 mSv/a for workers, which are lower than the CNSC regulatory limits. The predicted project-related dose is also expected to be less than that received by existing NEWs at the Bruce nuclear site. For non-NEWs, the project-related external dose rate is well below the compliance dose limit of 0.5 µSv/h (AMEC NSS 2011). Doses to members of the public were calculated using conservative methods focused on the (potentially) most exposed receptor groups, consistent with CSA Standard N288.1 (CSA 2008) and the existing Bruce Nuclear Site Radiological Environmental Monitoring Program (REMP). Doses to members of the public due to emissions from the DGR Project are predicted to be less than 1 µSv/a, which is well below the regulatory limit for members of the public of 1000 µSv/a (1 mSv/a).

The approach used to calculate the dose to non-human biota (adapted from that used in [OPG 2009]) calculated dose to non-human biota from internally deposited radioactivity and external radiation using dose coefficients, transfer factors and occupancy factors for each radionuclide in each type of organism for various environments (AMEC NSS 2011). The assessment concluded that doses to non-human biota were much less than dose criteria established to be protective by CNSC (Canada Gazette 1998) and other Canadian agencies (Environment Canada and Health Canada 2003).

As all predicted doses are less than established dose criteria, no residual adverse effects as a result of radiological releases from the DGR Project were predicted to occur, and no significance assessment was performed.

There is a high degree of confidence in the conclusions of the Radiation and Radioactivity TSD (AMEC NSS 2011), owing to the conservatism built into the assessment using a bounding assessment approach. Furthermore, the calculation of doses to humans and non-human biota in this study involved postulating scenarios leading to the highest possible doses, and then comparison with stringent regulatory and literature dose criteria for the assessment of consequences.

8.1 References

AMEC NSS. 2011. Radiation and Radioactivity Technical Support Document. AMEC NSS Ltd. report for the Nuclear Waste Management Organization NWMO DGR-TR-2011-06 R000. Toronto, Canada. (CEAA Registry Doc# 299).

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9. NEAR-SURFACE GEOLOGY AND HYDROGEOLOGY

Based on experience from other projects, OPG's hypothesis was that, for an effect to near-surface groundwater to be considered a significant adverse effect, the following would be required:

- *migration of contaminants of potential concern in excess of established criteria and/or guidelines relevant to human or ecological health, on a frequent and/or continuous basis; or*
- *alteration of the shallow groundwater flow regime to an extent that it would alter sensitive or critical habitats on a frequent and/or continuous basis*.

A comprehensive assessment of potential effects to near-surface geology and hydrogeology was completed (OPG 2011; Golder 2011a) and predicted that there will be no residual adverse effects as a result of the DGR Project. Since no residual adverse effects were identified, a significance assessment was not completed.

The existing conditions of the four VECs pertaining to near-surface groundwater were determined through field measurement and reference to available information. The DGR Project is situated on the east shore of Lake Huron on the Douglas Point promontory, a bedrock-controlled feature with nearly flat-lying dolostone bedrock outcropping along the shoreline. Douglas Point extends westward 2.5 to 3.0 km into Lake Huron over a distance of approximately 5 km between Inverhuron Bay to the southwest and Baie du Doré to the north.

Key characteristics of the groundwater regime within the Site Study Area include:

- The near-surface groundwater system is isolated from the deep saline groundwater system in which the proposed DGR would reside (Golder 2011a).
- There are no potable groundwater supply wells between the Project Area and Lake Huron (Golder 2011a).
- The Project Area is underlain by a dense, low permeability (K~10^{-10} m/s) silt till aquitard (10 to 20 m thick) (OPG 2012a, EIS-03-56).
- Overall, groundwater migration directly beneath the Site Study Area is oriented vertically downward within the till aquitard. Groundwater discharge from the till aquitard enters an underlying confined permeable (K~10^{-6} m/s) carbonate aquifer in which groundwater migration is horizontal to Lake Huron (Golder 2011a).

Within the Site Study Area there are some sensitive ecological features, namely the marsh located in the northeastern portion of the Project Area. The groundwater beneath the Project Area does not result in any recharge to these sensitive surface habitats (OPG 2013, EIS-09-473). Measures will be implemented to mitigate the risk of adversely affecting these sensitive ecological areas, such as sustaining a buffer of 30 m between the DGR Project infrastructure and the northeast marsh.

The DGR Project will introduce changes to the quantity and quality of the recharge to the groundwater that occurs from precipitation. The DGR Project includes a stormwater management system which will collect runoff from surface drainage and the rock waste management area for water quality monitoring and eventual discharge to Lake Huron via the drainage ditch at Interconnecting Road. The stormwater management pond and the waste rock management areas are underlain by a dense, low permeability (~10^{-10} m/s) glacial till aquitard with a very low potential for infiltration (OPG 2012a, EIS-03-56). This glacial till aquitard limits infiltration from the stormwater management pond into the underlying shallow groundwater.

The occurrence of fractures within the glacial till aquitard is not expected to influence recharge or solute transport rates to the underlying confined carbonate aquifer in which lateral off-site migration could occur (Golder 2012). Evidence includes the minimum thickness of the native glacial till unit (~10 m) and minor occurrence of an upper weathered till horizon (~2 m) based on observation. Although weathered/fractured tills are not expected, OPG has an allowance for the lining of the stormwater management pond and the waste rock management area as a mitigative measure should such conditions or intervening till deposits be encountered during site preparation construction (International Reporting Inc. 2013).

A quantity of leachate from the waste rock management area will ultimately enter the shallow groundwater regime below the site. The chemical characteristics of the leachate combined with leachate generating capacity will not lead to an effect on the groundwater quality, in part, due to the natural attenuation at the glacial till underlying bedrock interface.

This glacial till aquitard under the Project Area also prevents measurable drainage of water from surface water bodies (e.g., the northeast marsh) into the subsurface, which is confirmed by the continued presence of the water body long after rainfall events. Operational dewatering during construction of the shafts is not expected to have any measurable effect on the groundwater regime beneath the northeast marsh. The zone of influence of the dewatering is temporary and would extend only tens of metres (Sykes 2012a, 2012b) such that it will not have an effect on the overall site groundwater regime or sensitive ecological features located near the site, such as the wetland areas which are approximately 500 m away from the two DGR shafts.

Northeast Marsh within the Project Area

During shaft construction dewatering may temporarily influence groundwater flow paths and downgradient tritium plume migration in the confined carbonate aquifer. Natural attenuation assures that concentrations of tritium in groundwater downgradient of the WWMF and in the vicinity of the shafts will remain well below Ontario Drinking Water Standards (Golder 2011a). The tritium plume does not intersect ecologically sensitive areas, is not predicted to be mobilized to any of these areas, and poses no risk to human or ecological health.

Therefore, OPG concluded that there would be no measurable change to the near-surface geology and hydrogeology that would result in an adverse environmental effect, and thus no residual adverse effects were identified and no significance assessment was performed.

There is a high degree of confidence in the conclusions of the Geology TSD (Golder 2011a), owing to the extent of site-specific and historic local scale investigations completed (e.g., as documented in Golder 2011a, 2011b, 2012; NWMO 2011; OPG 2012b, EIS-04-101; OPG 2012c, EIS-05-185). Substantive groundwater and geological data collected for several decades was available due to historic and on-going routine groundwater monitoring programs.

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10. SURFACE WATER QUALITY

Based on experience from other projects, OPG's hypothesis was that, for an effect to surface water quality to be considered a significant adverse effect, the following would be required:

- *releases of indicator compounds at concentrations in excess of the relevant Provincial Water Quality Objectives or Canadian Environmental Quality Guidelines protective of human or ecological health in receiving waters; or*
- *alteration of the surface water quality regime to an extent that it would adversely affect sensitive or critical habitats on a long-term or continuous basis.*

A comprehensive assessment of potential effects to surface water quality was completed (OPG 2011; Golder 2011) and determined that there will be no residual adverse effects as a result of the DGR Project. Since no residual adverse were identified, a significance assessment was not completed.

The project was assessed to determine whether there was a potential to have a measurable change relative to baseline conditions. A change is considered measureable if any water quality parameters are predicted to be beyond the background variability of the receiving water body. Water quality modelling was conducted based on the understanding of the quality of the flows into the stormwater management pond (SWMP) to determine the predicted concentrations of indicator compounds. The results were compared to the following water quality criteria to determine the need for mitigation:

- Ontario Ministry of the Environment and Energy (MOEE) Provincial Water Quality Objectives (PWQOs) (MOEE 1994); and/or
- Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQG) for recreational water quality and aesthetics, as well as for the protection of aquatic life (CCME 1999).

All releases and surface runoff from the DGR Project will be captured in the perimeter drainage system and conveyed to the SWMP. Water from the SWMP will be discharged via a controlled outlet to the existing drainage ditch along the Interconnecting Road, which is frequently dry and not characterized by the Saugeen Valley Conservation Authority as providing fish habitat. There will be no releases from the DGR Project to either the North or South Railway Ditches, or Stream C (to which they drain).

The drainage ditch at Interconnecting Road drains towards MacPherson Bay in Lake Huron, ultimately the receiving waterbody for the proposed releases from the DGR Project. Water quality sampling results for nearshore samples collected in MacPherson Bay in 2007 and 2009, as well as in previous studies (Ontario Hydro 1973, Ontario Hydro Nuclear 1984, Bruce Power 2001), are provided in Table 6.3.5-1 of the EIS (OPG 2011), and were generally within the appropriate range of water quality guidelines. OPG undertook additional monthly water quality sampling over three seasons in MacPherson Bay from September 2011 to December 2012, which specifically included analysis of nitrates, nitrites and ammonia and a number of other parameters. Results were provided as part of OPG's response to Information Request EIS-08-387 (OPG 2013b) and were similar to previous sampling campaigns.

The SWMP will collect water from underground (process water and groundwater inflows), general site runoff, and leachate from the waste rock management area (WRMA). The SWMP will be designed to retain runoff during storm events, and control the total suspended solids concentrations in effluent discharges (MOE 2003). In between storm events, the SWMP will be used to control total suspended solids concentrations primarily from underground sources. During construction, a temporary settling pond will be used to settle out any excess solids in water pumped from underground before discharge into the ditch system leading to the SWMP. The temporary settling pond would be decommissioned at the end of construction.

The site drainage system has also been designed to avoid any measurable effect on wetland habitat. In addition to a commitment to maintain a 30-m setback from adjacent wetlands, the construction and operation of the SWMP will not change water levels or discharge water to adjacent wetlands, including the northeast marsh. The site drainage system design will not allow for water to overtop ditches or the SWMP to the adjacent wetland and will safely convey the peak outflow rate from a 24-hour, 100-year rainfall event (OPG 2012, EIS-04-130). Runoff from the waste rock piles will be directed to the perimeter ditches through grading, preventing runoff from the waste rock piles reaching the wetland.

Ultimately the quality of the water in the SWMP will depend on the quality of inflows to the pond, including both groundwater pumped to surface and stormwater runoff. Water quality modelling (OPG 2013a, EIS-08-394) identified salinity (as measured by total dissolved solids) from underground seepage and nitrogen compounds from blasting residues from waste rock pile runoff as the two water quality issues that may require additional mitigation. Both of these are readily managed using existing treatment technologies.

The final water quality criteria for the effluent from the SWMP will be developed as part of the Ontario Environmental Compliance Approval (ECA) process. The limits will be established taking into consideration the PWQOs, the acute toxicity thresholds for sensitive species that are present in the receiving environment, and the existing water quality in the receiving water at MacPherson Bay. The regulatory process will not allow the release of effluent from the SWMP that is acutely toxic to aquatic receptors.

A review of water quality predictions by Environment Canada and the CNSC determined that the proposed discharge criteria (NWMO 2011) would result in compliance with section 36(3) of the *Fisheries Act* and not be deleterious to aquatic communities in McPherson Bay (CNSC 2013). They also recommended that, before discharge from the SWMP is authorized, OPG conduct chemical characterization and acute and chronic toxicity tests of the effluent to provide further assurance of compliance with section 36(3) of the *Fisheries Act* (CNSC 2013).

It is expected that, if mitigation is required, it could include some type of treatment for one or more parameters for the final effluent to meet the applicable criteria. The project design and the commitments made by OPG provide for water treatment where required to meet applicable criteria (OPG 2012, EIS-04-130). The parameters that may need treatment are well understood, common in industrial environments and are easily managed with common treatment technologies. Ensuring that the discharge criteria are met prevents adverse effects on surface water quality. Therefore, OPG concluded that the DGR Project will not result in residual adverse effects to surface water quality and no significance assessment was performed.

OPG has a high degree of confidence in the conclusion because a conservative approach was used to identify and assess potential effects. Predictive modelling of the stormwater management system was conducted using standard mass-balance calculations. The input parameters are conservative to allow for a robust design with the expected performance of the system to be better than that modelled. Confidence in the determination that there will be no residual adverse effects to surface water quality comes from demonstrating that the discharge from the SWMP can meet the regulatory criteria (determined through the ECA and other regulatory processes) and will not be deleterious. OPG has a good understanding of the baseline conditions and is able to monitor and control inflows into the stormwater management system. The contaminants of concern are well understood and can be treated using commonly available and effective technologies.

Consideration was also given to whether the effects assessment conclusion for surface water quality is sensitive to changes in climate conditions (OPG 2011, Section 7.14). Climate changes that could potentially affect stream flow could indirectly affect water quality. Since the assessment concluded that climate change would not alter the conclusions of the hydrology assessment on surface water quantity and flow, no changes to the conclusions of the surface water quality assessment are predicted.

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ENCLOSURE

TO

OPG RESPONSE TO IR-EIS-12-511

OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Geoscientific Verification Plan

January 2014

Prepared by: Nuclear Waste Management Organization

NWMO DGR-TR-2011-38-R001

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

OPG's DEEP GEOLOGIC
REPOSITORY
FOR LOW & INTERMEDIATE LEVEL WASTE

Geoscientific Verification Plan

January 2014

Prepared by: Nuclear Waste Management Organization

NWMO DGR-TR-2011-38-R001

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Document History

Title:	Geoscientific Verification Plan		
Report Number:	NWMO DGR-TR-2011-38		
Revision:	R001	**Date:**	January 2014
Prepared by:	T. Lam		
Reviewed by:	M. Jensen, R. Heystee, P. Gierszewski		
Approved by:	D. Wilson		

Document Revision History

Revision	Effective Date	Description of Changes
000	March 2011	Initial Issue
001	January 2014	Update geoscientific verification activities and provide a more detailed description of various aspects of the 2011 plan. Specifically: • Added information about geological mapping of rock excavation walls using LIDAR survey (Sections 3.2.2 and 3.3.2.1). • More detailed description of probe hole drilling in upper 200 m and at selected horizons within each shaft (Section 3.2.3). • Provided details of the layout of extensometer arrays at seven depth locations in shaft. Included option of installing inclinometer system on inside of concrete liner (Section 3.2.5.1). • Provided details of the layout of extensometers in various locations in access tunnels and rooms. Included option of using LIDAR profiling at selected locations to measure rock deformation (Section 3.3.3). • Added pressure cells at two shale horizons along concrete/rock interface in shafts and stress cells within roof rock at each extensometer installation in access tunnels and emplacement rooms to measure rock loading (Sections 3.2.5 and 3.3.3). • Provided details of up-scaling geomechanical testing (Section 3.2.5.2 and 3.3.3.2).

		• Replaced two (2) orthogonal horizontal holes with one (1) vertical hole for USBM overcoring in situ stress measurements in Main Shaft excavation. Provided additional information of planned in situ stress measurement procedures (Section 3.2.6). • Relocated in situ stress measurement by under-excavation test in the shaft to the Geoscience Room (Section 3.3.4.2). • Added one in situ stress measurement in Sherman Fall Formation in down ramp to shaft bottoms (Section 3.3.4.1). • Added more detailed information of pillar integrity measurements for three pillars (Section 3.3.3.4). • Additional information provided for sealing material performance testing (Sections 4.2.6 and 4.3.6).

EXECUTIVE SUMMARY

Ontario Power Generation (OPG) is proposing to construct a Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Waste (L&ILW) from OPG-owned or operated nuclear generating facilities, on the Bruce nuclear site. A Preliminary Safety Report has been prepared, which describes the design of the DGR facility and associated Safety Case. This Geoscience Verification Plan describes investigations and monitoring activities that will be performed during underground construction.

The underground repository will be accessed by two circular shafts which will be excavated through a sequence of sedimentary rock comprised primarily of dolostones and shales. The underground repository will be located at a nominal depth of 680 m below ground surface within the low permeability and competent Ordovician-age limestone of the Cobourg Formation. The underground repository will be comprised of 31 emplacement rooms which are divided into two panels and each panel of rooms will be accessed by tunnels.

A Geoscientific Site Characterization Plan (GSCP) was initiated in 2006 for the purpose of obtaining site and regional data about geology, geomechanics, hydrogeology, geochemistry and seismicity, which are relevant to the geotechnical design of the DGR and to the DGR Safety Case. A major milestone for the GSCP was the successful completion of six deep boreholes (DGR-1 to DGR-6), which allowed characterization of the sedimentary sequence hosting and enclosing the proposed DGR. These six boreholes were located outside the DGR footprint.

DGR-7 and DGR-8 were drilled at the planned locations for the Ventilation Shaft and Main Shaft, respectively. The primary purpose of these two vertical boreholes was to gather additional data for the geotechnical design of the two shafts and the underground openings at the repository level.

In March 2011 NWMO issued a Geoscience Verification Plan that outlined a framework for verification activities to be performed during the underground construction of the DGR. This report has been revised to provide a more detailed description of various aspects of the 2011 plan. There will be two inter-related sets of verification activities:

1. Investigations and monitoring activities that will be performed to verify assumptions and geotechnical data used in the geotechnical design of the two shafts and the underground repository; and

2. Investigations and monitoring activities to verify assumptions and geoscience data used in analyses to support the DGR Safety Case. In particular data will be gathered to confirm that the host Cobourg Formation and the overlying rock formations will act as a long-term barrier to contain and isolate the L&ILW.

Verification activities will generally be completed during the construction phase. The results of these investigations and monitoring activities will be used to support a future application for an operating license. In certain circumstances long-term demonstration experiments that are initiated during construction phase will continue into the operation phase.

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1. INTRODUCTION

Ontario Power Generation (OPG) is proposing the development of a Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Nuclear Waste (L&ILW) from OPG-owned or operated nuclear generating facilities. The proposed DGR would be located on the Bruce nuclear site, which is located approximately 225 km northwest of Toronto on the eastern shore of Lake Huron in the Municipality of Kincardine. The site is underlain by an approximately 840-m thick sedimentary sequence of Cambrian to Devonian age, near horizontally bedded, weakly deformed carbonates, shales and minor evaporite horizons of the Michigan Basin. Within this sedimentary sequence, the proposed DGR would be excavated within the low permeability limestone of the Cobourg Formation at a nominal depth of 680 mBGS. The Cobourg Formation is overlain by 200 m of shale-dominated upper Ordovician sediments.

Site-specific geoscientific investigations began in the fall of 2006 and consisted of the coring, testing and instrumentation of two deep vertical boreholes (DGR-1 and DGR-2), the completion of a 2-dimensional seismic reflection survey, the refurbishment and monitoring of mostly preexisting US-series boreholes that allowed characterization of the shallow bedrock system (<180 m), and the installation of three borehole seismographs to monitor and observe micro-seismicity within 50 km of the Bruce nuclear site. Two additional deep vertical boreholes (DGR-3 and DGR-4) and two inclined boreholes (DGR-5 and DGR-6) were completed in 2009 and 2010, respectively. The results of all field and laboratory-based studies are documented in the Descriptive Geosphere Site Model (INTERA 2011) and synthesized with regional data in the DGR Geosynthesis (NWMO 2011). Data from these borehole investigations and the associated laboratory testing programs were used to support assumptions and parameter values used in analyses for the DGR Safety Case.

In 2011 borehole investigations were carried out at the planned locations for the two shafts (GOLDER 2013). DGR-7 was drilled to a depth of 190 mBGS at the Ventilation Shaft location and DGR-8 was drilled to a depth of 724 mBGS at the Main Shaft location. The primary purpose of these two vertical boreholes was to gather additional data for the geotechnical design of the two shafts and the underground openings at the repository level.

To-date the geotechnical design of the DGR and its safety case have been based on assumptions and data that are derived primarily from the aforementioned borehole investigations and associated laboratory testing programs. Investigations and monitoring activities will be carried out during shaft sinking and repository lateral development to verify these assumptions and data. Some of the investigations and monitoring activities will continue into the operations phase.

This report has been revised to present a more detailed description of various aspects of the initial 2011 plan. As the detailed design of the DGR is progressed, this Geoscientific Verification Plan will be updated and reissued as necessary. The plan will ultimately be developed in sufficient detail to allow the development of technical specifications for procurement of equipment and the services to execute the plan. All instruments to be used in investigations and monitoring activities, will be prequalified before installation. Investigations and monitoring activities will be conducted in accordance with the DGR Project Quality Plan (NWMO 2010). Specifically, test plans will be created for each of the investigation and monitoring activities, and the plans will provide a description of the design and execution of each activity.

Section 2 provides an overview description of the design and construction of the underground aspects of the DGR. More detailed information can be found in the Preliminary Safety Report (OPG 2011). The geoscientific verification activities are described in Sections 3 and 4. Section 3 describes investigations and monitoring activities that will be performed to verify assumptions and data used in the geotechnical design of the two shafts and the underground repository. Section 4 describes investigations and monitoring activities to verify assumptions and geoscience data used in the DGR Safety Case. The latter set of verification activities will place emphasis on confirming the integrity and long-term stability of the sedimentary sequence, and its ability to contain and isolate L&ILW within timeframes relevant to repository safety.

Sections 3 and 4 are divided into two major subsections: 1) activities to be carried out during shaft sinking through the sedimentary sequence from the Lucas Formation to the Kirkfield Formation; and 2) activities to be carried out during lateral development of access tunnels, emplacement rooms and other openings at the repository horizon within the Cobourg Formation. In addition to verifying assumptions and data used in the geotechnical design of the DGR and to support the DGR Safety Case, the results of these investigations and monitoring activities will also be used to support a future application for an operating licence.

2. DEEP GEOLOGIC REPOSITORY

The underground repository, shown in Figure 2.1, will be accessed by two circular shafts, the Main Shaft and the Ventilation Shaft. Both shafts will be excavated from ground surface to the repository horizon through a sequence of sedimentary rock formations. The Main Shaft will provide intake ventilation and primary access to the underground repository for transfer of waste packages, personnel, equipment and materials. The Ventilation Shaft, which is located about 80 m from the Main Shaft, will convey the air discharged from the repository and will provide a second (emergency) egress for personnel from the underground repository. It will also host a skip for the removal of waste rock during construction of the underground repository.

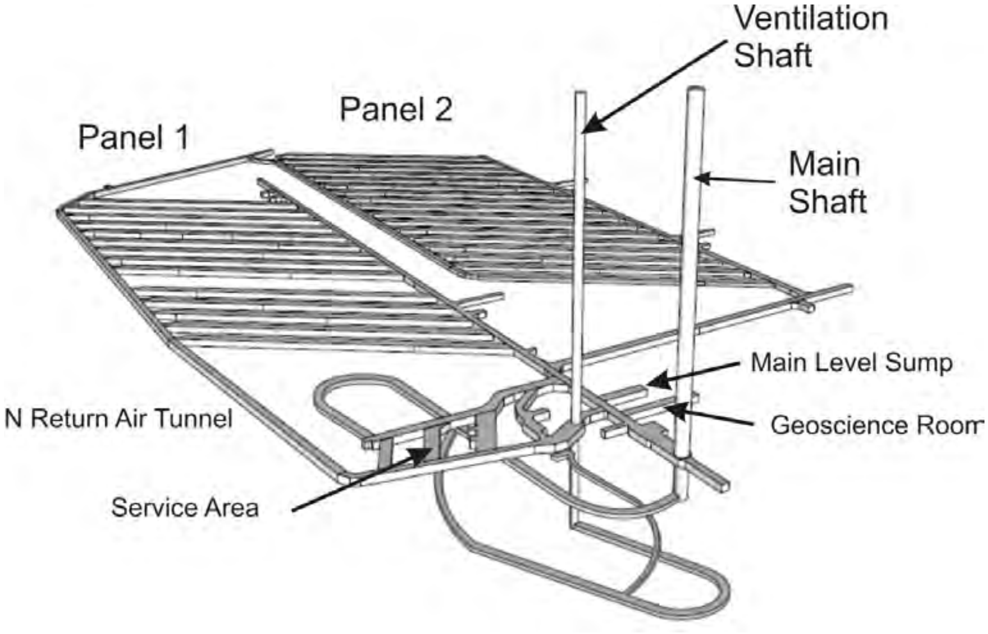

Figure 2.1: Proposed Underground Layout of the DGR

2.1 Shaft Design and Construction

The shafts will be excavated through five stratigraphic sequences (called reaches as shown in Figure 2.2). The key geotechnical characteristics of each sequence based on borehole investigations are as follows (see INTERA 2011 and GOLDER 2013 for additional information on geologic formations):

- Reach 1 is comprised of a thin surficial layer of topsoil and/or fill underlain by 12-m-thick deposit of dense low-permeability glacial till.
- Reach 2a is primarily fractured and permeable dolostones and is about 180 m thick. Without treatment of this bedrock groundwater inflows to shaft excavations is expected to be greater than 3 L/s (~50 USGPM).
- Reach 2b is comprised of a mixture of dolostones, shaley dolostones and some evaporites. Rock formations are generally competent and have low permeability. Two exceptions are the upper 4 m of the Salina A1 unit and the Guelph Formation, which are relatively permeable and a potential source of highly saline groundwater inflow to the shaft excavations.

- Reach 3 is comprised of low permeability shales. The shaft concrete liners poured against these shales could be subject to loading caused by time-dependent swelling deformation. Horizontal swelling potential within Ordovician shales could be as high as 0.3% per log cycle (INTERA 2011, Table 5.10 and GOLDER 2013, Appendix F).
- Reach 4 includes the competent and low permeability Cobourg Formation, which will host the underground repository. The Cobourg Formation (Lower Member) is a 28-m-thick argillaceous (clay rich) limestone with a mean uniaxial compressive strength (UCS) of 113 MPa (INTERA 2011, Sections 5.8.1.1 and 5.11.2).

The finished inside diameters of the Main Shaft and Ventilation Shaft are 6.5 m and 5.0 m, respectively. The two circular shaft liners will be unreinforced concrete structures where the concrete will be poured directly against supported rock. The liners will resist loadings in compression. It is expected the shaft liners will have a minimum thickness of 300 mm near ground surface, with the thickness of the liners (and thus excavated diameter) increasing with depth to resist varying hydrostatic and rock loading conditions. The liners will be constructed as a hydrostatic (water-tight) liner in the upper 200 m of the shafts where Reach 2a rock formations are relatively permeable. Below Reach 2a, the shaft liners are designed as a “leaky liner”. In the leaky liner design, any groundwater inflow behind the liner is allowed to drain into and down the shaft in a controlled manner. This prevents build-up of water pressure behind the liners and avoids the need to construct a thick hydrostatic liner to withstand water loading.

The planned shaft sinking methodology is described in Section 9.4.5 of OPG (2011). Prior to start of shaft sinking activities at both Main Shaft and Ventilation Shaft locations, the upper 180 m to 200 m of bedrock will be treated to reduce water ingress into the shaft excavation during sinking. Then the overburden material will be removed at both shaft locations to expose the bedrock and allow the shafts to be collared into the bedrock. The shafts will be sunk through the sequence of dolostones, shales and limestones using controlled drill and blast techniques to minimise rock damage at the shaft walls.

It is planned to sink both shafts concurrently with the excavation face of the Ventilation Shaft progressing more quickly and reaching the repository horizon sooner than the Main Shaft. The excavation of the shafts will generally be carried out in 5 m full-face rounds. The typical excavation sequence will include drilling of blast holes, blasting, venting of blast gasses, scaling of loose rock from the shaft wall, and installation of initial rock support. A 5-m-length of concrete lining will be placed when the shaft excavation has advanced approximately 15 m (3 rounds of advance) from the previously placed lining. Therefore the shaft lining will be approximately 10 m above the shaft bottom while the next shaft blasting round is being drilled. The shaft sinking approach will be further developed in consultation with the contractor[1]. As a result, some aspects of selected shaft sinking method may differ from the approach that is outlined here.

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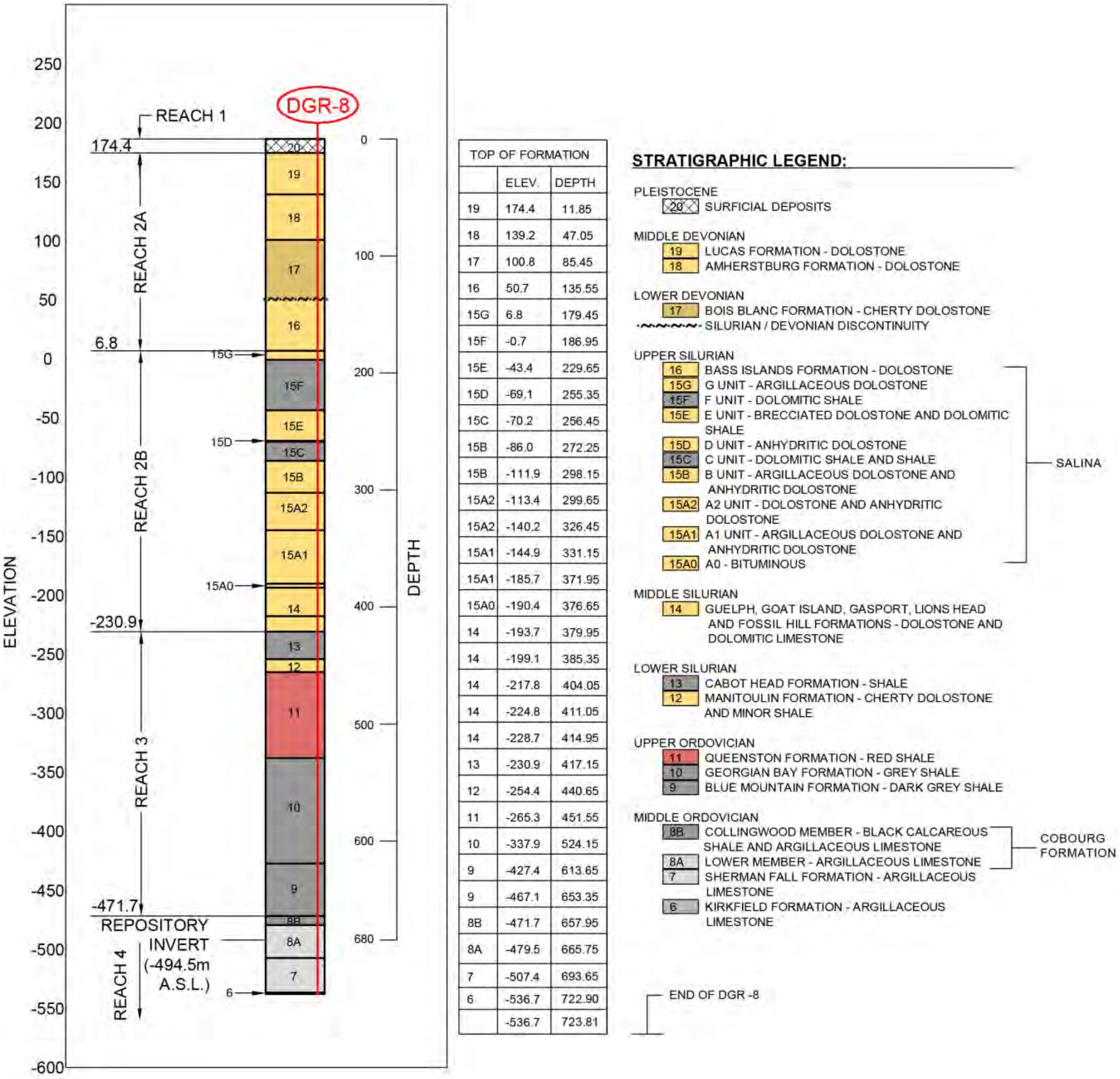
[1] *Contractor means a firm that contracts to supply labour and materials for the sinking of two shafts and/or the lateral development of the underground repository*.



TOP OF FORMATION		
	ELEV.	DEPTH
19	174.4	11.85
18	139.2	47.05
17	100.8	85.45
16	50.7	135.55
15G	6.8	179.45
15F	-0.7	186.95
15E	-43.4	229.65
15D	-69.1	255.35
15C	-70.2	256.45
15B	-86.0	272.25
15B	-111.9	298.15
15A2	-113.4	299.65
15A2	-140.2	326.45
15A1	-144.9	331.15
15A1	-185.7	371.95
15A0	-190.4	376.65
14	-193.7	379.95
14	-199.1	385.35
14	-217.8	404.05
14	-224.8	411.05
14	-228.7	414.95
13	-230.9	417.15
12	-254.4	440.65
11	-265.3	451.55
10	-337.9	524.15
9	-427.4	613.65
9	-467.1	653.35
8B	-471.7	657.95
8A	-479.5	665.75
7	-507.4	693.65
6	-536.7	722.90
	-536.7	723.81

Figure 2.2: Stratigraphic Column at DGR-8

2.2 Underground Repository Design and Construction

At the location of the two shafts on the repository level is the Services Area, which includes a Refuge and Lunchroom. Geoscience Room, Main Level Sump, Maintenance Shop, Service Garage, Diesel Fuel Bay, Explosives Storage and Cap Magazine (the latter two facilities will only be used during construction). A Main Shaft access tunnel will be driven from the Main Shaft station to the east, passing by the Ventilation Shaft and then proceeding towards the emplacement room panels. The Main Shaft access tunnel continues straight into the Panel 1 access tunnel, while a branch tunnel to the south leads to the Panel 2 access tunnel (Figures 2.1 and 3.7). These underground openings will be excavated in the competent and low permeability Cobourg Formation.

There will be two panels of emplacement rooms. The emplacement rooms are all aligned with the expected major principal horizontal in situ stress direction in the lower member of the Cobourg Formation (i.e., east-north-east) which has been inferred from the regional in-situ stress database and the observed borehole wall deformation in DGR boreholes (NWMO 2011, Section 3.3). This emplacement room orientation will minimize overstressing in the roof rock and rock support requirements.

There are 31 emplacement rooms where Panel 1 has 14 rooms and Panel 2 has 17 rooms. The majority of rooms are 7.1 m high by 8.6 m wide and the rooms are nominally 250 metres in length. The widths of rock pillars between emplacement rooms have been established to be twice the effective width of the two adjacent emplacement rooms. It is expected that vertical stresses in the centre of these thick pillars will be well below the compressive strength of the Cobourg Formation limestone.

It is planned to excavate underground openings by the drill and blast method (see Section 9.4.7.1 in the Preliminary Safety Report (OPG 2011)). It is anticipated that full-face excavation will be adopted in all access tunnels beyond the Services Area and in all emplacement rooms. Excavation of the shaft stations, the Main Shaft access tunnel and several of the Service Area excavations is expected to be by partial-face or benching excavation sequence.

2.3 Application of Observational Method

2.3.1 Geotechnical Design

During the construction of earth or rock structures (e.g. dams and underground rock openings) the Observational Method can be applied as a continuous, managed and integrated process of design, construction control, monitoring and review. It enables appropriate, previously-defined modifications to be incorporated during (or after) construction. The objective is to optimize designs without compromising safety (Nicholson et al. 1999).

In Eurocode 7 the Observational Method is defined as follows (Kovári and Lunardi 2000):

1. *Because prediction of geotechnical behaviour is often difficult, it is sometimes appropriate to adopt the approach known as “the Observational Method”, in which the design is reviewed during construction. When this approach is used the following four requirements shall all be made before construction is started:*
    - *the limits of behaviour which are acceptable shall be established.*
    - *the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits.*
    - *a plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage; and with sufficiently short intervals to allow contingency actions to be undertaken successfully. The response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system.*

  - *a plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.*

2. *During construction the monitoring shall be carried out as planned and additional or replacement monitoring shall be undertaken if this becomes necessary. The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put in operation if this becomes necessary.*

The Observational Method will be applied during the construction of the shafts and underground repository. A flowchart showing the application of the method is presented in Figure 2.3. For example, shaft and underground 2D and 3D geomechanical modelling has been conducted with a parameter set developed from the information collected during the aforementioned site characterization and shaft pilot hole investigations. Where information could not be measured from surface (e.g., in-situ stress conditions at depth), expected ranges were considered in the modelling parameters from a conservative perspective. Field verification of rock mass behaviour will be completed during the construction of shafts and underground openings at the repository horizon. In the event that actual behaviour values falls outside acceptable limits as established by modelling, then modelling will be redone with new parameter values that were obtained during field verification activities, and design and/or method of construction will be adjusted as required.

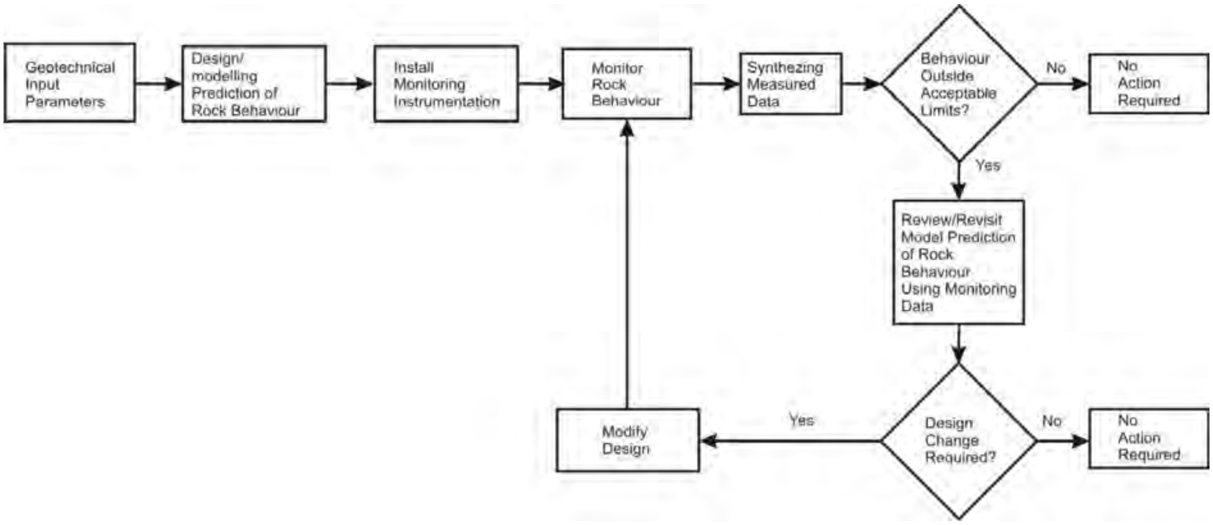


Figure 2.3: Observational Method during DGR Construction

This document presents the investigation and monitoring plan to reveal the actual in situ behaviour of the rock formations and to verify behaviour falls within predefined acceptable limits. The establishment of these limits and associated planned mitigation actions if behavior falls outside of the limits are outside the scope of this document. The limits and mitigation actions will be defined at a later date when the DGR design has progressed closer to issue-for-construction status.

2.3.2 Repository Safety Case

The geoscience verification activities will involve field investigations and monitoring activities during both shaft sinking and lateral development. These activities will yield data for the purpose of verifying assumptions and geoscience data used in analyses to support the DGR Safety Case.

Analyses that have been performed to support the DGR Safety Case were based on conservative assumptions and values for various geoscience parameters. In the event that the data arising from any of the various geoscience verification activities are significantly different than those assumed in analyses for DGR Safety Case, then following actions will be taken:

(a) the data will be assessed to determine if it is reliable, and
(b) new analyses will be undertaken to test the implications on the DGR Safety Case.

In most cases, it is likely that there will be an initial quick interpretation of field measurements, followed by a slower period with more extensive analysis and reconciliation with other measurements to yield a final representative value.

3. VERIFICATION OF GEOTECHNICAL DESIGN PARAMETERS

This section presents the investigation and monitoring plan that will be used to measure in situ behaviour of the rock formations during construction of the shafts and underground repository and to confirm rock formations are behaving as expected. This in situ investigation and monitoring program will also generate geotechnical data that will be used to verify equivalent data derived from the surface-based borehole investigations and associated laboratory testing programs.

The success of any underground construction project is fundamentally tied to successfully managing risks due to, for example, a major fall of rock or greater than expected groundwater inflows. The design of geotechnical monitoring program has taken into consideration the management of various geotechnical risks during shaft sinking and lateral development for the protection of worker safety.

The investigation and monitoring plan described below will be updated, as necessary, as the designs for the shafts and underground repository are progressed to completion.

3.1 Key Geotechnical Parameters

Table 3.1 summarizes the key geotechnical parameters that will be investigated or monitored during shaft sinking and lateral development. This table also lists the techniques that will be used to measure or characterize these parameters. A more detailed description of each technique that will be used during shaft sinking and/or lateral development is presented in Section 3.2 and 3.3, respectively.

Table 3.1: Key Geotechnical Design Parameters and Investigation or Monitoring Techniques to Be Used for Measuring or Characterizing Each Parameter

Geotechnical Design Parameter	Investigation or Monitoring Activity	
	Shaft Sinking [1]	Lateral Development
Rock Mass Quality	Geological mapping of shaft excavation wall by: • Direct visual inspection, and • Analysis of photographic and LIDAR images.	Geological mapping by tunnel and room excavation surfaces: • Direct visual inspection, • Analysis of photographic images, and • Analysis of LIDAR images
Groundwater Inflow	• Probe hole drilling in advance of shaft excavation bottom including optical televiewer inspection of hole. • Observations of seepage from shaft excavation wall	Observations of seepage from tunnel and room excavation rock surfaces
Excavation Deformation	• Array of extensometers at several depth locations in shaft • Array of convergence points at several locations on inside of concrete liner (to be decided) • Inclinometer system installed on	• Extensometers in roof at various locations in access tunnels and rooms. Access tunnels will also have extensometers in floor. • Array of convergence points at selected locations.

Geotechnical Design Parameter	Investigation or Monitoring Activity	
	Shaft Sinking [1]	Lateral Development
	inside of concrete liner (to be decided)	• Analysis of consecutive LIDAR surveys at selected locations • Visual inspection for rock movement (e.g. roof rock movement, floor buckling)
Rock Loading	Pressure cells at two locations embedded in concrete liner and between concrete liner and rock excavation surface. Stress cells embedded behind the surface of shaft wall at two locations. Each stress cell would be located adjacent to an extensometer.	Stress cells embedded in roof rock at several locations in access tunnels and rooms. Each stress cell would be located adjacent to an extensometer.
Geomechanical Properties	Up-scaling tests: 305-mm-diameter rock samples for laboratory testing to determine unconfined compressive strength and elastic modulus properties.	Up-scaling tests: 305-mm-diameter rock samples for laboratory testing to determine unconfined compressive strength and elastic modulus properties.
In situ Stress	Overcoring in situ stress measurements using USBM gauge in Main Shaft excavation only.	In situ stress measurement by under-excavation experiment. Overcoring in situ stress measurements using USBM gauge in Down Ramp to shaft bottoms.
Rock Pillar Integrity and Response	N/A	At selected pillar locations investigate integrity by: • Seismic tomographic survey, • Horizontal borehole investigations within pillars, • Analysis of extensometer and stress cell data; and • Analysis of LIDAR survey data

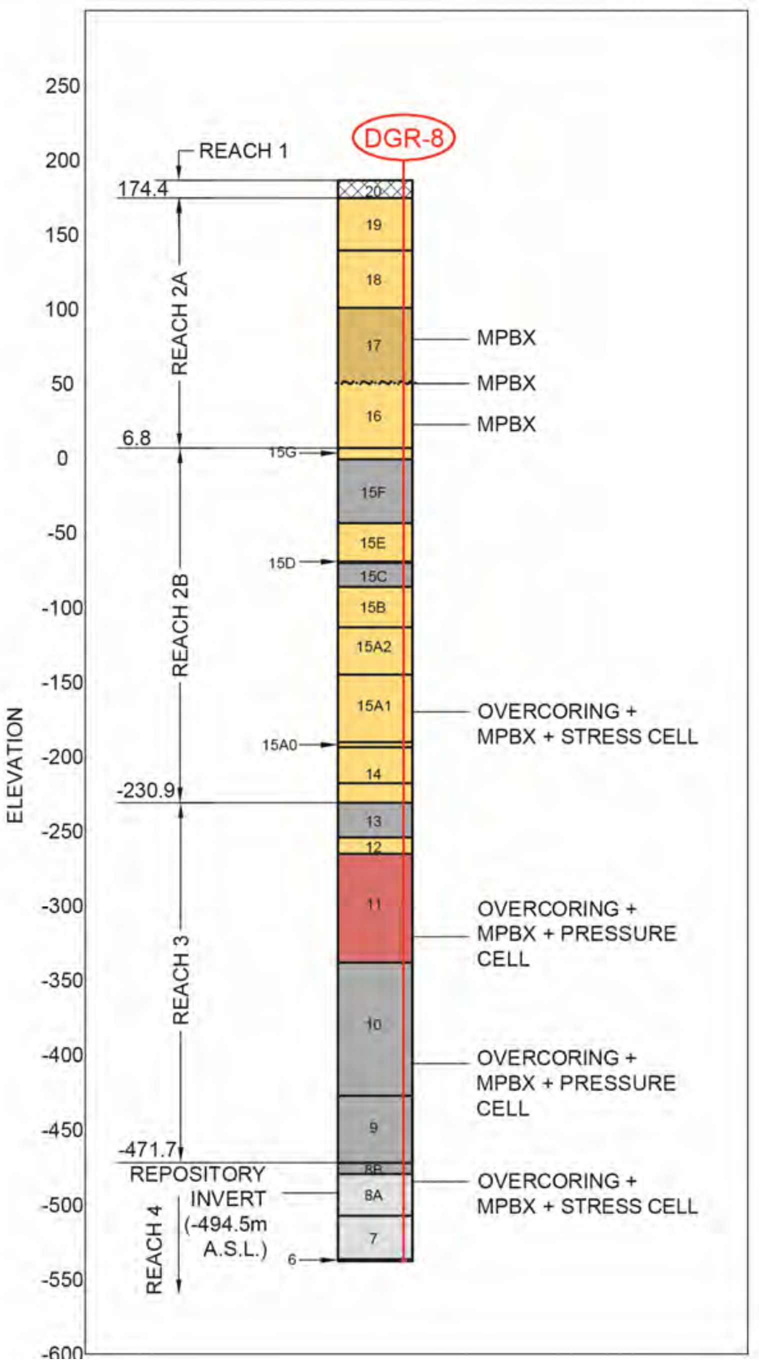
Note: (1) Unless otherwise stated, activity occurs in both Main Shaft and Ventilation Shaft

3.2 Shaft Sinking

3.2.1 Location of and Preparation for Investigation and Monitoring Activities

The geotechnical monitoring and testing locations along the shaft are shown on Figure 3.1 and are described in more detail in the following sections.

Safe access to measurement locations will be provided by the contractor, e.g. working platforms with sufficient lighting. Cleaning of the rock surface with air or water jetting might also be required.



Legend:
MPBX – for deformation measurement using **M**ultiple **P**oint **B**orehole e**X**tensometer
PRESSURE CELL – for stress change measurement at rock/liner interface
OVERCORING – for in situ stress measurement
STRESS CELL – for monitoring stress change

Notes:
1. Overcoring In situ Stress Measurements in Main Shaft only.
2. See Figure 2.2 for legend of geologic formations.

Figure 3.1: Geotechnical Instrumentation and Testing Locations along Shafts for Geological Characterization

The following activities will be performed in the two shaft excavations to verify geologic, hydrogeologic and geotechnical conditions as predicted on the basis of borehole investigations and, in particular, on the basis of investigations at DGR-7 and DGR-8. An exception is the in situ stress measurements which will be performed in the Main Shaft only.

3.2.2 Geologic Mapping

During shaft sinking, geological mapping will be carried out by professional geologists immediately following each round of blasting. Mapping will be continuous along the entire shaft wall to provide a complete record of lithology and structure. Mapping will be performed by direct visual inspection of the rock surfaces and by office-based analysis of the high resolution images of the rock surfaces. The excavation bottom face will not be mapped. Details of how and when geologists will gain access to the shaft excavation wall will be determined in consultation with the shaft sinking contractor.

Detailed geological mapping is required to: 1) verify the bedrock stratigraphy, stratigraphic continuity and predictability, lithology, discontinuities and structure; 2) refine knowledge on rock mass characteristics, including jointing, bedding plane thickness and spacing, and the presence of weak seams; and 3) verify the assumed rock mass classification rating used in the design.

The mapping will be conducted following each excavation cycle/shift (once or twice a day, depending on the rate of shaft advance). Geological, geomechanical (rock mass behaviour) and hydrogeological features (such as groundwater inflow) will be observed, described, imaged, measured and recorded. Guidelines, such as the ISRM Suggested Method for Rock Mass Characterization (1981) and USACE EM 1110-1-1804 (2001) will be used as a field guide during mapping activities to collect the required rock rating parameters. Rock and groundwater specimens will also be sampled for further visual or laboratory characterization. Joint and bedding plane orientations, spacing and characteristics will be measured, analyzed and used to verify the stability of underground openings. Suitable specimens of fracture infill materials will be collected and analyzed. Any petroliferous zones will be described, imaged and sampled for possible testing.

High resolution systematic overlapping still images of all shaft walls will be obtained. Rock mass data, such as discontinuity spacing and orientations, can be acquired rapidly from three dimensional images. These images will be used as templates for recording the geological mapping data that has been obtained by visual inspection of shaft excavation walls. Digital images of the rock surface will be taken by using photogrammetric techniques, such as those provided by 3DMCalibCam (http://www.adamtech.com.au) or ShapeMetriX3D (http://www.3gsm.at). All image recording devices would be lowered from the working platform of the shaft sinking cage to a fixed position for recording. Also, to supplement these still digital camera images, a computer-controlled automatic scanning laser profiler will be used to obtain a precise image and profile of the shaft walls (Lato et al. 2009).

3.2.3 Probe Hole Drilling

Probe hole drilling and camera inspection will be carried out in advance of the excavation face to explore for adverse geologic conditions, permeable bedrock horizons and rock formations that may contain elevated levels of natural gases (e.g. methane). The probe holes will be 60 mm in diameter and 45 m in length. In the upper 200 m of each shaft excavation, the probe hole will be drilled each time the shaft excavation face has advanced about 30 m. In the event hole intersects a water bearing feature and inflow is considered excessive, a mechanical packer with shut-off valve will be installed at the collar of the probe hole to prevent groundwater inflow into shaft excavation. These holes will be inspected and logged by using an optical televiewer and then subjected to backfill grouting.

Below 200 mBGS, probe holes will only be drilled as the shaft excavation approaches high permeability bedrock formations identified by the deep borehole investigations. In particular probe hole drilling will be performed as the Main Shaft and Ventilation Shaft excavations approach the upper 4 m of Salina A1 unit and the Guelph Formation (INTERA 2011).

3.2.4 Observations of Groundwater Seepage

If groundwater is observed to be seeping into the shaft excavation then an estimate of inflow rate will be made. In addition a sample(s) of groundwater will be collected for chemical analysis and, in particular, for analysis of groundwater salinity. Particular attention to groundwater seepage will be paid when either shaft intersects the Salina A1 unit and the Guelph formation.

3.2.5 Excavation Response

Allowable limits for deformation of the rock mass around the shafts during and after excavation will be defined prior to shaft sinking. The results of geomechanical modelling will be used for setting the deformation limits. The modelling uses rock property data derived from laboratory tests that have been performed on 76-mm-diameter vertically-oriented rock core samples. To verify that actual shaft wall deformation falls within acceptable limits, instruments to measure deformation will be installed. To help verify that aforementioned rock property data used in modelling is representative of rock mass properties, 305-mm-diameter horizontally-oriented rock core samples will be obtained in the field. Then, the samples will be sub-cored and tested in the laboratory.

3.2.5.1 Excavation Deformation Measurement

Figure 3.1 and Table 3.2 show the 7 planned monitoring locations in Main Shaft and Ventilation Shaft where each installation is comprised of an extensometer array. The bottom 4 installations will also have either stress cells or pressure cells. There will be a total of 14 monitoring locations between the Main Shaft and Ventilation Shaft. Different and/or additional monitoring locations may be established as the detailed design of the two shafts are progressed and/or during shaft sinking based on observations at already-installed monitoring locations.

Figures 3.2 and 3.3 show the typical extensometer array that will be installed at each location. There will be 3 pairs of multiple point borehole extensometer (MPBX) instruments where MPBXs in each pair are on opposite sides of the shaft excavation. Some key features of each MPBX array are as follows:

- One MPBX will have a deep anchor point to act as a reference point. This anchor will be located at a minimum of two shaft diameters from the shaft wall;
- Relative displacement along the excavated wall will be monitored using anchor points installed at various locations along the shaft wall;
- Anchors will be installed at close spacing near to the excavation wall so as to provide rock mass response data near to shaft excavation openings;
- The MBPX will be installed in holes created by percussion drilling;
- Temperature sensors will be installed in each deformation instrument; and

- Resin grout will also be used instead of cement-based grout to reduce the setting time of the instruments.

Each MPBX array will be installed close to shaft bottom excavation and then monitored as shaft excavation progresses to greater depth beyond the monitoring location. The contractor will be directed to limit the advance of the shaft excavation to 2.5-m-per-round for two rounds below the installation, and then return to the normal 5-m-per-round advance rate. Reducing length of two blast rounds immediately below instrument installation will provide an additional rock deformation measurement opportunity.

At the location of each deformation array, shaft wall displacements will be measured at least four times prior to casting of shaft liner; i.e. after the each aforementioned blast rounds. Monitoring will be performed to confirm that the expected rock relaxation has occurred prior to casting of concrete liner.

The inward shaft wall deformation is expected to increase gradually to its maximum value at a distance about 4 radii behind the excavation face (in the case of Main Shaft this distance would be about 15 m). Deformation monitoring will generally cease after extensometer array is covered by the concrete liner. Selected extensometer arrays will be left in-place and monitored during the operations phase for the purpose of confirming that rock deformations are very small or have stopped.

An array consisting of three stress cells will be installed in the Salina A1 Unit and in the Cobourg Formation and will monitor stress changes in the rock as the shaft excavation advances (Figure 3.2, and Table 3.2). The stress cells will be either CSIRO or LVDT-type depending on site conditions. Issues to be considered in the selection of stress cell type are described in Section 3.2.6. They will be installed in short boreholes about 1.5 m behind the shaft wall. The results will be used for back-analyzing the in situ stress. The results from this back analysis will be compared to in situ stress measured by using the USBM overcoring technique. Figure 3.2 shows the planned configuration of the three stress cells at each location.

Pressure cells with embedded strain gauges will be cast into the concrete liner at two locations in each shaft; i.e. at the Queenston and Georgian Bay formations (Figure 3.1). At each location one pressure cell will be installed against the shaft wall surface to measure the contact stresses at the concrete/rock interface as a result of rock swelling. Stress changes within the liner will also be monitored using another pressure cell that is embedded in the concrete and oriented perpendicular to aforementioned pressure cell. Strain gauges will also be embedded in the concrete. Figure 3.3 shows the schematic of the pressure cell and strain gauge array.

The extensometers that are kept for monitoring during operations phase will be exposed to saline groundwater and over an extended period of time, corrosion may lead to failure of the equipment. Thus a future decision may be made to abandon extensometers and measure deformation during operations phase by using convergence points and/or in-place inclinometers that are installed on the inside of the concrete liners.

To minimize the need for access to the instruments during the shaft sinking, remote measurements using wireless technology such as Mine Trax Wireless network (http://newtrax.com) or equivalent will be used for all in-shaft monitoring locations. The use of wireless technology will also allow remote collection of data from instruments to be monitored during the operations phase. However access to these monitoring locations will still be required for maintenance.

Table 3.2: Summary of Instrumentation and Rock Core Sampling Locations in Shafts

Elevation and Formation	Main Shaft		Ventilation Shaft		Large-diameter Rock Core Sample in Main Shaft	In situ Stress Measurements in Main Shaft
	No. of Units	Instrument Type	No. of Units	Instrument Type		
95 mASL (Bois Blanc)	5 1	Flexible MPBX Reference MPBX	5 1	Flexible MPBX Reference MPBX	--	--
60 mASL (Bois Blanc/ Bass Island)	5 1	Flexible MPBX Reference MPBX	5 1	Flexible MPBX Reference MPBX	--	--
30 mASL (Bass Island)	5 1	Flexible MPBX Reference MPBX	5 1	Flexible MPBX Reference MPBX	--	--
-160 mASL (Salina A1 Unit)	5 1 3	Flexible MPBX Reference MPBX Stress Cell	5 1 3	Flexible MPBX Reference MPBX Stress Cell	Five 305-mm-diameter samples[1]	USBM Probe
-310 mASL (Queenston)	5 1 2	Flexible MPBX Reference MPBX Pressure Cell	5 1 2	Flexible MPBX Reference MPBX Pressure Cell	Five 305-mm-diameter samples[1]	USBM Probe
-405 mASL (Georgian Bay)	5 1 2	Flexible MPBX Reference MPBX Pressure Cell	5 1 2	Flexible MPBX Reference MPBX Pressure Cell	Five 305-mm-diameter samples[1]	USBM Probe
-470 mASL (Cobourg - Lower Member)	5 1 3	Flexible MPBX Reference MPBX Stress Cell	5 1 3	Flexible MPBX Reference MPBX Stress Cell	--	USBM Probe

Note: (1) The 305-mm diameter sample will be further sub-cored to extract smaller diameter core sample for laboratory uniaxial compressive testing.

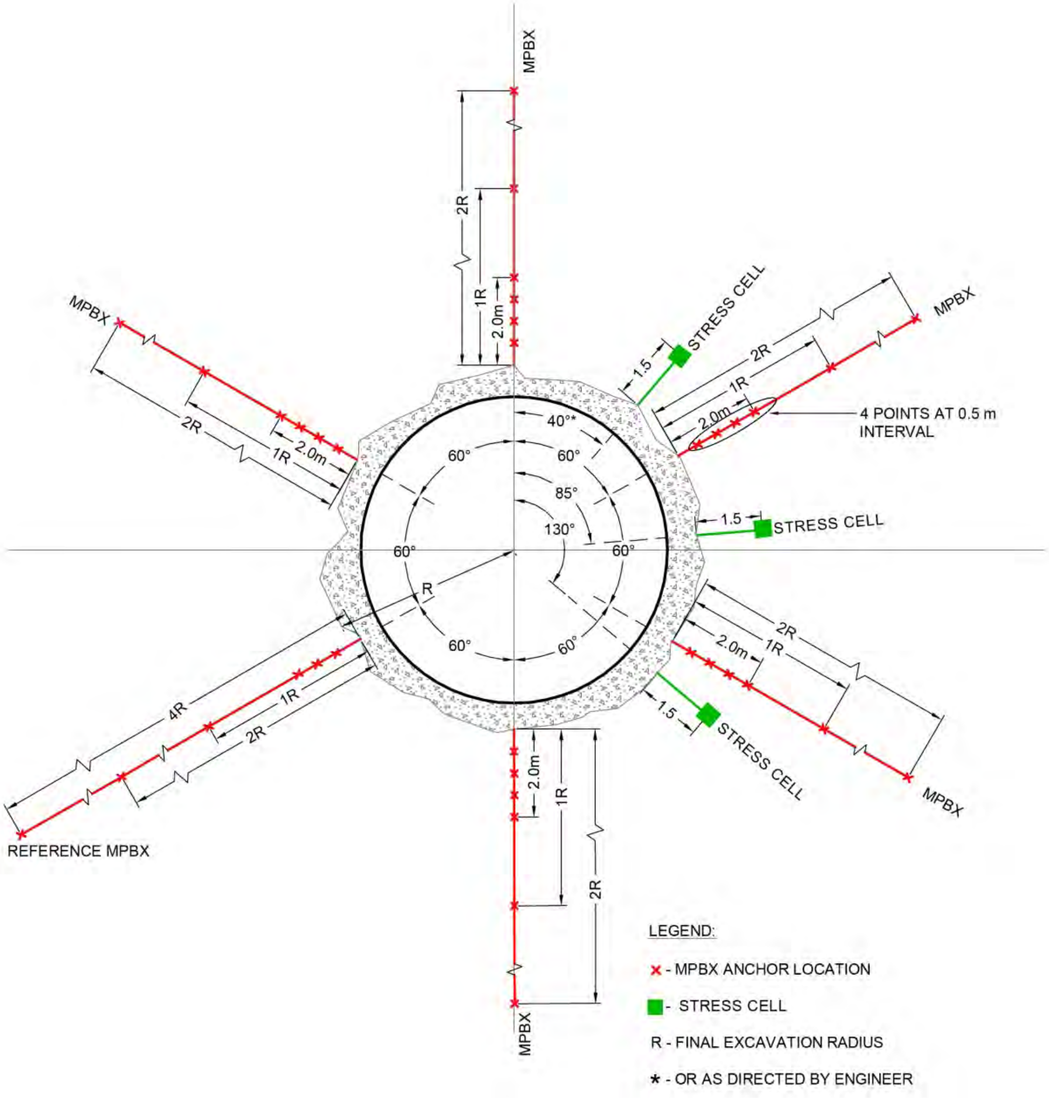


Figure 3.2: Configuration of Extensometer Array and Stress Cells at Selected Dolostone/Limestone Horizons

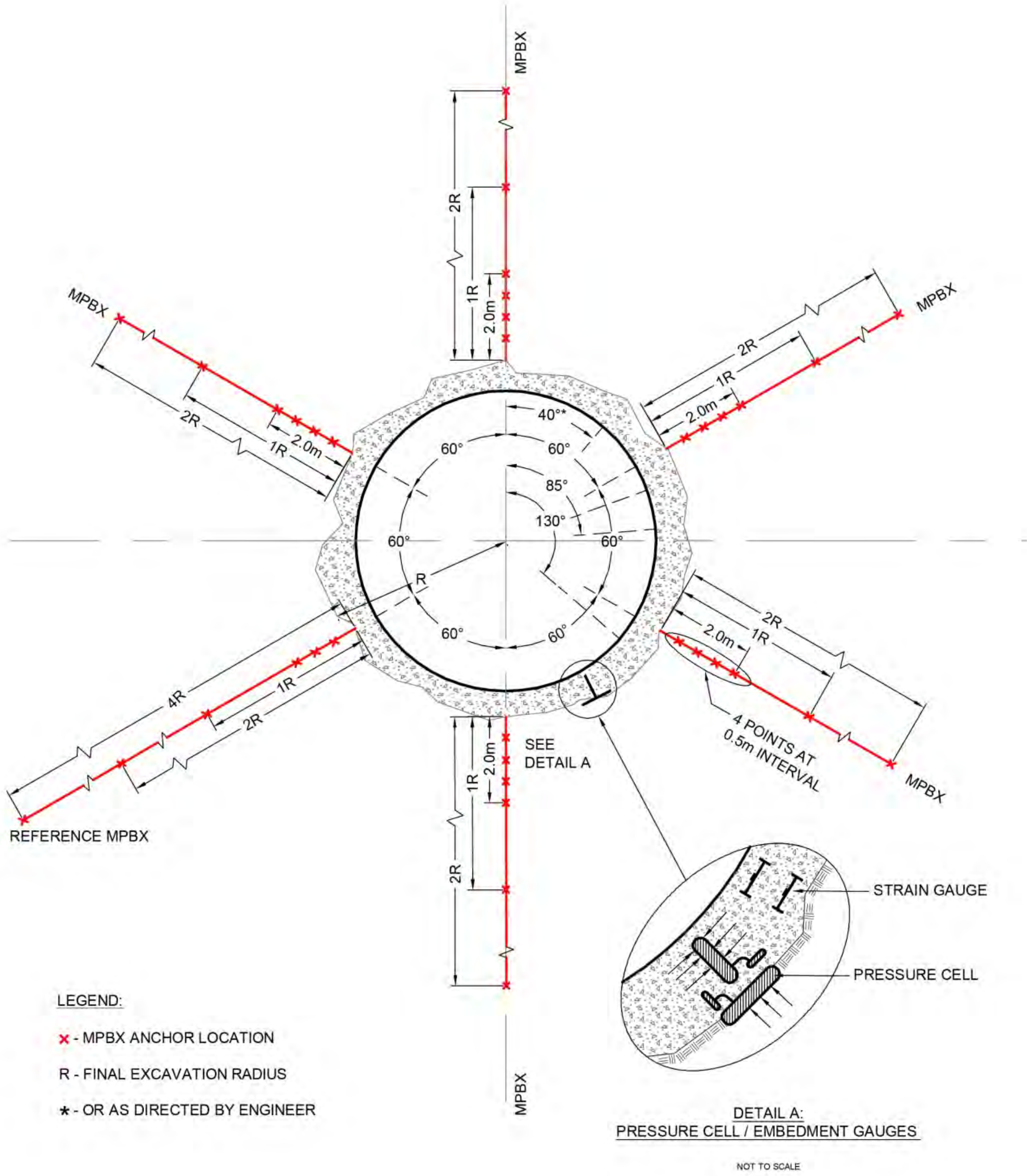


Figure 3.3: Configuration of Extensometer Array, Strain Gauges and Pressure Cells at Shale Horizons

3.2.5.2 Geomechanical Testing

The rock mass strength and stiffness data were primarily obtained from laboratory uniaxial compression tests conducted on vertically oriented (perpendicular to bedding) 76-mm-diameter core samples. The laboratory-derived rock property data were up-scaled to rock-mass-scale by taking into consideration the heterogeneity, anisotropy and inelasticity of the rock mass. The up-scaled rock property data were used in geomechanical modelling.

Shaft sinking will provide an opportunity to collect 305-mm-diameter rock core samples for the purpose of verifying the up-scaling and anisotropic assumptions. The 305-mm-diameter core samples will be obtained by horizontal diamond drilling into the shaft excavation wall at 3 locations as listed in Table 3.2. Cores of up to 160 mm in diameter will be sub-drilled and laboratory uniaxial compressive tested for up-scaling of rock properties. The test results will be used to verify the assumptions about rock properties that were used in modeling.

3.2.6 In Situ Stress Measurements

Stress measurements will be performed in the Main Shaft excavation by the overcoring method. There will be no stress measurement in the Ventilation Shaft because it is located about 80 m from the Main Shaft and therefore stress conditions are not expected to be different at the Ventilation Shaft location. Measurements will be performed in the following four formations (Figure 3.1 and Table 3.2):

- Salina A1,
- Queenston,
- Georgian Bay, and
- Cobourg (Lower Member).

At each of the four measurement locations, a total of five tests will be performed to determine horizontal stresses within the rock formation (Figure 3.4). It is expected that the rock will be competent at each location and that there will be no major geological features.

The United States Bureau of Mines borehole deformation gauge (USBM gauge) will be used for the in situ stress overcoring measurements. Details of the USBM gauge and the operational procedure are described in Hooker and Bickel (1974). The USBM gauge is preferred over the triaxial overcoring gauge (e.g. Commonwealth of Scientific and Industrial Research Organization (CSIRO HI) triaxial strain cells) for the following reasons:

- Creeping associated with the epoxy adhesive used to bond the triaxial strain cell to rock;
- Sensitivity of shales to the presence of water, e.g. drill water, that adversely affects the adequacy or stiffness of the bond between cell and rock;
- Long waiting time (over 10 hours) for epoxy adhesive to cure; and
- Poor reliability of test data as a result of the above factors.

The general procedure of the overcoring method is illustrated in Figure 3.5. At each measurement location, a 96-mm-diameter (HQ size) hole will be drilled from the shaft bottom to a depth of approximately 15 m. A 38-mm-diameter (EX size) pilot hole that is concentric with the HQ hole will then be drilled through the test position to a depth of approximately 600 mm. The USBM deformation gauge is then installed in a section of the pilot hole, which is free of joints and fractures and at distance of 200 to 300 mm from the end of the HQ hole. The pilot hole will be then overcored using a 96-mm-diameter thin wall coring bit to relieve the stresses around the pilot hole. The diametric deformation of the pilot hole will be monitored during overcoring by using USBM deformation gauge. The gauge will be connected by cable through the drill string to a digital strain indicator, and a switch and balance unit.

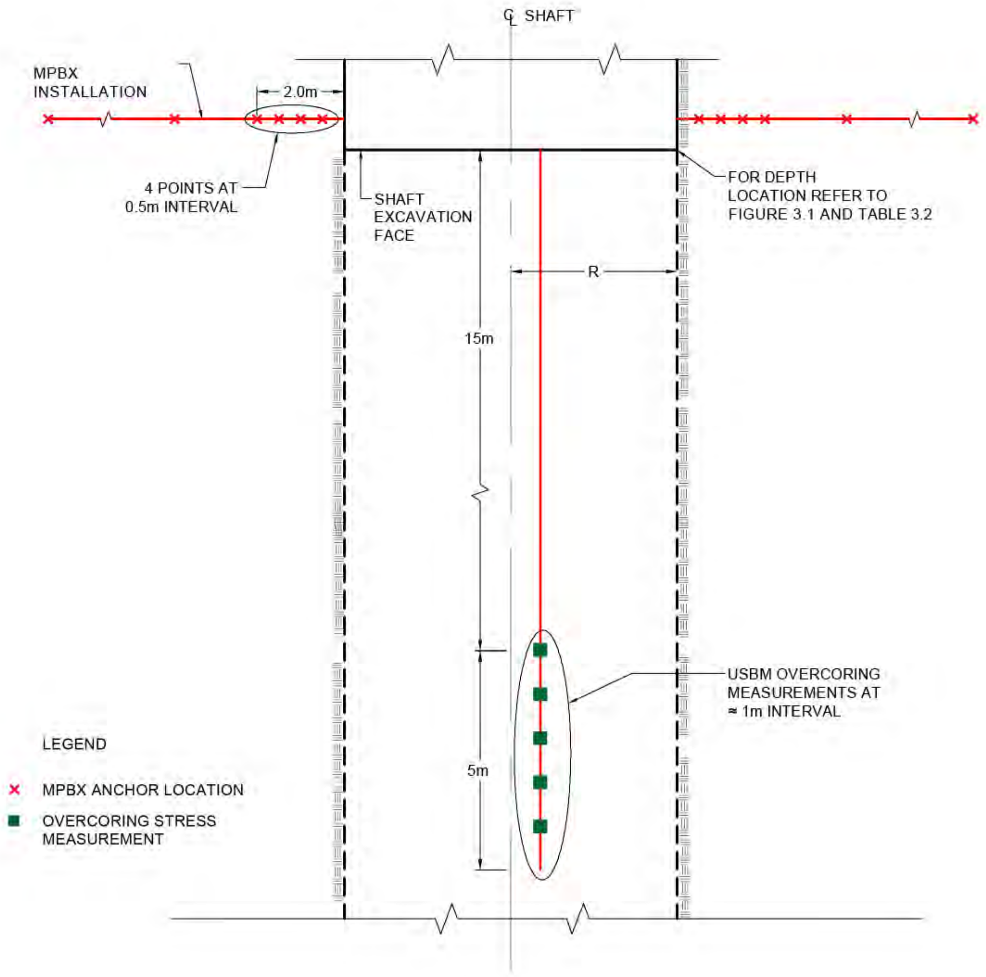


Figure 3.4: In situ Stress Measurement by Overcoring Method in the Main Shaft

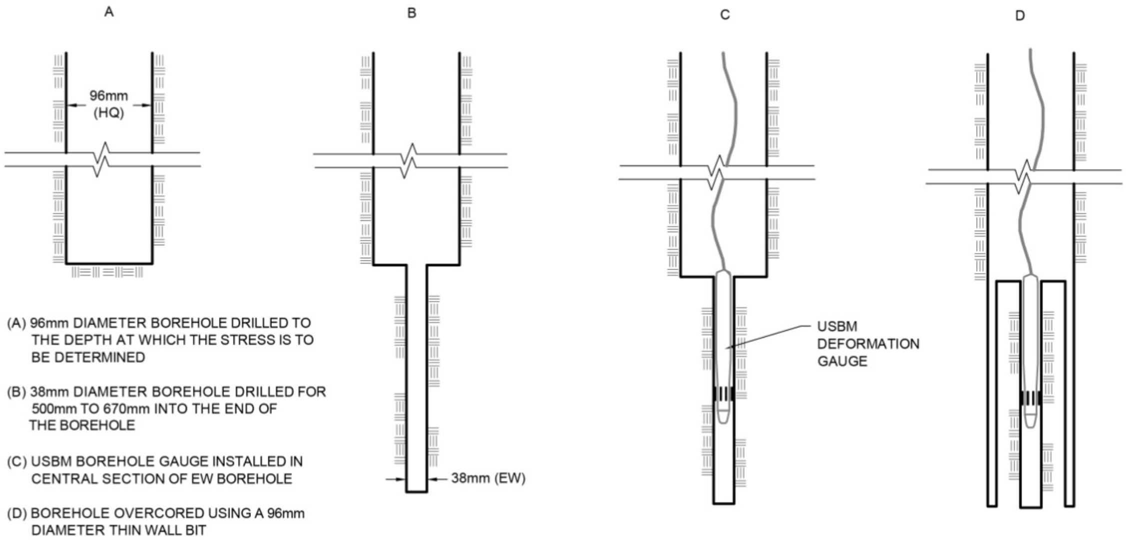


Figure 3.5: USBM Overcoring Method

The deformation modulus of the overcore sample recovered following the in situ test will be determined using a biaxial test cell. The cell consists of a cylindrical steel jacket with seals at either end of the cell. During modulus testing the USBM gauge is placed in the rock sample as shown in Figure 3.6 (ASTM 2002). Hydraulic oil is pumped into the space between the steel jacket and the sealed membrane applying a uniformly distributed radial pressure onto the rock sample. The deformation of the inner hole is measured at various pressure increments and decrements, and resultant data are used to calculate the deformation modulus of the intact rock sample.

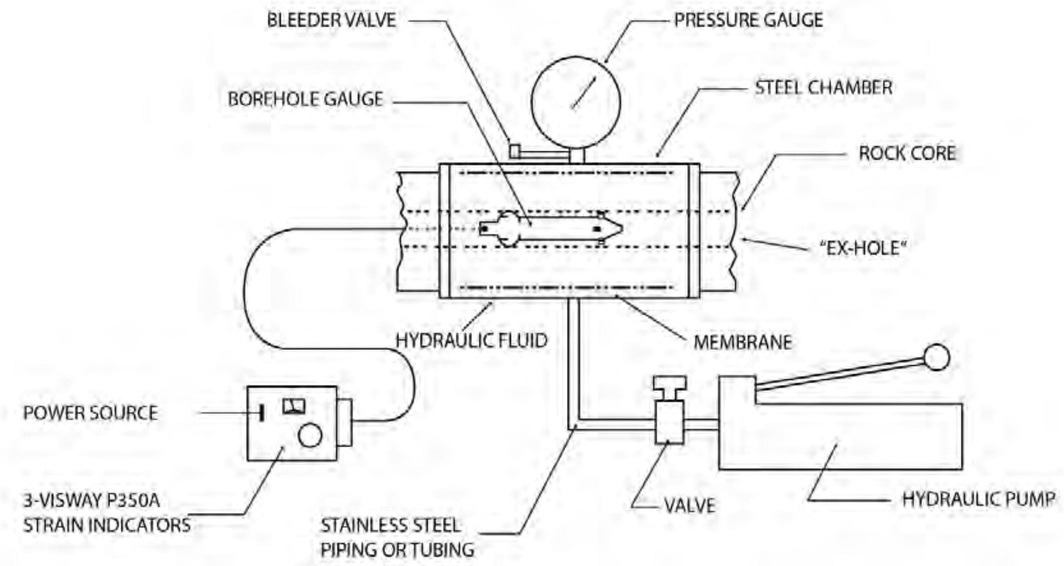


Figure 3.6: Biaxial Test Apparatus

The in situ stresses will be calculated from the measured changes in the deformation inside the 37.7-mm-diameter pilot hole and the deformation modulus determined by testing in the biaxial test apparatus.

3.3 Lateral Development

To verify that the behaviour of the Cobourg Formation limestone is within acceptable limits, a comprehensive geotechnical investigation and monitoring program will be carried during lateral development at the repository level. The following activities will also be used to verify that geologic, hydrogeologic and geotechnical conditions are as predicted on the basis of borehole investigations at the DGR site.

Some monitoring activities will continue into the operations phase.

3.3.1 Layout of Investigation Activities

The investigation and monitoring program at the repository level has been designed based on the anticipated geological conditions within the Cobourg Formation. Figure 3.7 shows the geotechnical monitoring and testing locations within the underground repository. The final location and density of instrumentation installation will be established taking into consideration the results of already-installed instrumentation and the lateral development schedule. Specific instrumentation areas and test stations will be prepared by the contractor to ensure safe access for the duration of the monitoring period.

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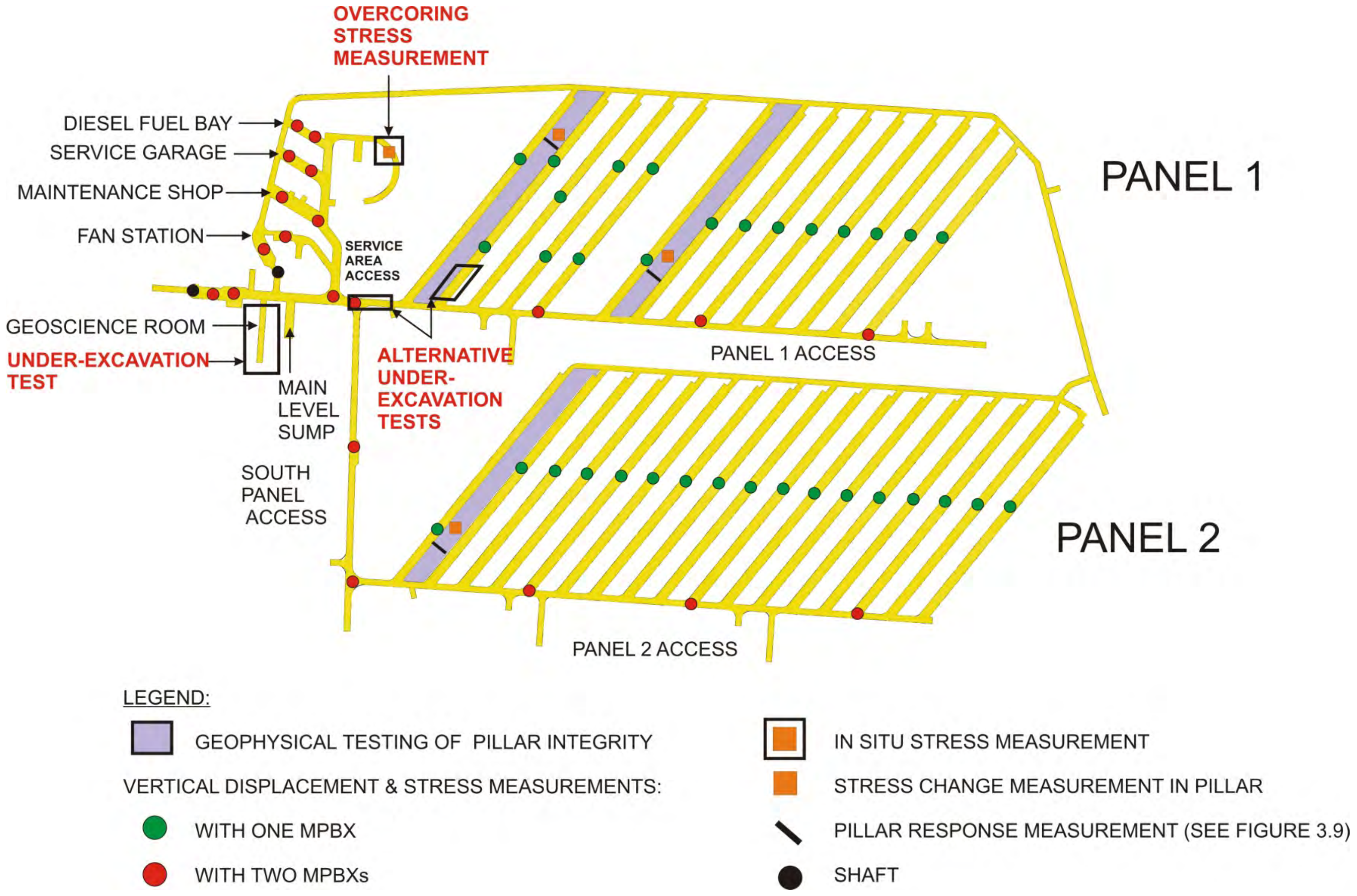


Figure 3.7: Plan View of Underground Repository Showing Location of Verification Activities

3.3.2 Geological Characterization

3.3.2.1 Geologic Mapping

Using techniques described in Section 3.2.2, geological mapping of all excavation surfaces will be performed by a professional geologist during each excavation cycle/shift.

The objective of detailed geological mapping is to verify rock mass characteristics, stratigraphy, lithology, discontinuities, structure and other rock conditions that were used in the geotechnical design of the underground openings. Guidelines, such as the ISRM suggested Method for Rock Mass Characterization (1981) and USACE EM 1110-1-1804 (2001) will be used as a field guide during mapping activities to collect the required rock rating parameters.

To optimize the length of time that a geologist spends mapping at the tunnel face, 3D laser scanning by means of the Laser Imaging Detection and Ranging (LIDAR) technique and high resolution digital photography will be performed to assist in characterizing the rock mass and to identify key structural features, which affect the kinematic stability of the excavation opening (Lato et al. 2009). The LIDAR technique will also be used to obtain a detailed permanent record of the geometry of the excavated openings (Fekete et al. 2010).

3.3.2.2 Geophysical Testing of Pillar Integrity

A seismic tomography survey will be carried out on selected pillars along the entire length of emplacement rooms (highlighted pillars in Figure 3.7). The travelling seismic waves allow the imaging of the interior of the pillar to examine the integrity of the pillars at different stages of the repository development and to explore for potential features within the pillars.

3.3.2.3 Seepage Water Collection

Due to the very low permeability of the Cobourg Formation, visible groundwater seepage from bedding planes and joints is not expected. However, in the unlikely event that seepage is encountered, the groundwater would be sampled for chemical analysis and the inflow rate estimated.

3.3.3 Excavation Response

3.3.3.1 Excavation Deformation Measurement

Vertical displacement and stress measurement instruments will be established at the locations shown on Figure 3.7. Table 3.3 tabulates the types and number of extensometers and stress cells in each location of the underground repository.

A typical installation in the access tunnels and in openings at the Services Areas is shown in Figure 3.8. Each monitoring installation will consist of flexible MPBX units in the floor and roof of the excavation and will be accompanied by a stress cell that is installed at the mid-point of the roof. The stress cell could be either the CSIRO or the LVDT-type cell depending on the rock conditions. For tunnels in which temperature fluctuation is anticipated, temperature sensors will be installed at selected anchor locations of the MPBX units.

In the emplacement rooms, only the roof-based MPBX and stress cell monitoring array will be installed. In addition convergence pins will be installed as a five pin array and used to measure relative displacement of the emplacement room walls (see section view in Figure 3.9). Each convergence pin will be in the form of a threaded bar with hook assembly grouted in a 300 mm short hole in the rock wall. The convergence pins will be measured using a tape extensometer across the five convergence points as shown in Figure 3.9. Most rooms will have a single 5-pin array with selected rooms having two 5-pin arrays (see Table 3.3).

Provision will also be made to carry out regular elevation survey of the repository floor to monitor the behaviour of the underlying weaker Sherman Fall Formation, particularly along the ramp.

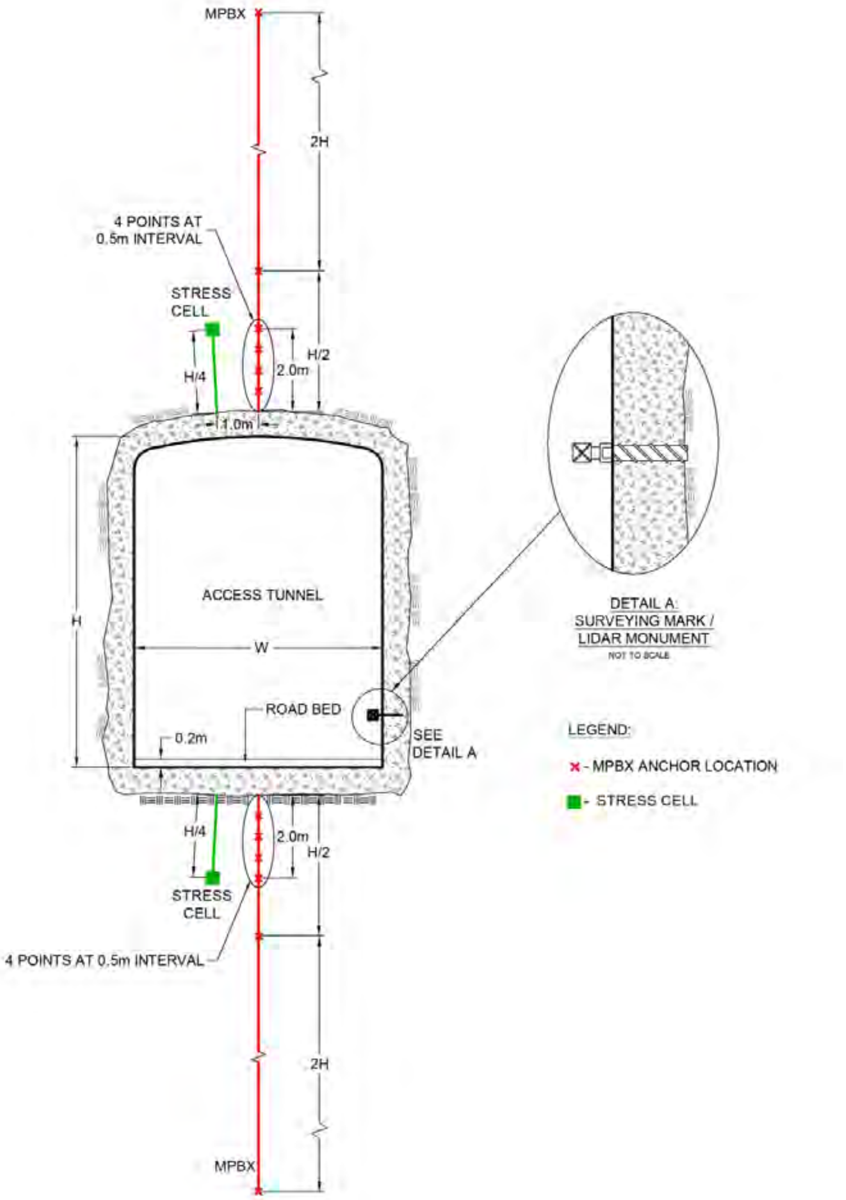


Figure 3.8: Typical Instrumentation Array in Access Tunnels

Table 3.3: Summary Instrumentation Arrays on Repository Level

Location	No. of Units	Instrument Type
Access Tunnels and Service Area		
Diesel Fuel Bay	4 2	MPBX Stress Cell
Service Garage	4 2	MPBX Stress Cell
Maintenance Shop	4 2	MPBX Stress Cell
Rock Dump	2 1	MPBX Stress Cell
Fan Station	2 1	MPBX Stress Cell
Service Area Access	2 1	MPBX Stress Cell
Panel 1 Access (North)	6 3	MPBX Stress Cell
Main Shaft Access	6 3	MPBX Stress Cell
Panel 2 Access (South)	6 3	MPBX Stress Cell
South Panel Access	4 2	MPBX Stress Cell
Emplacement Rooms		
Panel 1 Emplacement Room (1,3, 6 to 14)	11 11 55	MPBX (1 unit per room) Stress Cell (1 unit per room) Convergence Pin (5 pin array per room)
Panel 1 Emplacement Room (2, 4 & 5)	6 6 30	MPBX (2 units per room) Stress Cell (2 x 1 unit per room) Convergence Pin (2 x 5 pin arrays per room)
Panel 2 Emplacement Room (1 to 17)	17 17 85	MPBX (1 unit per room) Stress Cell (1 unit per room) Convergence Pin (5 pin array per room)
Repository	TBD	Survey Monument for LIDAR Profiling

3.3.3.2 Geomechanical Testing

The strength and stiffness of the rock mass properties used in the underground opening stability analysis will be verified by retrieving 305-mm-diameter rock samples from excavated openings at the repository horizon. Then 160-mm-diameter sub-cores will be obtained for uniaxial compression tests to determine the modules of deformation and other geomechanical parameters at a larger scale. Five 305-mm-diameter samples will be obtained near the Main Shaft station and at five other locations on the repository horizon for a total of 30 large diameter samples. Alternatively block samples of the limestone may also be obtained for laboratory testing. Should adverse discontinuities be encountered, large joint samples will also be obtained to determine the shear strength of discontinuities.

3.3.3.3 Laser Profiling

A computer-controlled automatic scanning laser profiler like the LIDAR used for the mapping of the excavation face (Section 3.3.2.1) will be used to obtain a precise profile of the tunnels and rooms. Profiles taken at different times at key locations will reveal whether any time-dependent deformation of rock has occurred and/or any response resulting from the excavation of adjacent emplacement rooms has occurred. Fixed mounts for the LIDAR equipment will be established at selected locations along tunnel openings. Imaging devices will be mounted on these established survey monuments to precisely re-survey these locations at various elapsed times after excavation (Figure 3.8).

In order to accurately define the opening geometry in sufficient resolution, the LIDAR survey will be carried out using an automated laser rangefinder to survey rock surface without the need for prisms. The accuracy of close range data is expected to be at the millimetre scale. The locations of the LIDAR survey stations will be laid out using a total station survey instrument. The surveys of the tunnel section can then be combined to create a 3-dimensional face profile. It is anticipated that the survey will be routinely carried out by the resident geological staff.

3.3.3.4 Pillar Response Measurement

Three pillars will be instrumented to measure in situ load and deformation characteristics in each pillar. The monitoring instruments will be installed via a fully excavated emplacement room and before the emplacement room on the opposite side of the pillar is excavated.

An inspection borehole will be drilled to obtain core samples for laboratory strength testing and to allow access for a televiewer to observe the extent of the potential damage zone across the pillar width. The MPBX and the stress cells that are installed across the pillar will reveal the lateral deformation and vertical stress distribution in the structure during the excavation of near-by rooms. In addition to these instruments, the geophysics measurement array will measure micro-seismic events which are associated with the stress redistribution within the pillar.

The locations of three arrays are shown in Figure 3.7 (see short black lines labeled “Horizontal displacement measurement in pillar”). A typical layout of the instrumentation across a pillar is shown in Figure 3.9. The measurements obtained from these arrays will be reviewed in conjunction with the measurements described in Section 3.3.3.3.

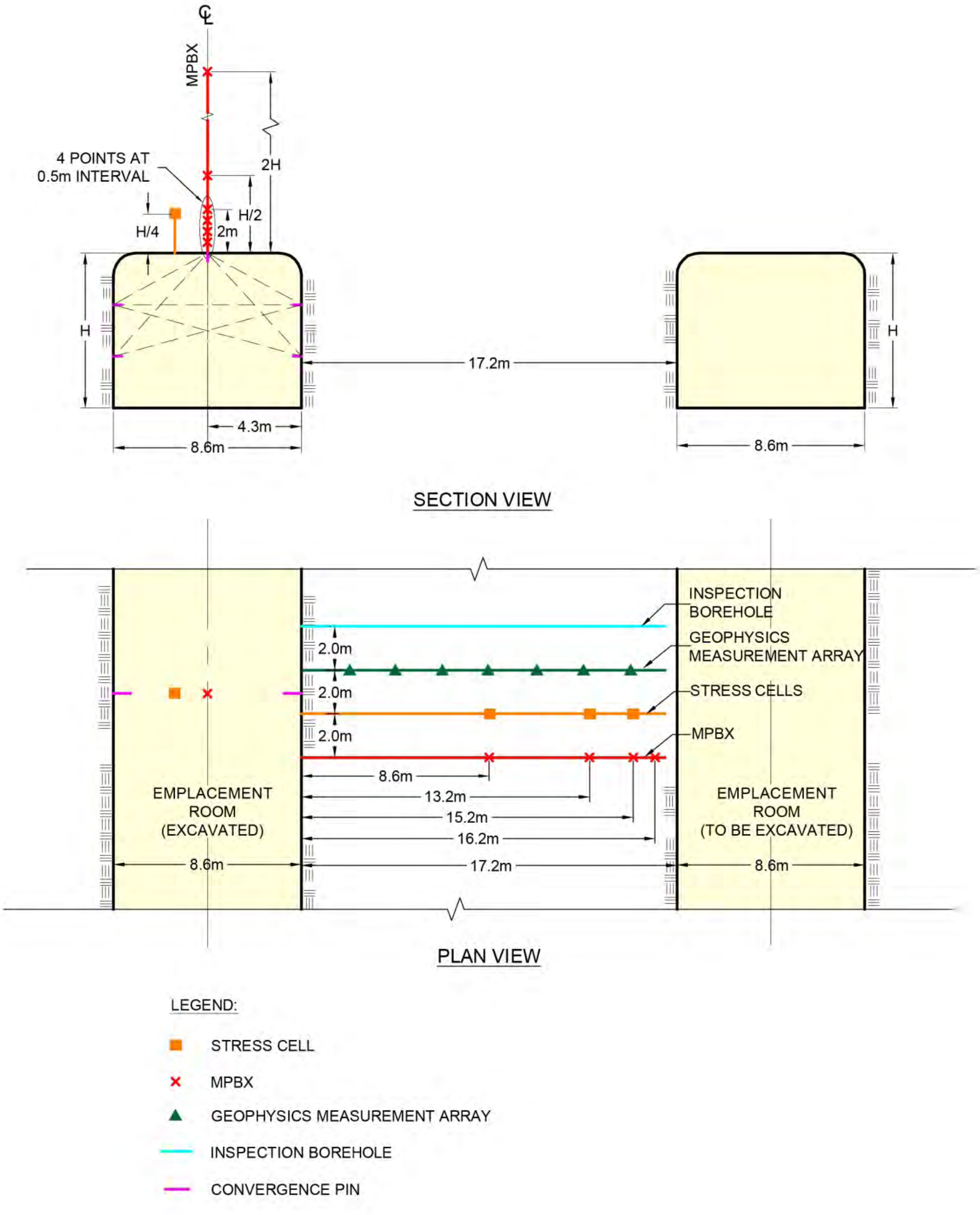


Figure 3.9: Arrangement of Boreholes and Instruments for Pillar Response Measurements

3.3.4 In Situ Stresses

3.3.4.1 Overcoring Stress Measurements

In-situ stress conditions in the Sherman Fall formation will be determined by the overcoring technique (see Section 3.2.6 description of testing method) in the down-ramp to shaft bottoms.

3.3.4.2 Under-excavation Test

Ground stress tensors in the Cobourg Formation will be verified by performing an under-excavation test during the early stage of the repository lateral development. It is expected that a test conducted at repository horizon will have a greater chance of successfully yielding representative results than an equivalent test in a shaft excavation. The preferred location for the test is at the Geoscience Room. The preferred location and two possible alternate locations for the test are shown on Figure 3.7. The final location of the test will be determined in consultation with the lateral development contractor and will take into consideration the schedule for early stages of repository lateral development in the vicinity of the two shafts.

Figures 3.10 and 3.11 show the instrumentation layout for the under-excavation test at the preferred location. Eight boreholes will be drilled from the Main Level Sump into the rock mass surrounding the Geoscience Room and will be drilled in advance of Geoscience Room excavation. Four of these boreholes will be instrumented with deformation strain-gauge-type inclinometers and three horizontal boreholes with installed MPBXs. At the end of each inclined inclinometer borehole, a LVDT, CSIRO or equivalent stress cell will also be installed to monitor change in stress during the test. Consideration will be given to installing a geophone array to monitor the acoustic emission generated along the periphery of the opening during the under-excavation test.

Ground response measurements recorded as the Geoscience Room is excavated can then be back-analyzed to determine in situ stresses in the Cobourg Formation. The in situ stress estimate will be compared with overcoring measurements in the Main Shaft in the Lower members of the Cobourg Formation described in Section 3.2.6.

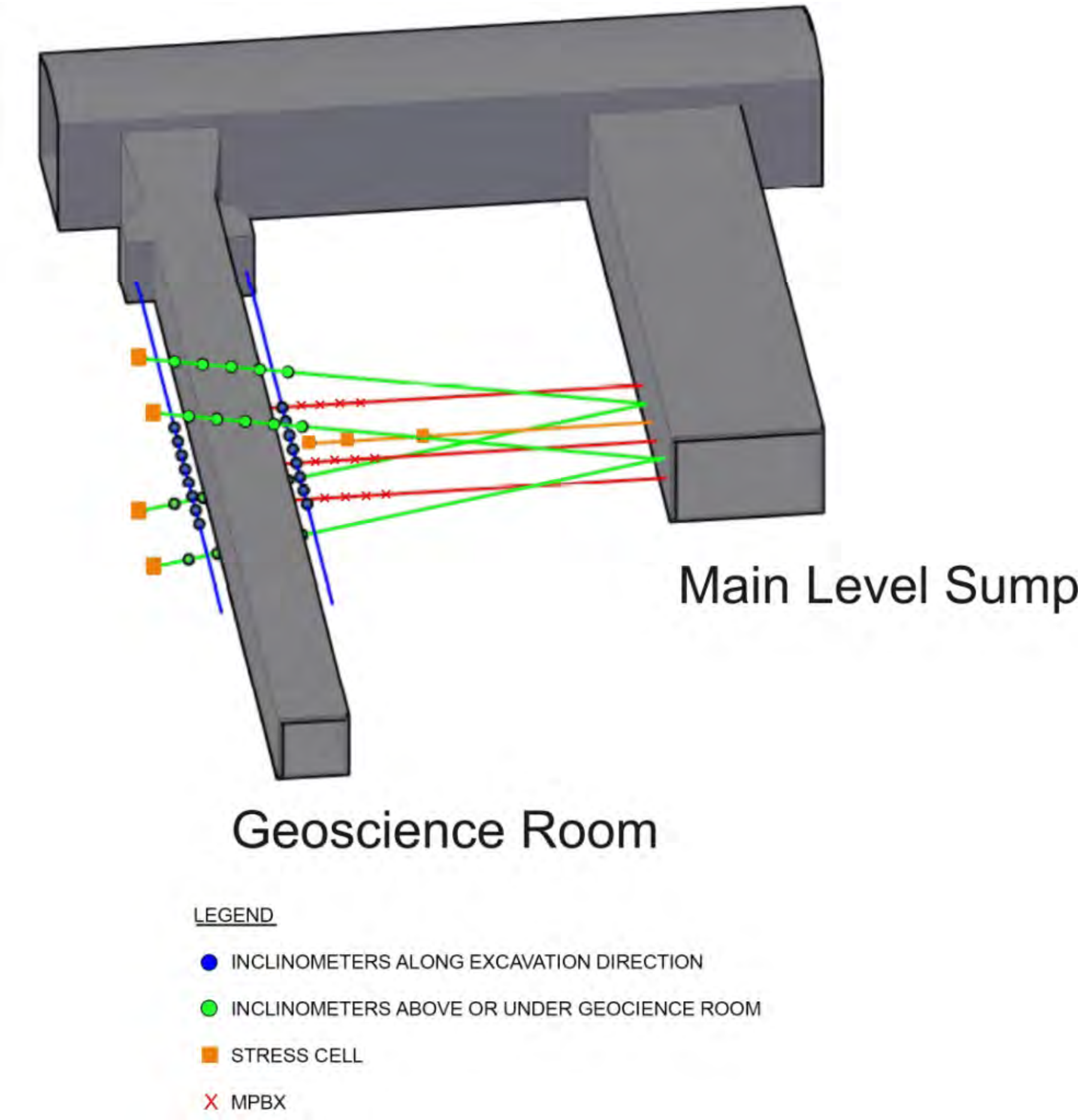
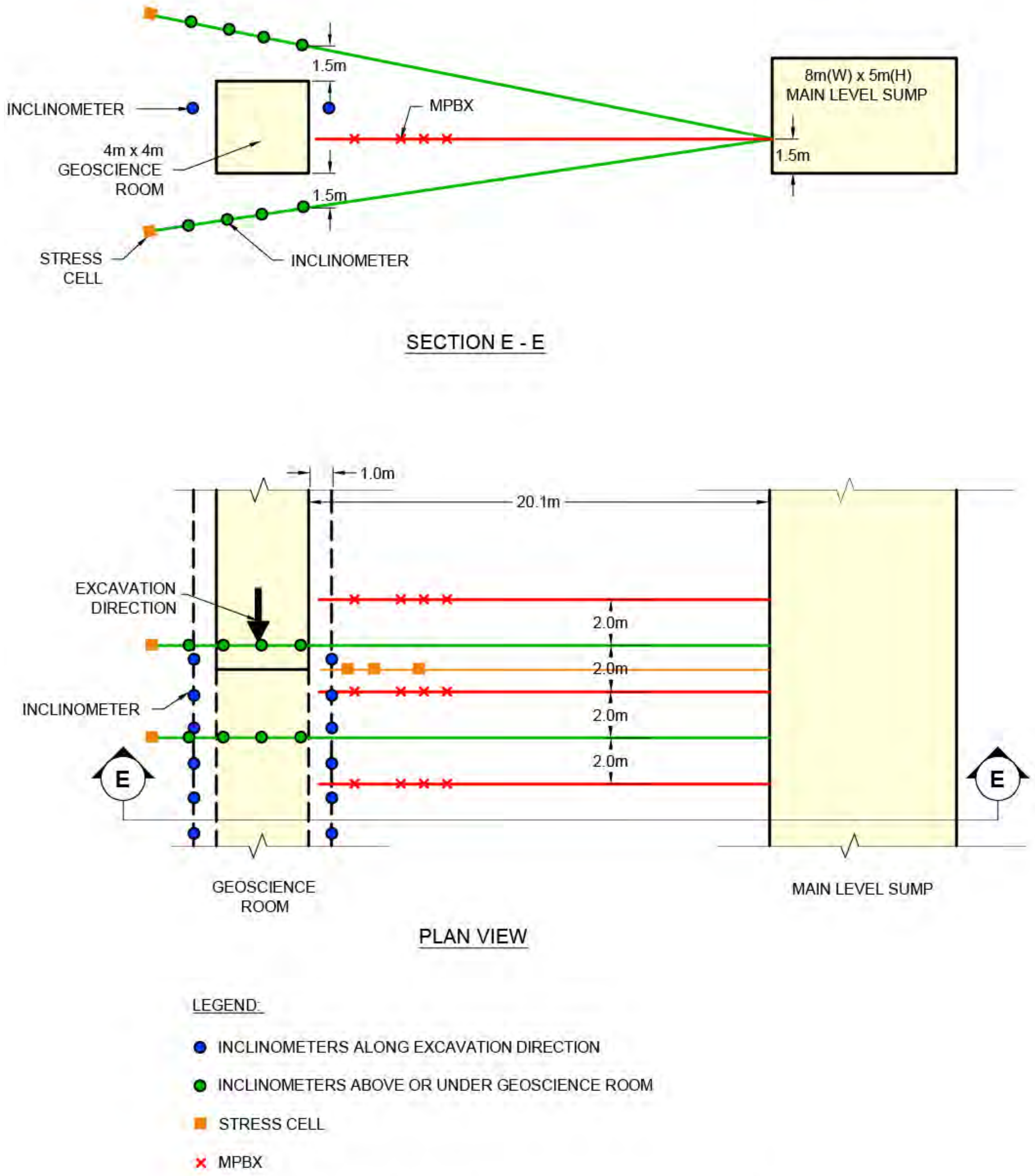


Figure 3.10: Isometric View of the Under-excavation Test



NOTE: ROOM DIMENSIONS AND GENERAL LAYOUT OF BOREHOLES TO BE DECIDED

Figure 3.11: Under-excavation Test

4. VERIFICATION OF GEOSCIENCE PARAMETERS FOR THE SAFETY CASE

This section of the report describes investigations to be performed during shaft sinking and lateral development for the purpose of verifying geoscience data used in the DGR Safety Case. In particular, data will be gathered to confirm that the host Cobourg Formation and the overlying rock formations will act as a long-term barrier to contain and isolate the L&ILW. The investigations include the characterization of the Excavation Damaged Zone (EDZ), bedrock formation permeabilities, diffusion properties, and hydrogeochemical and microbiological conditions. The results of the various geotechnical investigation and monitoring activities that have been described in Section 3 will also be used to verify properties and assumptions used in long-term geomechanical modeling for the DGR Safety Case.

Detailed test plan for the geoscience verification experiments will be developed before the commencement of the construction phase to take advantage of the best available technology based on the best international practice and experience within Underground Research Laboratories (e.g., Mt. Terri, Switzerland, Bure, France).

4.1 Key Geoscience Parameters

A key aspect of the DGR Safety Case is the geosphere barrier integrity and its ability to isolate and contain the radioactive waste for time periods on scale of geologic time; i.e. 1 million years. Key geoscientific parameters that contribute to the long-term geosphere integrity, and thus the DGR Safety Case, are presented in Table 4.1. Also listed are the investigations or monitoring activities that will be performed to characterize each parameter. Several geotechnical-related verification activities described in Section 3 will generate data that will also be used to verify geoscience assumptions and data used in the DGR Safety Case. Thus, only a brief description of these activities has been provided in the following sections.

Table 4.1: Key Geoscience Parameters and the Investigation or Monitoring Activities to Measure Each Parameter

Geoscience Parameter	Investigation or Monitoring Activity	
	Shaft Sinking [1]	Lateral Development
Rock Mass Quality	• See Section 3.2.2. • Mapping will also emphasize geoscientific aspects such as any adverse geological feature with the potential to enhance radionuclide migration.	• See Section 3.3.2.1. • Mapping will also emphasize geoscientific aspects such as any adverse geological feature with the potential to enhance radionuclide migration.
Excavation Damage Zone (EDZ)	EDZ investigation using an array of short boreholes drilled horizontally from the shaft wall of the Main Shaft. • Perform ultrasonic velocity measurement and acoustic televiewer and/or optical televiewer inspection at selected horizons. • Coring or overcoring to retrieve rock samples for visual inspection.	• See Section 4.3.3.

Geoscience Parameter	**Investigation or Monitoring Activity**	
	Shaft Sinking [1]	**Lateral Development**
	• Packer testing at small intervals and pressure monitoring. • Perform ground penetrating radar to detect the extent of the highly damaged zone (HDZ).	
Excavation Deformation	See Section 3.2.5.1.	See Section 3.3.3.1.
Geomechanical Properties	See Section 3.2.5.2.	See Section 3.3.3.2.
In situ Stress	See Section 3.2.6.	See Section 3.3.4.
Fracture infill mineral studies and dating	Should the opportunity arise, suitable specimens of fracture infill materials will be collected for further analysis and laboratory testing. Any petroliferous zones will be described, imaged and sampled for possible testing.	Collecting fracture in fill materials from Cobourg, Sherman Fall and Kirkfield formation for mineral chemistry, fluid inclusion studies, analysis of stable isotopes, cathodoluminescence imaging and radiometric age dating.
Two-phase flow study	N/A	To characterize multi-phase (fluid-gas-oil) pore saturations and transport properties.
Long-term diffusion test	N/A	Long-term monitoring of dedicated boreholes in a secure location.
Microbiology study	N/A	Characterization of microbial activity and influence on DGR performance.
Sealing Materials Performance Test	Test to be decided see Section 4.2.6	Vertical borehole tests in the Geoscience Room that are filled with sealing materials will be used to demonstrate that the materials form saturated low-permeable layers and long-term chemical compatibility with saline groundwater. Measurements with real-time instruments and through periodic extraction of cored interface samples.

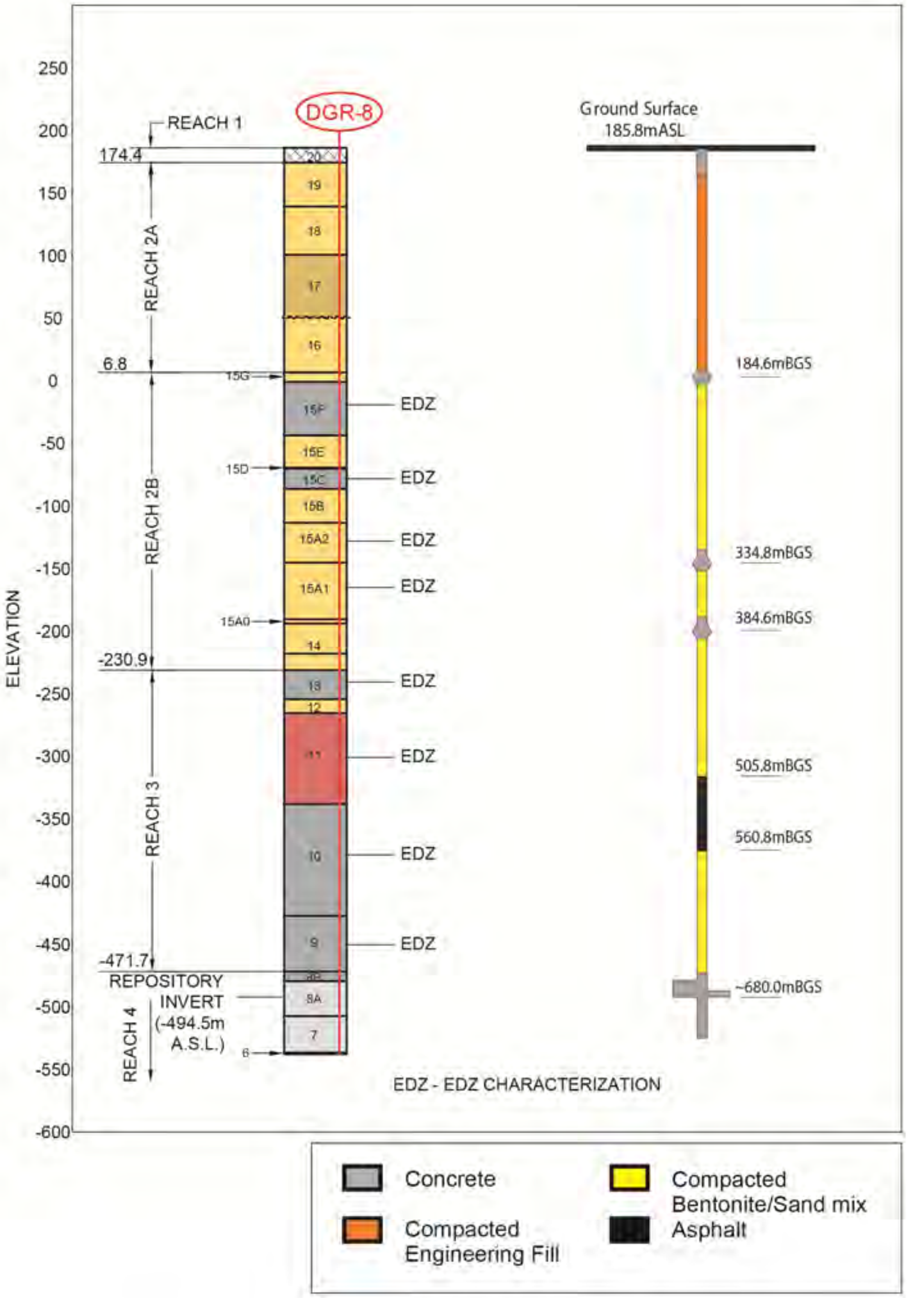
Note: (1) Unless otherwise stated activity occurs in both Main Shaft and Ventilation Shaft during shaft sinking

4.2 Shaft Sinking

4.2.1 Shaft Seal Design

Upon the closure of the repository, both shafts will be sealed and backfilled. The proposed method for sealing the two shafts and shaft seal arrangement are presented in Section 13.6 of the Preliminary Safety Report (OPG 2011). The seal system consists of a concrete monolith at the repository level, four zones of compacted 70/30 bentonite-sand mix, an asphalt seal and three low-heat high-performance concrete bulkheads. Figure 4.1 shows the general arrangement of the shaft seals.

Prior to placing the seal materials in a shaft the internal shaft infrastructure and concrete liner are removed. It is also assumed that an additional 500 mm of host rock will be excavated beyond the initial shaft excavated diameter to remove damaged rock that may have formed during shaft sinking and the operational period of the DGR. This layer of rock is referred to as the Highly Damaged Zone (HDZ). A zone of damaged rock, called the Excavation Damaged Zone (EDZ) will remain around the perimeter of the shaft excavation.



NOTES

1) FIGURE MODIFIED FROM NWMO (2011)
2) SEE FIGURE 2.2 FOR LEGEND OF GEOLOGIC INFORMATION

Figure 4.1: Proposed Shaft Seal Configuration and General Locations for EDZ Testing

4.2.2 Layout of Investigation Activities

This section discusses geoscientific investigations and monitoring activities that will be carried out during shaft sinking to provide field verification of geoscience information contributing to the DGR Safety Case.

The program will consist of multiple geological, hydrogeological, geomechanical, and geophysical activities, as described in the following sections. All geotechnical activities have been described in Section 3 and will not be repeated in detail here. Figure 4.1 shows the proposed EDZ characterization horizons along the Main Shaft.

4.2.3 Geological Characterization

Geologic mapping data will be collected as outlined in Section 3.2.2. In addition to this data, mapping will be carried out to provide data on the geological composition of the rock and compared with equivalent data collected in the DGR-series boreholes. Information on hydrogeology, such as the identification of hydraulically active features or zones, will be collected.

Detailed mapping of excavated surfaces will also provide information that can be used to study the extent and geometry of the EDZ around the shaft excavation in the various bedrock formations. This information will be helpful in contributing to an understanding of fracture origin, hierarchy and interconnectivity axially along the excavated openings.

During mapping, suitable specimens of fracture infill materials will also be collected for further analysis and laboratory testing. Any petroliferous zones will be described, imaged and sampled for possible testing.

Ground penetration radar (GPR) will be used to scan the shaft wall during geologic mapping near the EDZ characterization sections. This will provide information on EDZ extent and its geometry. Other geophysical techniques, such as resistivity, sonic, acoustic emission and seismo-electrical methods may also be considered for the characterization work.

4.2.4 EDZ Characterization

The EDZ characterization program will be based on a combined series of measurements using geologic, hydrogeologic and geophysical techniques. It is this multi-disciplinary approach to EDZ characterization that provides a strong basis to interpret conditions and verify numerical predictions. Prior to start of shaft sinking, detailed plans will be developed with the intent of ensuring that the best available EDZ characterization techniques, as demonstrated through experimentation at various international Underground Research Laboratories (URLs), are applied.

EDZ testing will be conducted in the Main Shaft only and at the eight locations shown in Figure 4.1. The proposed radial configuration of boreholes for these activities at a shaft testing horizon is illustrated in Figure 4.2. Prior to any testing and instrumentation, these boreholes will be inspected and logged using a borehole camera (optical televiewer) and/or acoustic televiewer. This geological characterization will provide identification of fractures induced by excavation.

The information collected from the geological characterization including GPR (Section 4.2.3), coupled with hydrogeological and geophysical activities will provide input to the characterization and delineation of the EDZ along the Main Shaft.

The majority of the verification work will be performed during shaft sinking. However, geophysical measurements and possibly hydrogeological measurements will continue into the facility operation phase. Thus, recess panels in the shaft concrete liner and temporary access will be required to perform periodic measurements during facility operations at all 8 locations.

4.2.4.1 Geophysical Testing

Ultrasonic velocity logging techniques will be used to to estimate rock mass and EDZ properties at locations shown in Figure 4.1. These investigations would be performed in the Main Shaft within the formations of Salina Units F, C, A2 (carbonate) and A1, Cabot Head, Queenston, Georgian Bay and Blue Mountain. These measurements would be conducted in horizontal and radially oriented boreholes extending at least 10 m beyond the shaft excavation. This process would allow correlation of velocity measurements with observed fracture patterns and rock mass permeability measurements (Section 4.2.4.3). Ultrasonic velocity measurements in regular intervals in boreholes are considered to be one of the most effective geophysical methods, which can be either applied standalone or integrated with tomographic or reflection surveys. Schuster and Alheid (2007) have used the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) mini-sonic probe to determine the extent of the EDZ around the shaft excavation at the Laboratoire Meuse Haute Marne (Bure URL) in France. They have also carried out similar measurement at the Mont Terri Rock Laboratory in Switzerland (Martin et al. 2002).

It is understood from the long-term shaft seal analysis (ITASCA 2011) that a majority of the EDZ will develop soon after the excavation. The extent of the EDZ around the shaft is not anticipated to change significantly during facility operation and post-closure phase unless the stress condition around the shaft and shaft dimension(s) change. The geophysical measurements, such as the ultrasonic interval velocity measurements, will be performed a second time soon after the completion of shaft excavation to gather evidence of the EDZ evolution. This will provide additional information on the evolution of the EDZ.

4.2.4.2 Core Retrieval

Small diameter boreholes of 10 m in length will be drilled at each EDZ testing location and core will be retrieved (Figure 4.1 and Figure 4.2). A section of these holes will be grouted with fluorescence-doped resin and a metal (or fiberglass) rod will be inserted. Overcoring will be used to extract the resin filled zone for EDZ fracture analysis. This will provide the information on the fracture distribution, apertures and the extent of the EDZ. This technique was developed at Mont Terri (Bossart et al. 2002, 2004) and has been applied at the Meuse Haute Marne underground Research Laboratory (Armand et al. 2007). The characterization of EDZ may also include deformation modulus measurements to determine the variations in the rock property at various distances from the shaft wall at the test horizons.

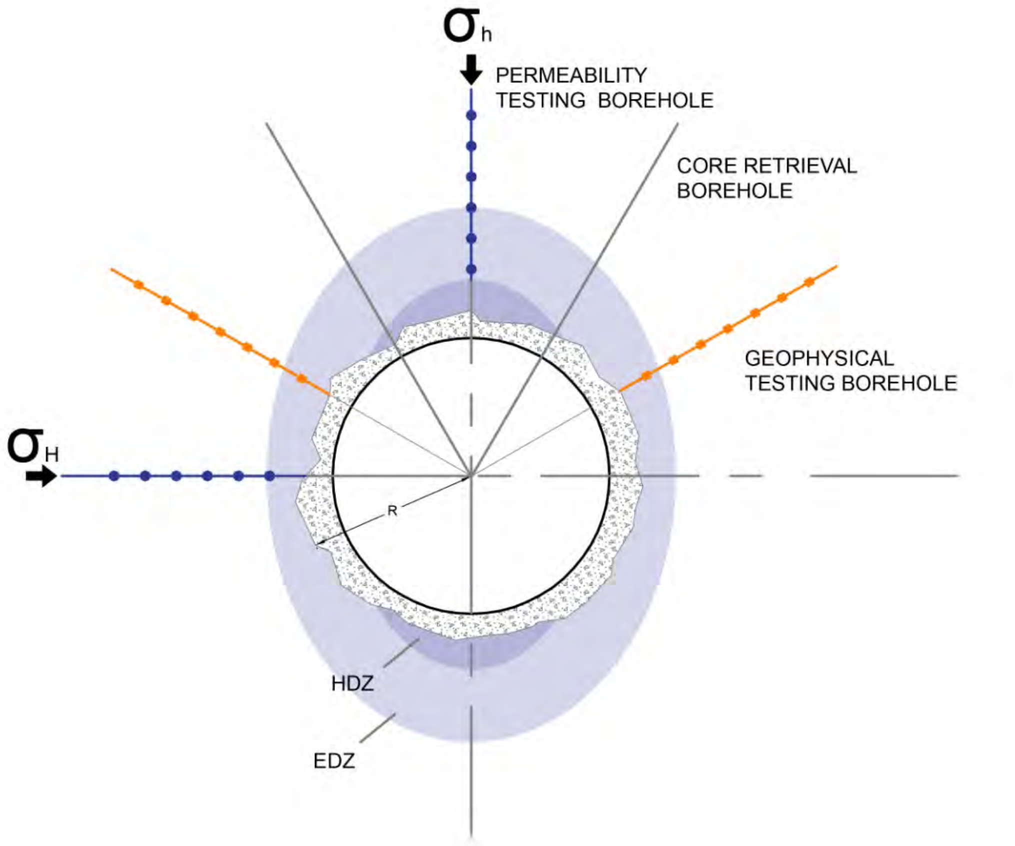


Figure 4.2: Proposed Borehole Configuration for EDZ Characterization

4.2.4.3 Permeability Measurement

Experience with EDZ studies in URLs has indicated that localized fracturing within the EDZ can lead to enhanced rock mass permeabilities. A key question relates to the interconnectivity of the fractures axially along the excavated opening and hence actual increases in permeability relevant to the safety of a repository (FRACTURE SYSTEMS 2011). Borehole hydraulic testing will be performed to provide estimates of in situ hydraulic conductivity. Measurements will be conducted using special hydraulic testing systems for EDZ, such as SEPPI System developed by ANDRA (Bossart et al. 2002) or MMPS System developed for Nagra (Armand et al. 2004) in the two dedicated boreholes (Figure 4.3), included as part of the proposed borehole array, to characterize changes in rock mass permeability resulting from EDZ formation. Upon completion of the permeability tests, selected sections of holes will be isolated for formation fluid pressure monitoring.

4.2.5 Excavation Response

4.2.5.1 Excavation Deformation Measurement

This activity is described in Section 3.2.5.1. Rock material parameters deduced from back-analyzing excavation deformation measurements will be used to verify rock property data used in the long-term geomechanical analysis and EDZ extent prediction (ITASCA 2011).

4.2.5.2 Geomechanical Testing

In addition to the geomechanical testing as described Section 3.2.5.2, the scope of the laboratory testing program will include geomechanical testing to collect data about the long-term strength and stiffness of the rock mass. Tests are needed to validate assumptions and current understanding about specific rock characteristics, such as strength and stiffness anisotropies and crack initiation stress threshold relevant to understanding long-term repository and formation barrier integrity. Testing of large diameter rock samples will validate these parameters and further constrain the variability of the data of shales and carbonates.

4.2.5.3 In Situ Stress Measurement

Contemporary ground stresses at selected horizons will be measured through overcoring as described in Section 3.2.6. The in situ stress measurements will be used to verify the contemporary in situ stresses assumed in the long-term stability analysis of shafts (ITASCA 2011).

4.2.6 Sealing Material Tests

Test(s) to confirm the behavior of the shaft seal materials in the shale formations have yet to be determined. Possible options for testing include the following:

- Horizontal borehole installed during shaft sinking at either the Queenston Formation or the Georgian Bay Formation;
- Vertical borehole tests in large shale block samples removed from the Queenston or Blue Mountain Formation during shaft sinking. Testing would be performed in the Geoscience Room at the repository horizon; and/or
- Vertical borehole tests in similar shale rock formations at other surface sites (e.g., a quarry).

The tests would be designed to demonstrate that the materials form saturated low-permeable layers. The tests would also provide information on long-term chemical compatibility. The latter would be dependent on coring into the boreholes to acquire materials from the interfaces for laboratory analysis after several years or longer of exposure.

4.3 Lateral Development

4.3.1 Layout of Investigation Activities

This section describes geoscientific investigations that will be performed at the repository level during lateral development. The program would consist of multiple geological, hydrogeological, geomechanical, geochemical and geophysical activities, as described in the following sections. Geotechnical activities have already been described in Section 3 and will not be discussed in details here. The geochemical and microbiological characterization and the seal material performance testing will be conducted in the Geoscience Room.

4.3.2 Geological Characterization

4.3.2.1 Geological Mapping

Geologic mapping data will be collected as per procedures outlined in Section 3.2.2. In addition to data collected in Section 3.2.2, mapping will be carried out to provide data about geological composition of rock and compare with equivalent data collected in the DGR-series boreholes. Information on hydrogeology, such as the identification of hydraulically active features or zones, will be collected.

During mapping, suitable specimens of fracture infill materials will also be collected for further analysis and laboratory testing. Any petroliferous zones will be described, imaged and sampled for possible testing.

4.3.2.2 Geophysics

A seismic reflection survey will be carried out along all emplacement rooms for their entire length. The purpose of this work is, to characterize the configuration of the Precambrian surface below the DGR, and to identify any structural discontinuities present in the Precambrian basement.

This activity will be conducted as tunnel and room excavations are finished.

4.3.2.3 Seepage Water Collection

It is not anticipated that any groundwater seepage from bedding planes and joints will be encountered during lateral development at the repository level. However, in the unlikely event a quantity of seepage is encountered, the groundwater would be sampled for analysis and the inflow rate and groundwater chemistry were be monitored.

4.3.3 EDZ Characterization in Cobourg Formation

EDZ characterization will be conducted in two locations in the vicinity of the underground shaft stations. The characterization work will be performed using procedures similar to those described in Section 4.2.4.

4.3.4 Excavation Response

4.3.4.1 Excavation Deformation Measurement

This activity is described in Sections 3.3.3.1. Rock material parameters deduced from back-analyzing excavation deformation measurements will be used to verify rock properties input to the long-term geomechanical analysis (ITASCA 2011).

4.3.4.2 Geomechanical Testing

In addition to the geomechanical testing as described Section 3.3.3.2, the scope of the laboratory testing program will include geomechanical testing to collect data about the long-term strength and stiffness of the rock mass. Tests are needed to validate assumptions and current understanding about Cobourg limestone characteristics, such as strength and stiffness anisotropies and crack initiation stress threshold relevant to understanding long-term repository and formation barrier integrity. Testing of large diameter rock samples will validate these parameters and further constrain the variability of the data of the carbonate.

4.3.5 Geochemical and Microbiological Characterization

4.3.5.1 Fracture Infill Mineral Studies and Dating

Fractures with infill materials will be identified and mapped in the field as part of geological mapping activities (Section 4.3.2.1) during lateral development in Cobourg, Sherman Fall and Kirkfield formations. Suitable samples of infill materials, such as calcite, gypsum and anhydrite, will be collected to determine mineralogy, for fluid inclusion studies, cathodoluminescence imaging and age dating, if possible.

The studies will be completed during the repository development phase.

4.3.5.2 Multi-phase Flow Study

The hydrogeologic environment in the Cobourg Formation is one of apparent discontinuous partial pore saturation with extremely low porosity and hydraulic conductivity and, as such, presents a challenge to characterization. In situ tests in dedicated boreholes within the Cobourg Formation are proposed to verify existing laboratory results and to provide additional constraints on the understanding of the spatial distribution of partial pore fluid/gas/oil saturations. Several nominal 20 m long boreholes would be subjected to long-term hydraulic/gas injection testing with straddle packers. Conclusions on aspects of multi-phase flow and transport would be interpreted from the test results.

Depending on the results of the long-term hydraulic testing, additional petrophysical testing for multi-phase flow and transport parameters may be carried out and would include additional laboratory testing necessary to advance the understanding of gas migration and release within the Cobourg Formation during repository evolution.

The studies will be carried out in the Geoscience Room and be completed during repository development phase.

4.3.5.3 Long-term Diffusion Test

Long-term in situ diffusion testing to verify existing laboratory test results will be conducted in the Cobourg Formation. In situ diffusion tests have been carried out in vertical boreholes by NAGRA on the Opalinus Clay at Mont Terri in Switzerland and by ANDRA on the Callovo-Oxfordian mudstone at the Bure URL in France. The tracers in the solution are circulated within instrumented boreholes and their concentration is carefully monitored over a period of one to two years. The concentration will gradually decrease as radionuclides diffuse into the surrounding rock mass. Upon completion, the rock around the test section, where the tracers diffused, is overcored. The tracer concentration profiles in the overcored rock are then analyzed. The effective diffusion coefficients are determined for each tracer from the profiles by applying an appropriate model. The in situ diffusion tests would be started in 10 m long ‘N’ size boreholes followed by overcoring. These tests will be conducted within the Geoscience Room which is a secure test area in Cobourg Formation unaffected by DGR construction or operational activities.

This test will be carried out in the Geoscience Room and will be completed during repository development phase.

4.3.5.4 Microbiology Related Study

Microbiological studies will be undertaken to determine the extent and nature of bacterial populations, to identify and differentiate between indigenous species and migrant species recently introduced by human activity (i.e., drilling/excavation), and study the possible long-term effects of microorganisms on the repository. Near-field and far-field studies will identify and study the indigenous microbial ecosystem, which includes the availability of nutrients and energy for microbial use and their interaction with the site geological environment (particularly geochemistry and mineralogy).

The effects of the construction and operation periods (when oxygen would be freely available in the repository environment) and the introduction of low and intermediate level radioactive waste (a potential new source of nutrient and energy) on microbial populations and future repository performance will be measured. Measurements of the pore throat diameter of the Cobourg Formation indicate that it is < 0.2 μm, in which case it is unlikely there would be metabolic activity as a pore throat > 0.2 μm is required. Additional petrophysical studies would be carried out to confirm. All efforts must be made to obtain pristine samples.

These studies will be conducted within the Geoscience Room, which will be a secure test area unaffected by DGR construction or operational activities. They will be conducted in the Geoscience Room and will be completed during repository development.

4.3.6 DGR Sealing Material Performance Test

In situ testing of proposed DGR sealing materials will be conducted through vertical borehole-based tests within the Geoscience Room at the repository level. The in situ tests would include verification of saturation, low hydraulic conductivity, and long-term chemical compatibility with the saline pore fluid in Cobourg Formation.

The compatibility test may be similar to Mont Terri CI experiment as shown in Figure 4.3. The CI experiment is intended to investigate the long term interactions of cement-bentonite-Opalinus clay. The porewater pressure in the clay, concrete and bentonite are monitored to follow the degree of saturation. In the CI experiment, samples will be taken at a logarithmic time scale, e.g., 2, 4, 8, 16 years, to examine the interface between materials and between materials and host rock.

Similarly, at the DGR it is likely that more than one vertical borehole test would be installed with the intent of coring into these tests at various time intervals to test the evolution of the interface between materials. Due to the low permeability of the host rock, it is expected that full test completion would require monitoring into the repository operations phase.

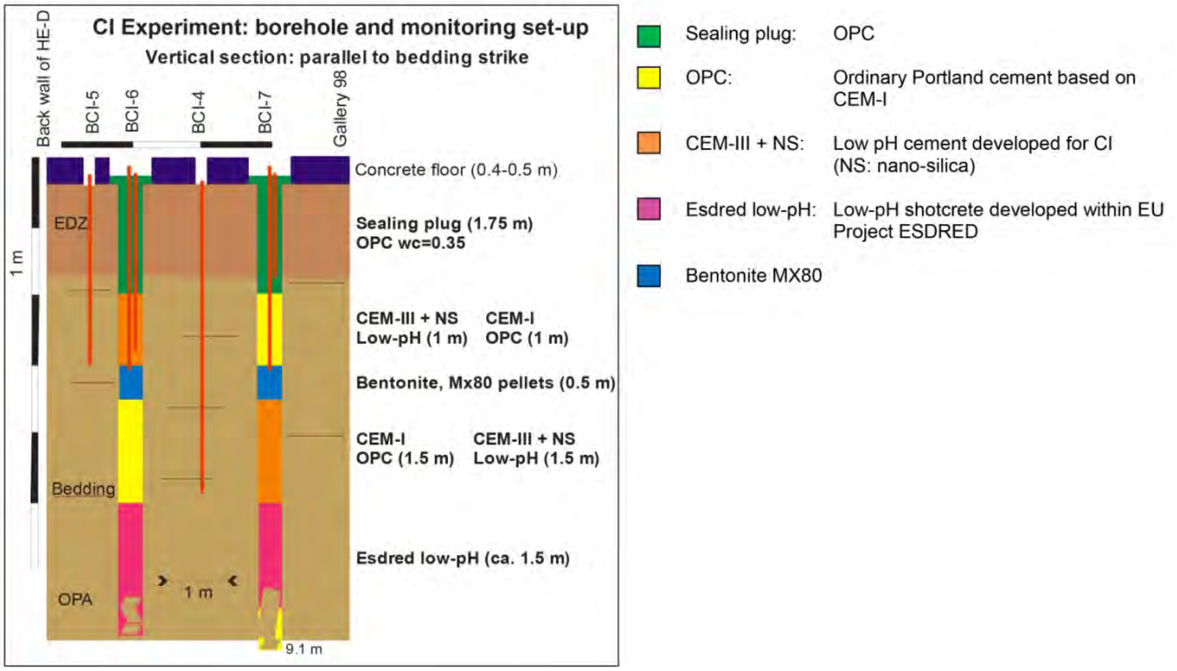


Figure 4.3: Mont Terri CI Experiment Concept and Layout in Opalinus Clay

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6. ABBREVIATIONS AND ACRONYMS

AE	Acoustic Emission
ANDRA	Agence Nationale pour la Gestion des Déchets Radioactifs (France)
ATV	Acoustic Televiewer
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CIRIA	Construction Industry Research and Information Association (U.K.)
CSIRO	Commonwealth Scientific and Research Organization (Australia)
CNSC	Canadian Nuclear Safety Commission
DGR	Deep Geologic Repository
EDZ	Excavation Damaged Zone
GSCP	Geoscientific Site Characterization Plan
HDZ	Highly Damaged Zone
LIDAR	Laser Imaging Detection and Ranging
L&ILW	Low and Intermediate Level Waste
mBGS	metres Below Ground Surface
MPBX	Multi-point Borehole Extensometer
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NWMO	Nuclear Waste Management Organization
OPG	Ontario Power Generation
OTV	Optical Televiewer
USBM	United States Bureau of Mines
SCP	Site Characterization Plan
URL	Underground Research Laboratory

ATTACHMENT A

TO

OPG RESPONSE TO IR-EIS-12-512

EIS-12-512: DGR Expansion Plans

This response to the Information Request presents the assessment of several components of the design, and the potential impact on the environment, of the potential expansion of the Deep Geologic Repository (DGR). The ability to support such a future expansion is identified as part of the project requirements (NWMO 2010) and is a consideration in all aspects of the design. As such, this information has not been formally documented in a stand-alone report. The information provided in this response shows that expansion could be achieved without major changes to the DGR facility infrastructure or safety case. Before the DGR facility is expanded to accept additional waste, further analysis would be completed in detail and the required regulatory approvals would be sought. Further, experience gained through the construction and operation of the proposed DGR would be incorporated into the expansion design and planning.

1. BACKGROUND

Ontario Power Generation (OPG) is currently seeking regulatory approval for site preparation and construction of a DGR with a capacity of approximately 200,000 m^3 (packaged volume) for low & intermediate level waste (L&ILW) arising from operations and refurbishment activities from OPG owned or operated reactors (see Figure 1) (OPG 2012). The activity that causes the waste to come into existence however is not an important consideration. Rather, it is the characteristics of that waste from a volume, material, and radionuclide perspective that is important. The 200,000 m^3 would provide sufficient capacity for disposal of the estimated L&ILW wastes to be generated through the operation and refurbishment of the OPG owned or operated reactors.

The DGR project has also assessed the feasibility of an expansion of the DGR from the current planned waste volume capacity of 200,000 m^3 to a capacity of 400,000 m^3. This additional capacity could account for the potential of future L&ILW waste volumes arising from either new operational and refurbishment activities or decommissioning activities.

This consideration of the expansion of the DGR also supported the requirement in the Environmental Impact Statement Guidelines to perform a cumulative effects assessment of including L&ILW arising from decommissioning. The following considerations respecting expansion of the DGR have been assessed at a conceptual level:

- Repository layout within the existing site constraints (assuming that the surface and underground footprint are not constrained within the lands currently designated as OPG retained lands at the Bruce nuclear site);
- Constructability of the expanded repository;
- Impacts to waste operations;
- Environmental impacts of expanded repository; and
- Safety implications of decommissioning waste inventory.

Section 2 describes the proposed design impacts (to both underground and surface facilities) and operational impacts of expanding the repository. Section 3 describes additional considerations specific to L&ILW arising from decommissioning activities, and Section 4 discusses timing of the potential expansion.

2. REPOSITORY EXPANSION

A general layout of the expanded underground repository has been prepared to assess the feasibility of this planning assumption. For this layout, the DGR was conservatively assumed to be expanded to double in size (i.e., 400,000 m^3 packaged waste volume). Figure 2 shows the expansion layout and Figure 3 shows the proposed and expanded repository footprint on the Bruce nuclear site. The underground layout and required number of emplacement rooms would be updated when the volume of additional waste is better defined. The expansion assumes that the emplaced waste is isolated by closure walls prior to initiation of expansion (i.e., no waste emplacement during construction activities).

The expanded layout retains the general features of the original layout. It is designed to accommodate Panels 1 and 2 having been filled and isolated by closure plugs. It maintains the following post-closure safety relevant features: no additional shafts, same geologic formation for the repository openings with a shale cap rock, maintaining the same minimum distance from Lake Huron, and the same geomechanically stable room positioning (i.e., parallel with the assumed principle horizontal stress direction).

The following provides additional information on impacts to specific aspects of the design and repository operations resulting from an expanded facility.

2.1 IMPACT TO UNDERGROUND FEATURES FOR EXPANSION

Expansion of Underground Repository

It is currently assumed that an additional 32 rooms would be excavated in two panels to provide the additional volume. The rooms in the two expansion panels would be similar in size and arrangement to rooms in Panels 1 and 2.

The host Cobourg Formation is present beneath the entire Bruce nuclear site and thus could accommodate this expansion. This would be confirmed by drilling additional deep boreholes (minimum of 3 additional boreholes) outside the footprint of the expanded repository.

Underground Services Area

The existing Maintenance Shop, Service Garage, Diesel Fuel Bay, Cap Magazine and Explosives Storage facilities would be re-established to service underground mining equipment and to support mining activities in the same manner as they would have been used during the initial construction.

The underground Refuge Station and Lunchroom would be equipped as required for the construction force. The permanent compressed air system providing emergency air for breathing inside refuge stations during operations would remain in service for repository expansion. The two portable refuge stations used in Panels 1 and 2 during operations would also be available for use during the expansion.

Lowering of Mining Equipment

Mining equipment that would be required to construct the rooms and tunnels in the expansion area would be disassembled, as required, to allow equipment to be lowered to the repository level inside the Main Shaft cage. Some mining equipment may also be lowered to the repository level using the Ventilation Shaft hoisting system. Once underground, the equipment would be reassembled either in the Main Shaft station or in the Maintenance Shop.

Underground Ventilation System

The underground ventilation system installed for the initial construction would remain for use during DGR operations. However, due to lower airflow requirements in operations, the system will operate at a reduced capacity. Once repository expansion commences, the system would be reprogrammed to operate at the higher capacity required for construction.

The equipment and general approach to mining during repository expansion is assumed to be similar to that used during initial construction of the underground repository. Therefore, airflow requirements are expected to be similar and major ventilation equipment allocations at the time of initial construction would be suitable for use during repository expansion. This would also include auxiliary booster fan and temporary ducting arrangements to provide ventilation to construction areas.

During repository expansion and depending on the timing of the expansion, the first five rooms in Panel 1 would likely be empty and not isolated by closure walls. The ventilation through these rooms could be stopped by closing the louvers at the backend of each room. However, if one or more of these rooms are required for storage or laydown of materials and equipment needed for the expansion, the ventilation could be maintained in these rooms and has been accounted for in the required air volumes.

To establish flow-through ventilation in the expansion panels, a return air tunnel system would need to be constructed that bypasses the now-isolated Panels 1 and 2 (see Figure 2). These panels would be isolated by closure walls at locations shown on Figure 2. As each section of the repository expansion is completed and connected to the permanent return air tunnel system, the aforementioned temporary ventilation would be removed.

Underground Waste Rock Handling System

The underground waste rock handling system is located at the Ventilation Shaft. At the end of initial DGR construction, the equipment for the underground waste rock handling system at the loading pocket would be removed. However, major structures at the Ventilation Shaft would remain, including the underground rock structure (waste rock raise) to the loading pocket, concrete-lined 5-m-diameter shaft, headframe and hoist house. The hoist at the ventilation shaft used during construction for skipping waste rock to surface, along with all headframe and shaft equipment for these activities, is removed following construction to avoid the need for extended maintenance.

Prior to the start of underground expansion work, the waste rock handling system would be re-established. Specifically the following equipment would either be re-installed or refurbished at the Ventilation Shaft:

- Double-drum hoisting system in hoist house;
- Surface waste rock handling system in Ventilation Shaft headframe;
- Rock skip in Ventilation Shaft;
- Underground loading pocket system; and
- Rock dump including rock grizzly and hydraulic rock breaker.

2.2 IMPACT TO SURFACE FEATURES FOR EXPANSION

Expansion of Waste Rock Management Area

The waste rock from the expansion of the underground repository could be accommodated on the DGR site through expansion of the Waste Rock Management Area (WRMA). This expansion of the waste rock pile would increase height by about 20 m to a total height of 35 m and the footprint area would increase by approximately 2 ha from the current proposed area (i.e., increase from 9 ha to 11 ha - see Figure 4).

Stormwater Management Pond

The Stormwater Management Pond (SWMP), as designed and accepted for initial construction, would be sufficient to handle the run-off and underground water discharge that would occur during the construction of the expanded repository. The quality and quantity of surface water run-off from the DGR site during expansion would not change significantly relative to run-off expected during initial construction. Similarly, it is likely that the quality and quantity of process water used and pumped to surface during repository expansion would be similar to initial construction. Should there be a need to increase the holding capacity of the SWMP, there is sufficient space adjacent to the proposed SWMP to the south-west to extend the pond. Any water treatment processes that may be deemed necessary during the initial construction phase would be installed and commissioned prior to the start of the repository expansion work.

Surface Facilities and Services

At the time of repository expansion, the Waste Package Receiving Building would be decontaminated, as necessary, and used as a staging area for underground mining activities. Similarly, the Ventilation Shaft and hoist house would be turned over and used for expansion activities (see above). Areas for Contractor trailers for temporary office space, change rooms, and equipment trailers would be located in areas marked in green on Figure 4.

The following describes the anticipated impact of repository expansion construction work on various services:

- Electrical – no impact. The size of the electrical distribution system is based on the initial construction needs. There is no predicted change to these needs during the expansion of the underground facility as they are very similar to those of the initial construction needs.

- Service water – minor impact. The service or process water demand during expansion is expected to be the same as the demand during initial construction. The service water supply system installed at surface during initial construction would still be in-place at the time of expansion. However, large-diameter service water piping would be reinstalled in the Main Shaft and Ventilation Shaft to bring water to the repository level for mining activities. At the end of the initial construction, large-diameter service water piping would be removed and replaced with smaller-diameter piping that is sized for operational needs.

- Compressed air – no impact. Compressors would be brought to the site to meet the compressed air requirements for the construction equipment. Temporary air lines for the distribution of the compressed air would be installed, as required. The permanent compressed air system that services the refuge station would remain operational.
- Underground dewatering – minor impact. Pumps used for operations dewatering would be removed and a similar dewatering system as used during initial construction would be installed. Temporary sumps would be installed, as required, in the repository expansion area to bring the construction water to the main sump. At the end of repository expansion, pumps used for operations dewatering would be reinstalled.

Commissioning of Expanded DGR Facility

Prior to turn-over to operations staff, all systems would be commissioned by following same or similar procedures used following completion of initial construction.

Environmental Emissions during Construction

Emissions to the surface environment resulting from the construction of the expanded repository would be similar to those that will occur during initial construction. Dust and noise emissions would arise due to handling, transfer and placement of waste rock in the Waste Rock Management Area. Surface water run-off from the waste rock pile would be directed to the Stormwater Management Pond. Monitoring and mitigation options that are planned for initial construction would also be implemented during repository expansion.

2.3 IMPACT TO DGR OPERATIONS FOR EXPANSION

Temporary Stoppage of DGR Waste Package Receipt and Emplacement

At the time of underground expansion, waste-filled rooms in Panels 1 and 2 would be fully isolated by concrete closure walls in the access tunnels. This ensures that there is no contaminated airflow for the construction period as the shafts would be turned-over for construction use. Contamination checks would be performed and, if necessary, areas would be decontaminated prior to allowing construction workers to work and travel through previously zoned areas.

Before the start of expansion construction activities, the emplacement of operational L&ILW in the underground repository would cease. At the time of expansion, most of the L&ILW stored above ground at Western Waste Management Facility (WWMF) would have been transferred into the DGR. During the expansion, operational L&ILW would continue to be delivered to WWMF from operating nuclear generating stations and, after processing, would be stored as usual in a Low-Level Storage Building(s) (LLSB) or in-ground structures. Once DGR expansion has been completed and the DGR facility is again operational, these wastes would then be retrieved from temporary storage and transferred to the DGR.

Operational Changes

The expanded DGR facility would be operated using the same procedures as will be used during operation of DGR with Panels 1 and 2 only. It is expected that waste packages would be similar in design to the waste packages that would be placed in Panels 1 and 2. Therefore the same or similar equipment would be used to handle and stack the waste packages.

Environmental Emissions

Air emissions due to operation of the expanded DGR facility would be similar to emissions during DGR operations with Panels 1 and 2 only. Air emissions are expected to be similar because: a) most of the rooms in Panels 1 and 2 would be isolated by closure walls and thus the majority of underground ventilation air would be passing through rooms in the two expansion panels; b) the characteristics of the wastes are expected to be sufficiently similar to currently proposed wastes such that radionuclide releases from packages to ventilation air would be similar; and c) the sequence of waste emplacement operations would be similar to the sequence used during initial operations; i.e. small number of active emplacement rooms, minimal ventilation through waste-filled rooms and periodic isolation of a series of waste-filled rooms with closure walls.

The quantity and quality of water that would be discharged from the Stormwater Management Pond during operation of the expanded DGR facility is expected to be same as quantity and quality of water discharged during initial operations.

3. CONSIDERATIONS FOR WASTE ARISING FROM DECOMMISSIONING

OPG is planning to place L&ILW arising from decommissioning in the DGR. However, as decommissioning is not expected to occur for several decades, the detailed waste volumes and characteristics are not currently available since the full characterization cannot occur until reactor shutdown and will also depend on decommissioning methods available at that time. Therefore, OPG is not presently seeking a licence to accommodate additional L&ILW from decommissioning activities. A decision on whether to formally seek a licence, and the supporting analyses, would only occur decades in the future as discussed below.

L&ILW Waste Volume

Initial assessments from decommissioning cost estimates indicate that the volume of L&ILW generated by decommissioning of the stations will correspond to a volume of approximately 135,000 m^3 packaged volume (OPG 2011a, Section 3.1). It is presently estimated that the wastes will be approximately 10-20% ILW by package volume (comparable to the 20% ILW volume in L&ILW from operations and refurbishment), although the exact ratio will vary depending on the waste treatment and volume reduction options available at the time of decommissioning.

Although the present estimate of decommissioning waste volume is 135,000 m^3 (as packaged) compared with the current reference volume of 200,000 m^3, a doubled repository size was considered for conceptual design purposes. The specific repository volume would be adjusted for the amount and nature of wastes arising from decommissioning.

L&ILW Characteristics

The waste types arising from decommissioning activities are fundamentally the same as those arising from operations and refurbishment activities, but the amounts of the various wastes will be different.

Low Level Waste (LLW) arising from decommissioning will include the same lightly contaminated tools, cleaning materials and other supplies as with operations. It will also include large amounts of materials from the dismantlement of the facility systems, structures and buildings, such as mechanical, electrical and instrumentation materials as well as concrete and structural steel. These materials are also present in LLW arising from operations, but at lower volumes.

The Intermediate Level Waste (ILW) waste arising from decommissioning will include components from dismantling of reactor systems and immediate structures, similar to irradiated core components and retube wastes currently received. The ILW is not expected to include significant amounts of ion exchange resins, as these would have been removed at station shutdown. The ILW from decommissioning contains a similar high proportion of metal as with ILW from refurbishment. Additionally, it will have higher activity steel from the core internals.

A full characterization of decommissioning waste will depend upon the stations operating history, life of the reactors and length of radiological decay prior to decommissioning. The total radionuclide inventory for all the Pickering stations is presently estimated to be about 53,000 TBq at 30 years following shutdown. The inventory for all reactor units is estimated to be 390,000 TBq at 30 years following shutdown. The inventory of decommissioning waste with time is shown in Figure 5.

Similar to the wastes from operations and refurbishment, almost all the radioactivity resides in the ILW component from decommissioning. The radioactivity inventory is larger due mostly to the presence of Ni-63, which is a component of activated stainless steel associated with the reactor core. The total amounts of Ni-59, Ni-63, Fe-55, Co-60, Cl-36 and Ca-41 are expected to be higher in wastes from decommissioning than in operational and refurbishment wastes. Ni-59 (101,000 year half-life), Ni-63 (100 year half -life), Fe-55 (2.7 year half-life) and Co-60 (5.3 year half-life) are primarily activation products in metal. Cl-36 (301,000 year half-life) and Ca-41 (102,000 year half-life) are primarily activation products in concrete.

Implications of Expansion on DGR Safety

The aspects which most affect safety related to waste arising from decommissioning are:

- Higher radionuclide inventory, and
- Larger amount of concrete and metal.

The characteristics of waste arising from decommissioning and the potential implications of including wastes arising from decommissioning in an expanded DGR on both operational safety and long-term safety are discussed below.

Operational Safety Implications

Waste arising from decommissioning is assumed to be emplaced at the start of the post-expansion operational phase (mid 2040's) with Pickering waste arising from decommissioning first (see Figure 2). Initially, the wastes arising from decommissioning could be emplaced in the remaining rooms of Panel 1 along with wastes from ongoing operations and refurbishment. As per the current design, the other rooms in Panels 1 and 2 would have been isolated with closure walls with no radionuclide release to the environment.

For L&ILW arising from operations and refurbishment, the most important radionuclides for operational safety are H-3 and C-14 for inhalation exposure and Co-60 and Cs-137 for external irradiation (OPG 2011b, Chapter 7). Due to the nature of the waste, the total H-3 inventory in the decommissioning wastes in ventilated rooms is expected to be less than the H-3 inventory in ventilated rooms in the reference design with operational and refurbishment wastes. Similarly, the total C-14 inventory in the decommissioning wastes in ventilated rooms is also expected to be less than the C-14 inventory in the current assessment. Therefore, the impact of wastes arising from decommissioning would result in similar or less inhalation dose than in waste arising from operations and refurbishment.

The Co-60 inventory in wastes arising from decommissioning, primarily associated with activation products in steel from the core internals, is expected to be higher than in the waste arising from operations and refurbishment. This would require a detailed waste characterization following station shutdown and detailed assessment of dose rates. Mitigating measures such as shielding or greater stand-off distance would be considered as part of the ALARA assessment during detailed design of the expansion case, and drawing on the experience gained during the operation of the DGR with wastes arising from operations and refurbishment. These measures would ensure that doses remain within OPG dose targets.

Long-Term Safety Implication

For L&ILW from operations and refurbishment, the most important radionuclides in terms of the higher dose scenarios for long-term safety are C-14 and Nb-94. Since the wastes arising from decommissioning are expected to have roughly similar amounts of these radionuclides to that in the current licence application for wastes arising from operations and refurbishment, the impact of adding waste arising from decommissioning to the DGR would result in a calculated postclosure peak dose that is approximately double the dose calculated for waste arising from operational and refurbishment only. The increase in other radionuclides, notably Ni-59 and Ni-63, has limited effect since these are sufficiently small dose contributors for L&ILW from operations and refurbishment that their dose contribution remains relatively small even considering their larger inventory in L&ILW from decommissioning. For the Normal Evolution Scenario, the dose remains many orders of magnitude below the dose criterion of 0.3 mSv per year. For the Disruptive Scenarios, the impact remains within the risk criterion of 10^{-5} per year.

This is based on a very preliminary assessment. A request for permission to expand the DGR would be supported by detailed waste characterization following station shutdown and confirmed through a full safety assessment of an expanded DGR to accommodate L&ILW from decommissioning.

The gas generation potential in L&ILW from decommissioning could be larger than that from L&ILW from operations and refurbishment due to higher metal content. This would have to be taken into account in the repository design and safety assessment supporting the safety case for the inclusion of low and intermediate level waste from decommissioning. Since much of the metals and organics reside in the LLW from decommissioning, they may be reduced through future volume reduction, and/or decontamination and recycling technologies. Increased space may also be required to accommodate gas generation from L&ILW from decommissioning.

4. TIMING

The DGR is anticipated to start operation in the 2020's. It would operate for about 40 years, with the first waste panel filled in approximately 10-15 years and then isolated by closure walls. The next half-panel would be filled and closed off in another 10-15 years based on receipt of L&ILW from operations and refurbishment.

The first station to be decommissioned will be Pickering A. This is scheduled to shutdown in the 2020's. The earliest time at which decommissioning will start is the 2040's. The schedule for shipment of wastes from decommissioning to the DGR (assuming a license has been obtained) would be selected to allow isolation of a panel before repository expansion would begin. It is possible that some L&ILW from decommissioning would be placed in Panel 1 to allow either the full panel or the half-panel to be filled and closed.

At that time in the 2040's or 2050's, the further emplacement of wastes into the DGR would be suspended. The construction and commissioning of the expanded DGR would proceed over a 4-5 year period. Following completion of the expansion, the repository would then resume operation.

5. CONCLUSIONS

This response to the Information Request presents preliminary design and environmental considerations for the potential expansion of the Deep Geologic Repository (DGR). The information shows that expansion of the DGR to accommodate L&ILW arising from decommissioning activities could be achieved without major changes to DGR facility infrastructure or safety case.

The potential need to expand the DGR to accommodate waste arising from decommissioning does not arise until approximately the 2040's. Before the DGR facility is expanded to accept additional waste, further analyses would be completed in detail. This would include waste characterization, safety assessment and environmental assessment. It would also require a full regulatory approval of the expansion.

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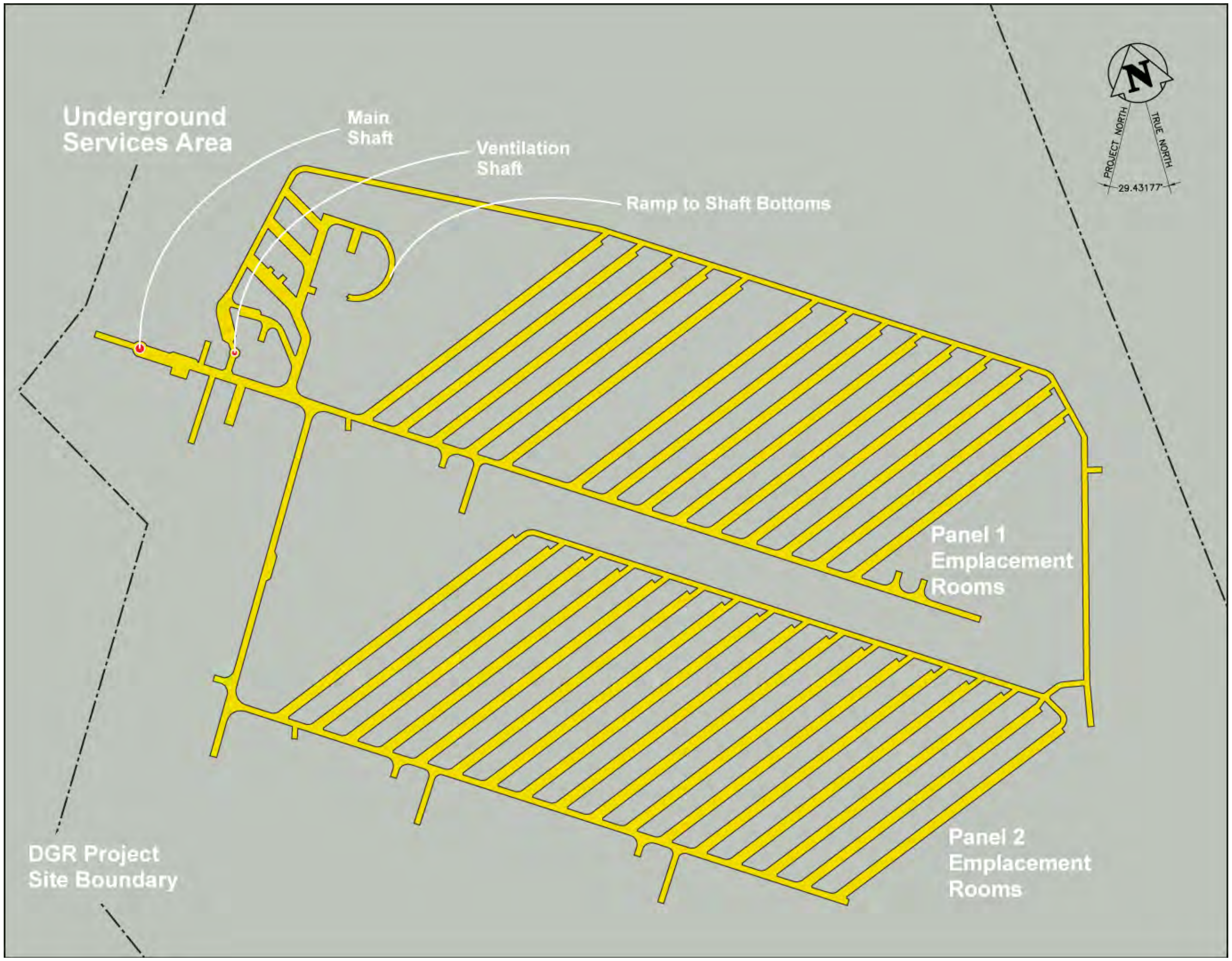


Figure 1: OPG’s Deep Geologic Repository for L&ILW – OPG’s Proposed Layout for Operational and Refurbishment Waste

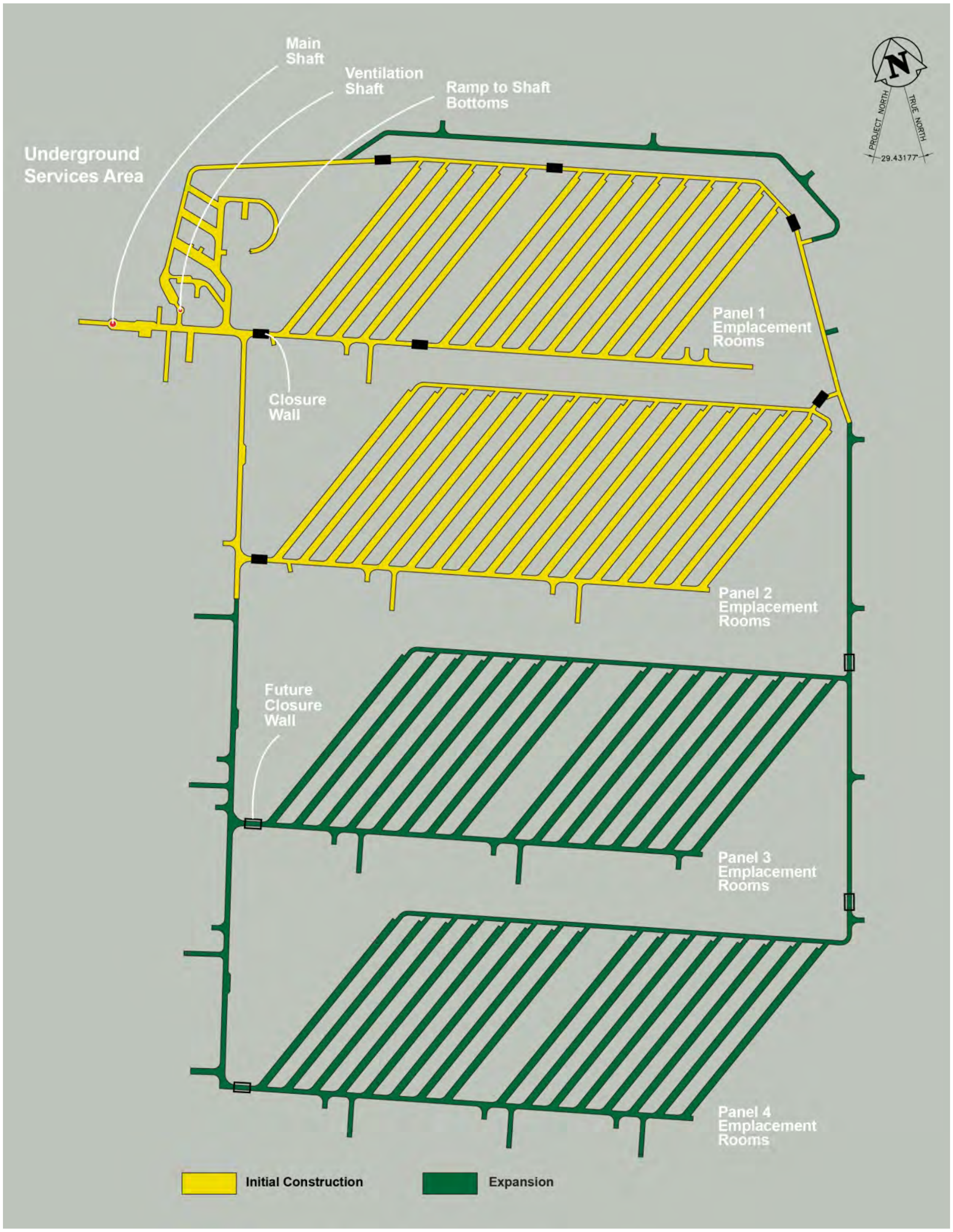


Figure 2: OPG's Deep Geologic Repository for L&ILW – Conceptual Expansion Layout

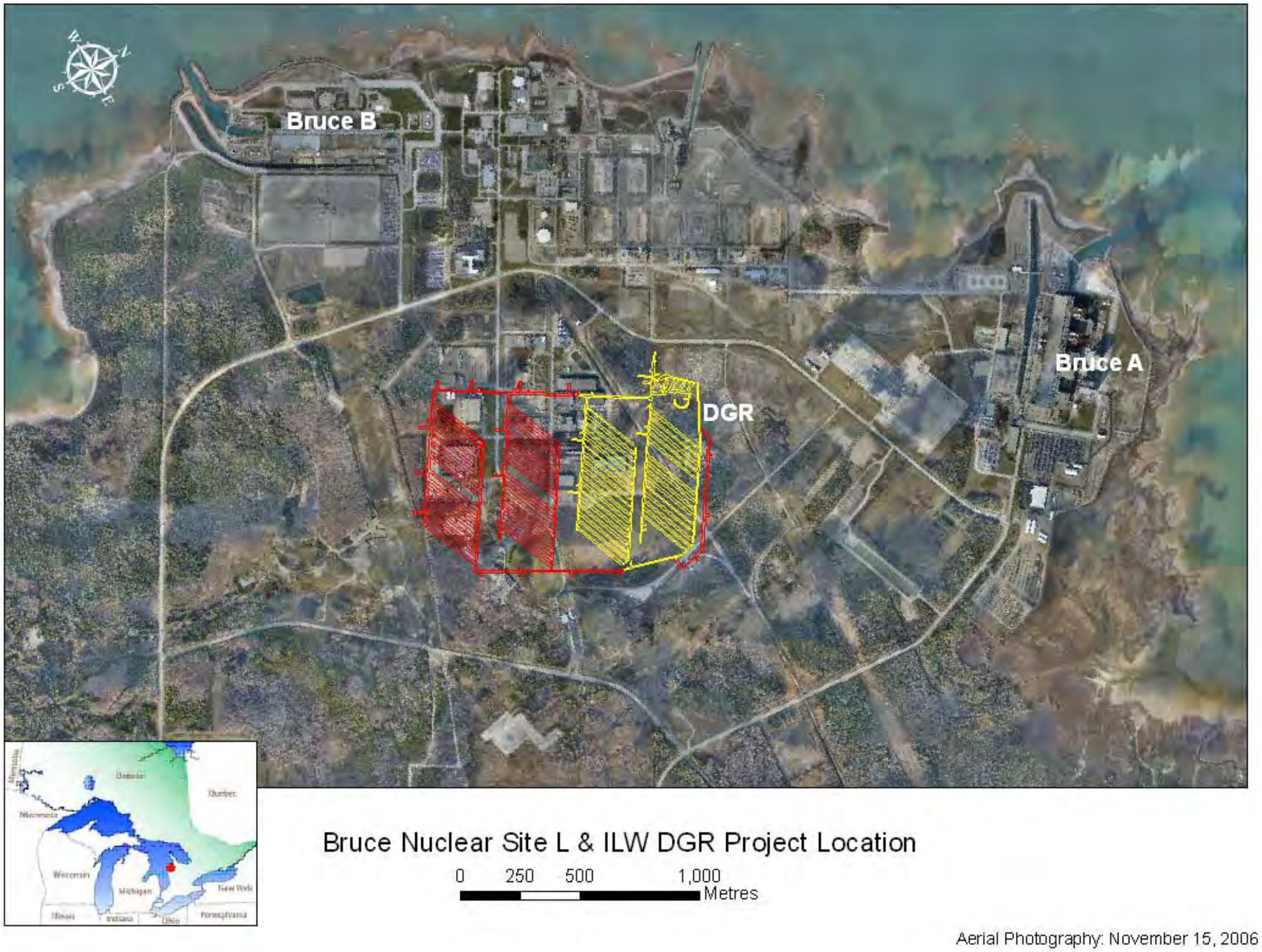


Figure 3: OPG's Deep Geologic Repository for L&ILW – Relative Positioning of the Expansion Layout on the Bruce Nuclear Site

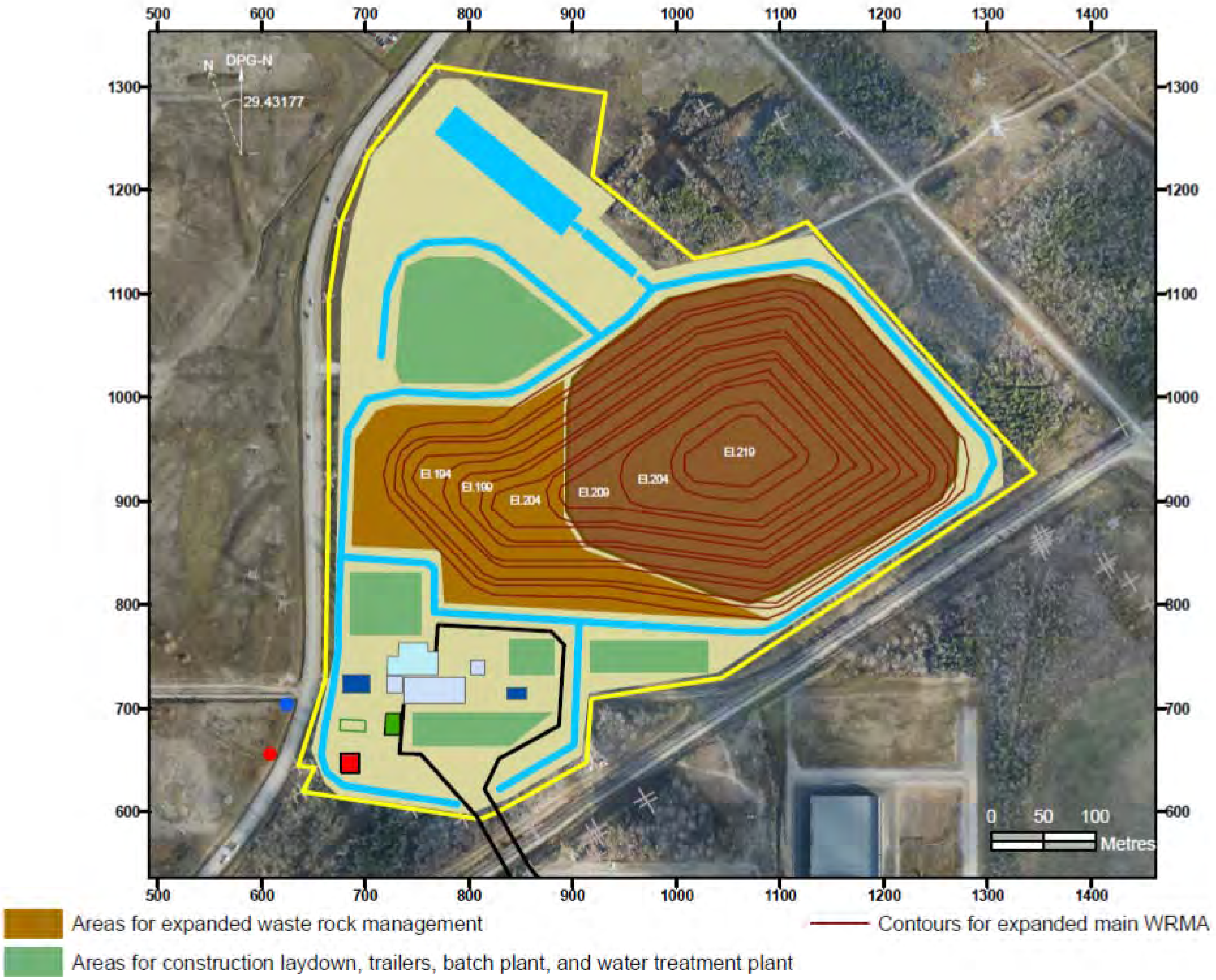
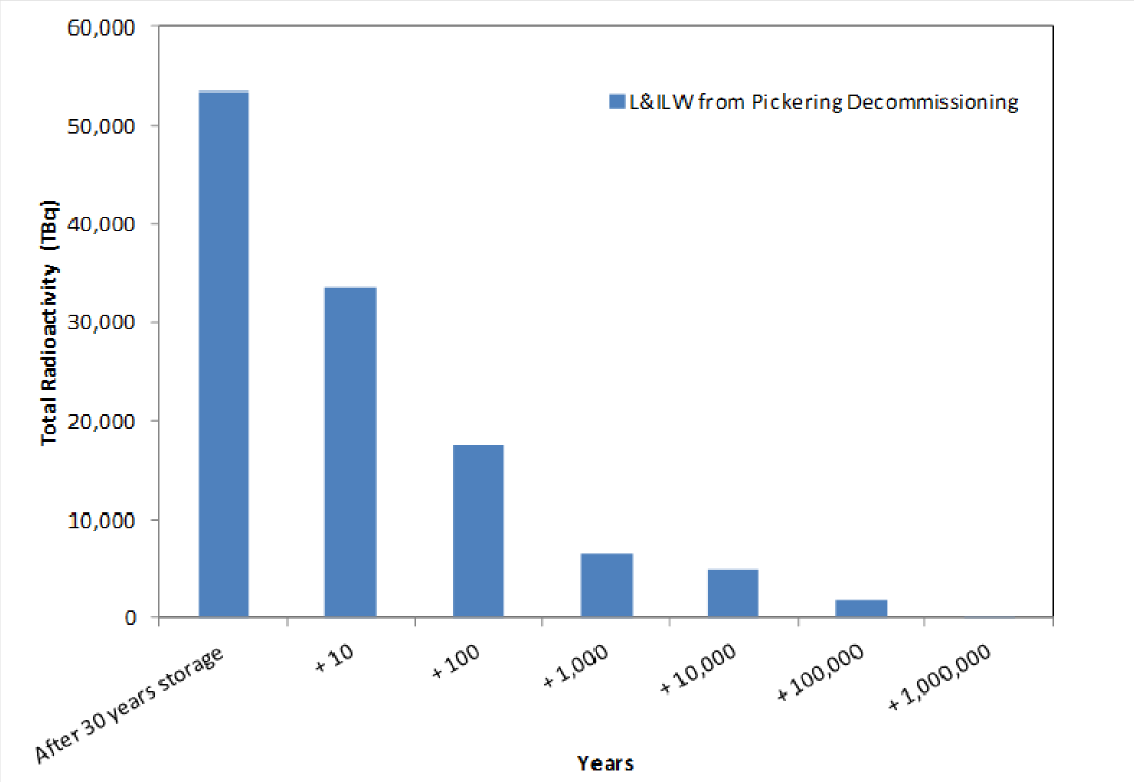


Figure 4: OPG's Deep Geologic Repository for L&ILW – Expansion Surface Layout



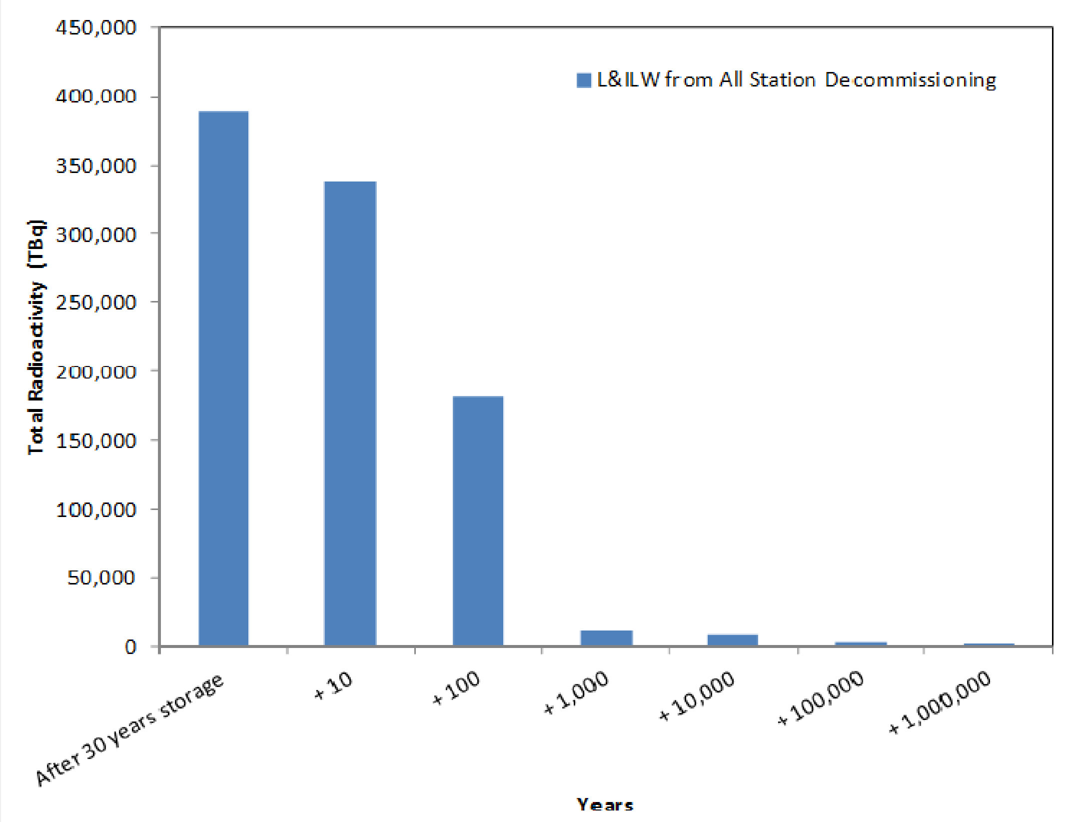


Figure 5: Total Projected Radionuclide Inventory of L&ILW from Decommissioning (top: Pickering stations; bottom: all the stations)

ENCLOSURES

TO

OPG RESPONSE TO IR-EIS-12-513

University of Ottawa
R. Samuel McLaughlin Centre for Population Health Risk Assessment
1 Stewart Street, Ottawa, ON K1N 6N5

28 March 2014

Ms. Laurie Swami
Vice-President, Nuclear Services
Ontario Power Generation
889 Brock Road
Pickering, ON L1W 3J2

Dear Ms. Swami:

On behalf of my colleagues in the Independent Expert Group – Maurice Dusseault, Tom Isaacs, and Greg Paoli – I am pleased to transmit herewith our "Report of the Independent Expert Group on Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low- and Intermediate Level Radioactive Waste in Ontario."

I would be pleased to respond to any questions that you have; to reach me by phone: 613-297-4300.

Sincerely,

William Leiss, O.C., Ph.D., FRSC
Professor emeritus, School of Policy Studies, Queen's University
Scientist, McLaughlin Centre for Risk Assessment, University of Ottawa
wleiss@uottawa.ca

Report of the Independent Expert Group on Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario

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SUBMITTED BY:

MAURICE DUSSEAULT, TOM ISAACS, WILLIAM LEISS (CHAIR), GREG PAOLI

SUBMITTED TO:

THE JOINT REVIEW PANEL FOR THE DEEP GEOLOGIC REPOSITORY PROJECT
FOR LOW AND INTERMEDIATE LEVEL
RADIOACTIVE WASTE (DGR)

March 25, 2014

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Introduction

This report contains four sections and a set of appendices, as follows:

Section 1: An Approach to the Task of Qualitative Risk Comparison

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Section 3: Qualitative Risk Comparison of Four Options

Section 4: Results and Observations for the Qualitative Risk Comparison

Appendices:
I. Thematic Requests to the Expert Group from JRP and OPG
II. Concordance Table: JRP Requests and IEG Risk Pathways
III. Contributions to Sustainability and the Precautionary Approach
IV. Letter to OPG on the Matter of "Community Acceptance"
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VII. Short List of Technical Sources

1 An Approach to the Task of Qualitative Risk Comparison

This report deals with the task of comparing a set of alternative management options (or alternative means) in a specific area, namely, the safe management of low- and intermediate-level radioactive waste (hereafter abbreviated as L&ILW) in Ontario. Further, the directives for this task indicate that it should be addressed in terms of the concept known as relative risk. The first step in this type of task is to develop a robust method for carrying out the comparison exercise.

Development of a method must begin with the selection of a set of criteria or parameters in terms of which the alternative management options may be arrayed against each other. These criteria are usually elaborated according to judgments as to how well any group of alternative options will perform against a set of underlying objectives, for example, environmental protection.[1] Next, comparison requires the specification of a scale of relative performance, either quantitative or qualitative. A quantitative scale uses a range of numbers, such as 0 - 100, to differentiate performance against objectives; a qualitative scale, on the other hand, expresses the same type of judgment along a scale of relatively better and worse. In either case the judgments may be made by a group of experts who have technical knowledge in specific areas (such as geosciences), or professionals with general expertise in the area of risk assessment, or others such as policymakers or members of the public.

Whatever the method that is chosen, it should be capable of being explained and applied in such a way that others, who were not involved in the original exercise, can understand the reasons behind the judgments that were made and also repeat some form of the exercise for themselves. In other words, the method should have the virtues of being *transparent, defensible, and repeatable.* These three virtues also encompass the requirement that the judgements that are made should be *evidence-based*, that is, arrived at with reference to a body of knowledge that is widely known and generally accepted as being reliable at the time when the decision exercise was carried out. The requirements for transparency and repeatability, on the other hand, reflect the legitimate expectation that judgments in such matters as these will have an element of subjectivity to them, and thus that another group of reasonable persons may very well come to different conclusions based on deliberations involving the same body of evidence.

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[1] Ideally, the set of criteria will not exclude any objectives that are regarded as being critically important to the overall performance of any management option, as judged by technical experts, policymakers, and the public. In addition, the various criteria should be independent of each other (that is, not overlap to any significant degree).

As noted above, the assigned task for this report also included a requirement to undertake a relative risk comparison among four specific management options. Risk is the product of two dimensions, *probability* (or likelihood) and *consequences* (or outcomes). Undertaking a risk comparison requires us to consider both dimensions simultaneously. For example, the group of risks known as “high-probability, low-consequence” includes something like seasonal influenza: We expect it to occur each year without fail, but we also believe that we do not need to make extraordinary efforts to control the outcomes beyond the risk control measures already in place (such as vaccination). At the opposite end of the spectrum, there are “low-probability, high-consequence” risks, such as terrorism attacks: Experience to date indicates that, for a country such as Canada, such events will be rare (in part because of the precautionary measures we have implemented), but if they did indeed occur, they could be expected to have quite significant consequences – in part because our reactions to them include severe psychological shocks.

* * *

Section 2 of this report provides the understanding – on the part of the Independent Expert Group (IEG) – of the four management options (or alternative means) for the safe management of low- and intermediate-level radioactive waste. It is based on the following sources: a background study carried out by OPG, which is included in its entirety in Appendix V; technical knowledge contributed by members of the IEG; Internet searches; and on a review of a number of specific documents (see Appendix VII for a list).

Section 3 of this report explains a method of risk comparison which was designed specifically for this present task. It uses a matrix diagram in which relative probability is shown along one axis and relative consequences along the other. For each of the decision criteria or risk pathways, the four management options or alternative means are shown at a specific location on the matrix diagram. Their placement indicates the judgments made about the expected performance of each option, relative to the others, for each criterion. There are two different formats for each matrix diagram: The larger diagram format indicates relative likelihood and consequences using the “Status Quo” Option – the existing WWMF operation at the Bruce nuclear site – as the “base case” for the comparison exercise. (For this purpose, the Status Quo Option is placed at the centre of the diagram.) The smaller, inset diagram format places all four options in relation to each other on the two dimensions of likelihood and consequences.

Section 4 of this report contains observations and discussion on the implications of the risk comparison exercise.

2 Narrative Description of the Four Alternative Means

2.1 Introduction.

In the following discussion all four alternative waste management options are assumed to be operating indefinitely and to be holding 200,000 m^3 of L&ILW. Of the total, 80% by volume is low level waste (LLW) and 20% is intermediate level waste (ILW). The "inventory characteristics" of radioactive waste are assumed to be as shown in Figure 1.1 of Appendix V ("OPG: Description of Alternative Options"). For the LLW, the radioactivity will have decayed in 300 years; the ILW, however, contains longer-lived radionuclides and therefore "the options need to provide isolation and containment for a timeframe of at least 100,000 years" (App. V, Section 1).

2.2 Two Surface Storage Options.

Conceptually, any surface disposal option assumes that (a) a robust societal structure exists indefinitely into the future, (b) an appropriate level of technical control can be maintained indefinitely to manage the surface requirements, and (c) the level of technical control in the future remains capable of coping with the expected events and changes that may take place. For all of the time spent in surface storage, the LLW and ILW will be retrievable and moveable, if required by events or technological changes.

2.2.1 The WWMF "Status Quo" Option.

Here we provide a brief account of the existing Western Waste Management Facility at the Bruce nuclear site, with the assumption that it continues indefinitely as it is currently operating. (See Appendix V, Section 2 and Section 3, for a more complete description.) WWMF was established in 1974 and at present contains about 95,000 m^3 of L&ILW, almost half of all the expected wastes of this type that are planned to be held there under this option. The facility as a whole consists of:

- A LLW incinerator and low-force compactor;
- 14 LLW storage buildings (LLSBs);
- In-ground structures for LLW (trenches) and ILW (tile holes, ICs);
- Above-ground structures for ILW (quadricells);
- Steam Generator Storage Building (SGSB);
- Retube Component Storage Building (RCSB);
- Service Buildings.

The LLSBs and SGSB are constructed of pre-fabricated, pre-stressed concrete and have a geomembrane beneath the structure. ILW materials stored above-ground are all in shielded spaces or containers to prevent radiation leakage. In-ground, covered trenches for LLW are made of reinforced concrete and waterproofed. In-ground structures for ILW consist of steel containers emplaced in concrete structures and separated by till and steel barriers. All facilities are monitored for radiation leakage. Buildings and containers have a 50-year design life, at the end of which they must be replaced. At the end of 300 years LLW could be moved to landfill; ILW, on the other hand, would have to be stored indefinitely (>100,000 years).

2.2.2 An Enhanced and Hardened Surface Storage Option.

We are not aware of any definitive characterization of either an "enhanced" or "hardened" set of at-surface facilities that would be utilized for the *storage* (as opposed to *disposal*) of low- and intermediate-level radioactive waste. ["Definitive characterization" is used here to mean facilities that are well-described in published technical bulletins and widely-recognized by interested parties in discussions of radioactive waste management.] In the following paragraphs we describe our understanding of the distinctions among the types of facilities that are relevant to our consideration of this Option.

(a) Storage vs. Disposal for Surface Facilities Handling Low- and Intermediate-Level Waste.

The WWMF operation at the Bruce site is not, as indicated in the discussion of the "Status Quo Option," intended to be a permanent disposal facility. It is in this respect similar to the existing COVRA facility (http://www.wmsym.org/archives/2002/Proceedings/26/28.pdf) in the Netherlands (App. V, Figure 4.1). Facilities designed for interim at-surface storage of L&ILW are constructed and maintained with a view to transferring the waste to some other more permanent facility at some time in the future.

On the other hand, there are certain types of at-surface sites for such waste which are designed specifically for permanent disposal: "Near-surface disposal facilities at ground level: These facilities are on or below the surface where the protective covering is of the order of a few metres thick. Waste containers are placed in constructed vaults and when full the vaults are backfilled. Eventually they will be covered and capped with an impermeable membrane and topsoil. These facilities may incorporate some form of drainage and possibly a gas venting system" [NEA[2]]. The sites themselves have been chosen in part on the basis of hydrogeological and geochemical features that also act as an additional barrier against leaching into the environment.

Examples of such facilities currently in operation are the ones at Centre de l'Aube in France and El Cabril in Spain.[3] However, these facilities only accept LLW and certain types of ILW,

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[2] http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Appendices/Radioactive-Waste-Management-Appendix-2--Storage-and-Disposal-Options/

[3] France, ANDRA in Aube facility:
http://www.andra.fr/download/andra-international-en/document/editions/379fva.pdf
http://www-pub.iaea.org/MTCD/publications/PDF/csp_006c/PDF-Files/paper-27.pdf
Spain, El Cabril Facility:
http://www.enresa.es/activities_and_projects/low_and_intermediate_wastes
http://www.csn.es/index.php/es/fuel-cycle-facilities/el-cabril

specifically, ILW containing short-lived radionuclides with a half-life of 30 years or less. These are referred to with the acronym ILW-SL, as opposed to ILW-LL, and the latter are not thought to be suitable for disposal in the at-surface facilities in France and Spain.

“Below-surface” refers to facilities of a type (such as in Sweden and Finland) that are constructed in shallow underground excavations, at a depth of 50 – 100 meters: “Near-surface disposal facilities in caverns below ground level: Unlike near-surface disposal at ground level where the excavations are conducted from the surface, shallow disposal requires underground excavation of caverns but the facility is at a depth of several tens of metres below the Earth’s surface and accessed through a drift [NEA].”

(b) “Hardened” Surface Storage.

An Internet search carried out on 4 March 2014 returned no results for the search phrase “hardened surface storage for low- and intermediate-level radioactive waste,” but did return some results for a concept known as “hardened on-site storage (HOSS).” Following is an example of this usage which was presented before the Joint Review Panel (JRP) hearings:

- “Hardened On-Site Storage (HOSS) involves surrounding dry-cask nuclear waste containers in reinforced concrete and steel structures, and further protecting them by mounds of concrete, steel and gravel. Each of these mounds would be spread apart by about 60 to 70 feet—much farther apart than is currently done. This ought to provide a reasonable amount of security from a terrorist attack while keeping the waste on-site to prevent the vulnerability it would have during transport.” (An excerpt from a presentation to the JRP by Angela Bischoff, speaking on behalf of the Canadian Voice of Women for Peace: http://bluffsadvocate.ca/triptokinkardine.html.) The reference to “dry-cask nuclear waste containers” appears to indicate that it is high-level nuclear waste that is being referred to.

- The Joint Review Panel then asked Ms. Bischoff for further clarification on HOSS, which was provided here: http://www.ceaa-acee.gc.ca/050/documents/p17520/94877E.pdf. Among the additional statements referenced in that document are the following: (1) “HOSS facilities must not be regarded as a permanent waste solution, and thus should not be constructed deep underground.” (2) “Although it is focused on high-level radioactive waste, the wisdom of HOSS can and should be applied to ‘low’ and ‘intermediate’ level radioactive wastes as well.” And the supplementary information in this document, including the reference to “irradiated fuel,” further supports the view that most discussion of HOSS is related to high-level waste (HLW), and is part of a more general argument advocating the retention of HLW at reactor sites, rather than moving them to a DGR in the near term, in order to avoid perceived risks associated with the transport of HLW over long distances.

- In these discussions “hardening” is described as producing a surface-structure configuration that would resist destruction by attacks using fuel-laden aircraft, missiles, and anti-tank weapons.

- The Internet search for Hardened On-Site Storage (HOSS) for Radioactive Waste turned up no other technical details about how such a facility would be constructed.

For the reasons given in the foregoing, we interpret the concept of an Enhanced Surface Storage Option as encompassing a temporary storage facility which is neither a permanent, at-surface disposal facility nor a hardened at-surface "HOSS" facility as described above. Rather, we view it as being a structurally-upgraded version of the existing WWMF, the features of which would be designed to increase the operating life of the buildings and waste containers in which the wastes are stored. Further details are provided in the following section.

(c) Reference Case for "Enhanced" Surface Storage.

In view of the potential range of viewpoints on what qualities an "enhanced and hardened" surface storage option might actually have, we have chosen to focus on a straightforward example of this option. This means an option which exhibits quite specific types of enhancements to an actual, operating surface storage facility (i.e., the WWMF) which will utilize existing technologies. Such varied enhancements include strengthening of both buildings and waste containers and volume reduction for LLW (in order to reduce the number of containers). The improvements are assumed to be such obvious strategies as "thicker walls, more durable materials, and active control of storage options (e.g. control of humidity).... In addition, it may be assumed that the structures are emplaced further apart than is current practice; this could limit the extent of releases from a single accident or malevolent act." A more secure perimeter with restricted access would also be envisaged. (See further Appendix V, Section 4) In *these specific senses* an enhanced surface storage option located at the Bruce nuclear site could be considered to be a "hardened" facility.

In general the enhanced option would seek to double the operating life of both the buildings and the waste containers, from the >50-year assumed lifespan in the "Status Quo" option to a 100-year life, thereafter replacing all of them during each 100-year period. The LLW (at half the volume after volume reduction) would be transferred to more robust containers, emplaced in more robust buildings, for a total period of 300 years, after which it could be moved to landfill. The ILW would be transferred to more robust in-ground and above-ground storage containers, which would also have to be less frequently extracted and re-emplaced, on a 100-year cycle, continued indefinitely.

2.3 Two Deep Geological Repository (DGR) Options.

One of the two options is in the Cobourg Formation at the Bruce nuclear site (see Appendix V, Section 5 for a summary); it is, of course, characterized at much greater length in the technical documents cited in "Section 7: References" in Appendix V. The second option is based on the idea that a DGR for L&ILW could possibly be constructed in an appropriate granite formation somewhere in the Canadian Shield, although no actual site has been selected for this purpose. A short summary of this option, based on experience to date in the characterization of sites in similar geological formations elsewhere, is contained in Appendix V, Section 6.

The following narrative discussion of the two DGR options considers them together, rather than in sequence, in order to facilitate the comparison and contrast between them. It is based in part on the exposition and referenced materials in Appendix V, and also on a more general understanding of the characteristics of these geological formations that may be found in the available scientific and technical literature. Because such formations can have very complex characteristics, which are less familiar to people than are the surface features of land and water in the Bruce Peninsula, we have devoted more space to this discussion.

2.3.1 Deep Geological Repository (DGR): Introduction.

Conceptually, any DGR option is based on a long-term passive storage approach that can be demonstrated to present extremely low risks, based on detailed geoscience and engineering analyses. It is assumed that the storage is passive so that no future human intervention will be needed, and that the LLW and ILW placed in the DGR will become inaccessible (within reasonable effort) to society. Therefore, once ultimate closure takes place, there are no longer requirements for active management or for assuming a continued existence of a robust societal structure. In this set of options, there is no requirement for the maintenance of a well-trained technical and professional cadre to oversee the facility in the post-closure phase. However, long-term geological issues now become dominant for the DGR options because other sources of risk (severe weather, malevolent acts, dropping of a container, etc.) have disappeared. For surface storage, on the other hand, the geological issues remain the same, and a number of other sources of risk also stay approximately the same over time because the storage facilities are assumed to be actively operated for the indefinite future.

Time Frame Choice.

A 100-year time frame has been chosen to discriminate between “the short term” (or “pre-closure” for the DGR options) and “the long term” (or “post-closure” for the DGR options) because the DGR closure date is likely to be on the order of 100 years, or somewhat less. Furthermore, any assumption as to the elapsed time at which institutional control might be lost for a surface storage facility is difficult to fully justify (100 years, or 1000 years?). Hence, a 100-year elapsed time has been chosen to discriminate between long-term risk and short-term risk, accepting that this choice also strongly discriminates between the DGR and surface storage options because the closure of a DGR suddenly changes the nature of the risks in many categories.

2.3.2 Comparing the Bruce Site DGR vs. a Hypothetical Canadian Shield DGR.

In weighing comparative risks of a DGR project in the sedimentary rock of the Bruce nuclear site and the risks associated with a DGR project at an unspecified site in the granite of the Canadian Shield, a first-order geological context must be established. The details of such a context for comparison are hard to specify: The Bruce site has been intensively studied, but there has been no similar level of characterization applied to a specific site in the Canadian Shield in Ontario that could conceivably become the DGR site for L&ILW. This is the major reason why we have considered the DGR in granite to be a conceptual option only – a hypothetical Granite DGR.

The IEG was also asked to consider the hypothetical granite site (hereafter called the Granite DGR) to be in many ways similar to the real Bruce site (called the Bruce DGR). For example, the directions indicated that the hypothetical Granite DGR site would have a similar geographical and hydrological disposition to the real Bruce DGR site as it is now understood, being defined as proximal to a (small) wetland area, a stream-and-small-lake region, and a Great Lake (i.e., sited near a large lake). It is also assumed by the IEG that:

- The geometrical dispositions of the Bruce and Granite DGR are the same in terms of depth (about 675 m below ground surface), underground volume, the number of galleries, the number of containers to be placed, and so on.
- The physical design in both cases is similar and appropriate to the mechanical properties of the rock mass, with similar steps being taken to avoid undue damage to the rock during shaft sinking and gallery creation.
- The hoisting equipment and all the other facilities related to the movement and placement of the containers in either of the two DGRs are identical.
- The method of abandonment of the Granite DGR and the Bruce DGR is essentially the same, although perhaps with minor design differences to account for the different rock types (igneous vs. sedimentary) and stratigraphic disposition.
- Other significant characteristics not explicitly mentioned here are similar, except of course the nature of the rock and rock mass in the two sites.

On this basis, it is possible to make some general comparisons between the hypothetical Granite DGR and the well-characterized Bruce DGR.

Sources of Radionuclides: Aqueous and Gas Phase Transport.

From a deep geological repository, the source of non-natural radioactive species (radionuclides) is the low-level and intermediate level wastes stored at depth. In order to intersect the biosphere and present a risk to nature and society, the radionuclides must experience transport to the surface. This can happen in one of three ways: solid transport, aqueous transport, and gaseous transport.

Solid Phase Transport: This requires the physical removal of some mass containing radionuclides from the repository level and bringing it to the surface. In turn, this must involve some process such as deliberate re-accessing of the DGR storage galleries through removal of the barriers and physically entering the repository by humans or robotic devices, or accidental drilling into the DGR if social control is lost in the future. There is no reason to differentiate between the Granite DGR and the Bruce DGR in this access aspect – the transport of radionuclides in the solid phase – and therefore solid phase transport will not be addressed further.

Aqueous Phase Transport: This transport mode requires that the radionuclides become incorporated into water in the form of dissolved species or small, colloidal-sized particles that can be carried by the water. Achieving this first requires that water come into the repository level (considered to be a certainty after some time), dissolve or entrain radionuclides into the water, and move toward the surface where the water might exit directly, enter into the local shallow groundwater, or exit under a body of surface water. Up to the point of transport, it is assumed that the Bruce and Granite DGRs will experience the same histories. However, when it comes to the potential for transport to the surface in the aqueous phase, there are differences between the Granite DGR and the Bruce DGR. All granite bodies in the Canadian Shield are known to be naturally fractured, and the details of the disposition, extent, connectivity, and aperture (opening size) of these fractures are uncertain and no amount of investigation can reduce the uncertainty to zero. The sediments around and above the Bruce DGR have been determined by the site investigation carried out to date to be not only of exceedingly low permeability, but largely unfractured, such that there is no evidence of significant groundwater flow flux through the repository horizon for millions of years. This difference is discussed in greater detail below, and it is the major factor affecting a comparative risk assessment of the two cases (although the risk is expected to be exceedingly low in both cases).

Gaseous Phase Transport: There will be some amount of CO_2 and CH_4 arising from the wastes in the DGR from decomposition of the organic materials in the waste packages, as well as H_2 generated from anaerobic metal corrosion, especially when the wastes become fully contacted by water (considered to be inevitable in the long timeframe). Apparently, the only radionuclide of consequence in the gaseous transport mode is ^{14}C, as other radioactive species are not present in significant amounts in gaseous form because of a short half-life (e.g. radon) or because they are generated extremely small quantities and can only be transported dissolved (or suspended, which is exceedingly unlikely) in an aqueous phase. The same comment as in the previous paragraph applies: up to the point of transport of the gaseous phase, there is no reason to differentiate between the Granite and the Bruce DGRs. Once the point of potential transport is reached, the two cases are different because of the presence of natural fractures in the case of a Granite DGR. This is discussed in more detail below.

General Geological Disposition of the Bruce Site (Figure 1).

The sedimentary and evaporitic strata at the Bruce site include a number of ancient and geologically distinguishable formations made up of carbonates [$CaCO_3$, $CaMg(CO_3)_2$], shales (quartz-illite, sometimes with $CaCO_3$), evaporites (salt and anhydrite), and clastic strata (well-cemented, low-porosity, fine-grained particulate sediments such as fine-grained sand and silt with the grains being dominantly quartz, with some feldspars and other minerals). The sequence of sedimentary strata lie on the NE edge (the platform) of the Michigan Basin, and dip very gently toward the center of the Michigan Basin, which lies roughly west of the site near the center of the Michigan Peninsula that separates Lake Michigan from Lake Huron. To the east of the Bruce site, the oldest strata gradually disappear as the Algonquin Arch granites are found at shallower depth (Figure 1), and some individual formations terminate against the granites of the Algonquin Arch, or have been terminated at their top by erosion that took place over the hundreds of millions of years that these rocks have been uplifted and exposed to weathering and glaciation. The Algonquin Arch developed slowly and episodically as sedimentation took place so that most of the strata become slightly thinner in the up-dip direction to the east.

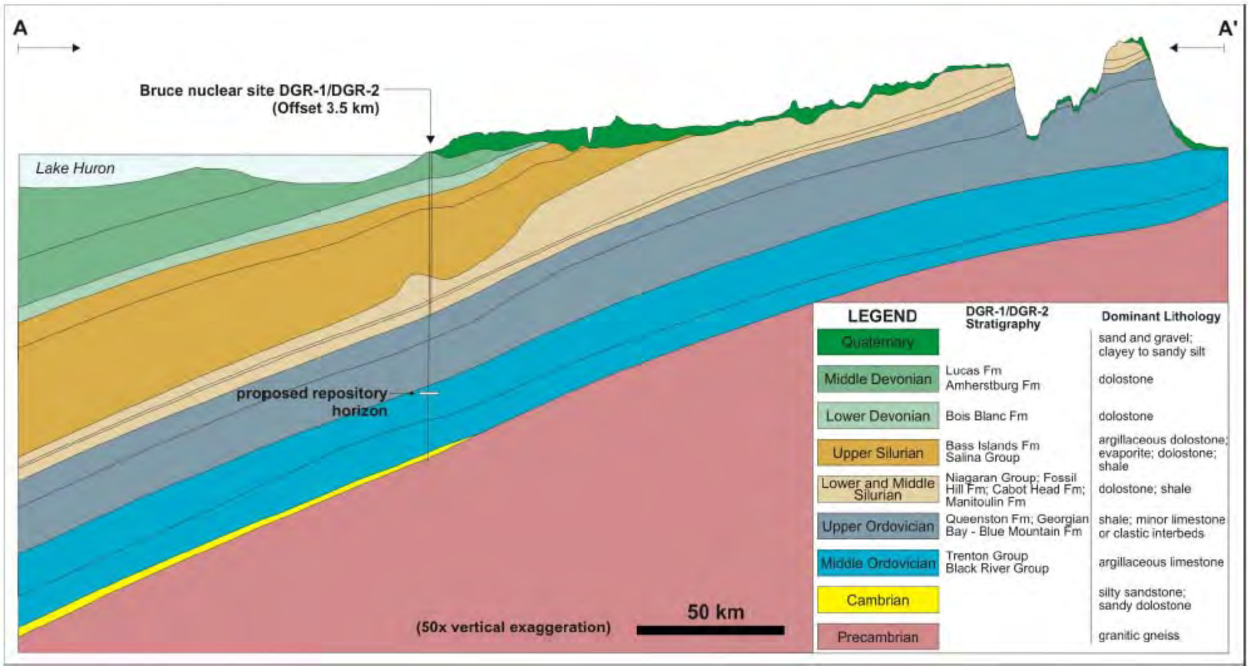

Figure 1: Geological Cross-Section of the Bruce DGR site. Figure 6.2.6-3 from the 2011 OPG Report – Environmental Impact Statement, Vol. 1 (00216-REP-07701-00001 R000). (Vertical distances are greatly exaggerated, dips are actually very low)

The sediments were deposited hundreds of millions of years ago, approximately 400 to 500 million, and are of Cambrian, Ordovician and Silurian geologic age. Slow geological processes involving burial (depths <1 km) coupled with physical and chemical compaction and cementation over hundreds of millions of years have resulted in lithification, leading to rocks that are now strong and stiff. The limestone and dolomitic strata tend to be relatively massive in nature, without a large number of bedding planes, whereas the shales have many bedding plane features disposed parallel to the near-horizontal dip of the bedrock formations.

Because there has been negligible tectonic activity in this part of the Michigan Basin Platform, there is no evidence of folding or faulting of the rocks since the time of deposition. Furthermore, there is no evidence of the existence of substantial extensional or compressional conditions in the past that would have led to the rock mass being subjected to an exceptional stress field in their remote geological history. Other than gentle uplift of the entire Michigan Basin, the slow development of the Algonquin Arch, and the erosion of the sediments that has gone on for the last 300 to 200 million years, not much has happened in the Bruce region. Because of the very slow uplift and erosion that has taken place, the horizontal stresses in the Ordovician-age sedimentary rocks at the depth of the Bruce DGR are likely to be greater than the vertical stresses, but because of the strength of the rocks and the depth of burial, higher horizontal stresses are almost certainly of no consequence to the site stability during or after construction of the DGR.

From a hydrogeological standpoint, the Bruce DGR site at the repository depth has been characterized by the geological and geotechnical studies carried out over the last decade as being stagnant, with the age of the groundwater being in the tens to hundreds of millions of years; essentially, the water at the repository level is not moving. The surrounding sedimentary formations are of low porosity and of exceedingly low rock mass permeability: if any groundwater flow pattern exists, the flow rates appear to be so slow that the velocity of through the strata water transport rates could only be expressed in terms of millimeters per year. Such slow rates are beyond sciences' ability to measure directly; they can be estimated through the study of the geochemistry of the small volumes of pore water in the rock mass (isotopic analysis) and estimation of the rates at which natural tracers dissolved in the water are moving. It appears that instead of bulk flow, mass transport through the sediments at the Bruce DGR site takes place by diffusion, an exceeding slow process in low porosity, low permeability strata.

Furthermore, it appears that there is no regionally interconnected natural fracture network in the Bruce DGR location at the repository depth, even though these sediments are carbonate rocks which are usually naturally fractured. There are geological reasons for this lack of fractures, such as the absence of any tectonic forces. Also, the hundreds of millions of years of compaction and loss of porosity, largely because of the movement of the calcium carbonate ($CaCO_3$), simply destroyed most of the original pores and any open natural fractures that developed. This process is called diagenesis, a form of chemical densification that takes place through the gradual dissolution and re-precipitation of calcium carbonate. In exceptional conditions of rapid flow of fresh water, calcium carbonate can dissolve to generate channels and large openings. In part, because of the lack of sub-aerial exposure and isolation by the overlying shale formation, this phenomenon (karstification) has never taken place in the carbonate rocks of the repository level, nor would it be expected to take place in the future.

Similar comments can be said of the overlying shales, which are comprised of silicate minerals including clays (<50%), but which have sequences that may be rich in precipitated salt or carbonate minerals that can reduce the porosity. Shales, however, tend to be of extremely low permeability in any case because of the tight compaction of the small grains so that the internal channels (pores and pore throats) are exceedingly small, and generally do not permit fluid flow of any kind. Because the shales above the repository level also appear to be generally unfractured, there are few pathways around the Bruce DGR site available for the transport and release of radionuclides.

General Geological Disposition of a Granite Site Repository.

The assumed granite repository is in a high-quality unaltered body of relatively isotropic granite such as plutons, at a distance from through-going faults or major lithologically- different bodies of rock that might possess substantially different mechanical or transport properties. Such a site would be deliberately identified and chosen based upon extensive site investigation to lead to the demonstrated existence of a suitable rock mass that has a low density of natural fractures and where the natural flow system in the fractures can be shown to be relatively slow – a region of low topographic elevation differences, no strong recharge and discharge areas indicative of rapid groundwater flux, and so on.

The Granite DGR site would almost certainly be at a location where the granite is clearly exposed at the surface. In other words, the granite would be available for direct geological and geotechnical examination in its natural state so that various factors could be estimated, such as fracture density and spacing at the surface, the heterogeneity, the presence of lithologically different zones or zones that are more intensely fractured. These various characteristics are not the same at the surface as at the depth of the repository; progression of a detailed site investigation program will provide for the collection of more information about the granite site, reducing the uncertainty to levels that can be deemed acceptable for repository advancement (development of shafts, adits and galleries). Because exposed granite is desired, there will be no recent sediments covering the entire site, part of it will be bare rock. Because of the glaciation history of the Canadian Shield, the sediments would be very young (on the order of

10,000 years of age), would fill in all the lower parts of the site (the wetlands and shallow valley bottoms), and would be much coarser-grained and permeable than the surficial sediments at the Bruce DGR site.

However, the most important difference between the Bruce DGR and a hypothetical Granite DGR in the Canadian Shield is that there is a certainty of the existence of natural fractures in the igneous (granite) rock mass, whereas it seems almost certain, based on the site investigations to date, that the strata around and above the Bruce DGR are either unfractured or extremely lightly fractured, with the fractures likely to be closed or of low aperture.

Tectonically, any site chosen for the Granite DGR will be completely inactive, with no evidence of folding, faulting or fracturing for the last half a million years. This is a characteristic of the rock and geological histories of the Canadian Shield, which is tectonically one of the quietest and oldest parts of the world's crust, which makes it appealing for a long-term repository for radioactive wastes. In this comparison between the Bruce DGR and a Granite DGR, as stated previously, only consideration of low-level and intermediate-level radioactive solid wastes is taking place.

Rock Strength and Stability of Mine Structures.

Both the Bruce and a Granite DGR have exceptionally strong rocks at the repository level. There will be no significant differences between the two cases in terms of rock response. In both cases, the rock mass is extremely compact and strong, capable of supporting all of the loads arising from the excavation and use of the galleries for an indefinite time. The rocks are so strong and the design of the Bruce DGR is so conservative that there will be no instability over the time the repository is actively being used (and for many hundreds of years thereafter). Assuming a similar design at a similar depth in a Granite DGR, the same may be said: there will be no significant instability over the open life of such a repository. There is no reason to differentiate between the two cases on the basis of rock strength, mechanical properties and the stability of the shaft and the underground structures. In both cases, there is every expectation of great stability during the active life of the DGR. The uppermost part of the Bruce DGR shaft (the shaft collar) will pass through some thickness of unconsolidated glacial sediments, on the order of 10 m, and then through a sequence of shallow rock that to a depth of about 200 m (450-500 m above the repository level) within which there is lateral groundwater flux. In a Granite DGR, the shaft collar would be directly embedded in exposed granite at the surface. This difference is considered to be inconsequential in terms of a comparison of risk between the two cases, as it is difficult to see how such a difference could affect future pathways. It is reasonable to assume that in both cases the shaft seal is equally effective.

Seismic Risk.

Both the Bruce and Granite DGR cases may be assumed to be subject to exceedingly low seismic risk over millions of years. This is the case for the following reasons:

- There is no evidence of tectonic activity (faulting, folding, intense fracturing) having taken place for several hundreds of millions of years at the Bruce DGR site (ever since the sediments were deposited), and all potentially suitable Granite DGR sites in the Canadian Shield would also have no evidence of tectonic activity for several hundreds of millions of years in the geological past.

- Both sites are in areas where the level of seismicity measured over the last 60 years by geophysical methods (seismometers) has been determined to be extremely small. Seismic events that have occurred are far below any motion level which could cause damage at the surface, and the events that have been recorded to date are so small that they cannot even be felt at the surface by humans. The probability of a damaging seismic event in the geological future (tens of millions of years) is low.

- Deep tunnels and mines are much less sensitive to damage from seismic ground motion than surface facilities because the most damaging effects of earthquakes arise from the high-intensity surface waves (“ground roll”), which do not develop at depth.

- Given the earthquake history of the region, there is a low probability of any event which could cause significant damage to the surface facilities during the active period of waste container placement into the DGR. Furthermore, any such damage is even less likely to lead to a breach of a low-level or intermediate-level waste container.

- Surface facilities are expected to be operational for no more than 40-50 years after the start of construction.

- There is no rational geologic reason to expect seismic activity of significant magnitude to impact a DGR in the geologic future (millions of years) as there are no active volcanic processes, continental margins, or crustal deformation processes within a thousand kilometers or more.

In both cases, the seismic risks are exceedingly low, and it is not possible to differentiate between the proposed Bruce DGR and any suitable Granite DGR site anywhere within the Canadian Shield in Ontario.

Mass Transport.

Transport through a rock mass can occur through diffusion or advection. Advective transport refers to the carrying of something (dissolved salt, a colloidal particle, gas dissolved into a liquid) in a fluid by bulk flow. If water can flow, it can transport material advectively. If water cannot flow, for example if it is truly stagnant or is very still because it is density stratified, then dissolved species or colloidal particles can still move through the water, but through diffusion processes driven by chemical gradients (differences in chemical compositions and concentrations). In the small pores in the intact rocks at both sites, advective mass transport is unlikely and diffusive solute transport is expected to be exceedingly slow.

Gas can carry a radioactive species by advective transport, such as ^{14}C, which could be carried as part of CH_4 or CO_2.

It is reasonable to make the following assumptions for mass transport with respect to low-level and intermediate-level radioactive waste:

- Mass transport by advection through the intact blocks of rocks between natural fractures, either at the Bruce DGR or a Granite DGR, is extremely unlikely, if it can occur at all, because of the small size of pores in these materials and because many of the pores are not interconnected.
- In the absence of advection through the intact rock blocks between natural fractures, mass transport by diffusion must also be extremely slow for the same reason. In fact, if advective flow is not possible, then only diffusion can be considered to be a transport mechanism.
- Colloidal transport in matrix porewater or fracture groundwater is unlikely because of the absence of advective flow conditions and because of various filtration and adsorption processes that impede migration. It can reasonably be assumed not to happen in any realistic time frame at any rate of concern.
- Thus, the mass transport process of concern is the dissolving of radioactive elements and compounds in water and the advective transport (bulk flow) of this water through natural fractures.
- If species dissolved into water come into contact with minerals of high surface area and adsorptive capacities, the concentration will be reduced by adsorption unto the surfaces of the minerals, leading to a slowing of the rate of transport of the dissolved species compared to the bulk flow of the aqueous phase.
- Gas is a buoyant phase compared to water, therefore if a generated gas phase can overcome the capillary entry pressure associated with a vertical or inclined narrow aperture natural fracture, it can rise upward as a bubble or potentially develop a continuous flow path if there is enough gas and the pressure is high enough.

- Gas-phase transport is unlikely to carry significant dissolved salts or colloidal particles, only gases (mixtures of gases), as any likely rates of gas transport would be so slow as not be be able to entrain any colloidal particles or liquid micro-bubbles.
- As gases rise through water-containing pores and fractures, the gases will dissolve into the aqueous phases, thereby attenuating the transport process through the gas phase. For example, if there is ^{14}C in CO_2, and if the CO_2 is under a high enough pressure to enter the natural fractures and move upward through buoyancy-triggered advection, the amount moving will attenuate as the CO_2 dissolves in the water. This water will then be denser than the surrounding water, and will have a reduced tendency to advect and move to the surface more rapidly.
- Once gases are dissolved into water, geochemical processes such as CH_4 bacteriological consumption nearer the surface and CO_2 reaction (as weak carbonic acid) with minerals would severely attenuate flux, preventing and significant escape to the surface.

In a water-wet system, for gas to migrate through the rock mass, it is necessary to displace the water. There is a surface tension between the water and the gas, and this means it becomes increasingly difficult for gas to be forced into the smaller pores. This force that resists flow is called the capillary entry pressure, and it is the reason that it is impossible for gas to migrate through a fine-grained rock or through a natural fracture that is extremely tight (very small aperture or discontinuous aperture). In the Bruce DGR at depth, the porosity of the rock matrix is very low and there is no evidence for the occurrence of open natural fractures. Hence, even if at some time in the future enough gas is generated so that a free gas phase under some pressure can exist without dissolution into the water (dissolving of the gas in the water), the gas would have to enter a crack or a pore as a free phase. Furthermore, there would have to be continuity of the pores or the cracks sufficient to allow the gas to continue to migrate under its buoyancy forces. The capillary entry pressure can be over 10 MPa for shale and low-porosity limestones, and this is a substantial barrier to gas migration.

In a suitable Granite DGR, the intact rock itself is very low permeability and no substantive flow through intact rock will take place; all of the flow capacity is through the natural fracture system. Because fractures tend to have some continuity and be interconnected in granitic terrain (at least in the shallower portion), it is more likely that if any free gas could be generated at depth and not be adsorbed into the water phases, it could escape from the repository horizon more readily than in the Bruce DGR case and move toward the surface under the buoyant forces. However, given the narrow aperture of cracks at depth expected in a competent granite pluton, the gas entry pressure would be high, on the order of several MPa at least, and flow capacity of the low-aperture natural fractures would be low, therefore the flow rates of any escaping gas would be expected to be low.

Water in the pores and joints in a rock mass usually has a density of between 1.0 g/cm^3 (fresh water) and 1.20 g/cm^3 (saturated NaCl brine). In the region of the Bruce DGR at the repository depth the waters are close to saturated with NaCl, therefore the density is close to 1.2 g/cm^3. Furthermore, in both cases, the Bruce and the Granite DGRs, it can be expected that the water in the pores and the natural fractures increases in density with depth (more saline with depth until the saturated condition is reached) as it has had less and less influence from the meteoric water (surface run-off, rain, snow). This increasing density with depth is a strong stabilizing factor in natural flow systems: the density gradient counteracts the tendency for surface recharge to penetrate deeply into the natural fractures or pore spaces, so that the active groundwater flow regimes fed by precipitation tend to be shallow. For denser water to flow up from depth through less-dense water, the differential pressures have to be quite large to overcome the density effect. Thus, a density stratified groundwater system means that mixing by advection becomes even slower that it normally would be in a system where the fluid density is the same throughout. The increased water density with depth is the case at both at Bruce DGR and in a Granite DGR; the shallow water is fresh, the deep reservoir at repository level is saline and denser. This density difference is an important phenomenon mitigating upward groundwater flow or contaminant advection.

In either a Granite DGR or the Bruce DGR, groundwater systems exist (although the water at the depth of the Bruce DGR has been deemed to be essentially stagnant). Groundwater flow is activated by the presence of highlands (recharge areas) and low points (e.g. rivers, wetlands or lakes). At the Bruce DGR the highlands to the east comprise the recharge area and are several hundred meters higher in elevation than the site, but quite distant, more than 100 km east on the height of land of the Niagara Escarpment. There are shallow groundwater systems (local hills and streams or wetlands) at all scales, but the deep groundwater system is at the scale of a hundred kilometers. In other words, any deep flow in the system at the depth of the repository would be the result in the difference in head between Lake Huron and the regional height of land along the Escarpment. Furthermore, given the stratification and inclination of the rocks from the height of land to Lake Huron, it would be expected that the large-scale groundwater system (100 km scale at a depth greater than 500 m) would be characterized by near-horizontal flow or slightly inclined flow along the beds if these beds have some permeability anisotropy (higher permeability along bedding). The greater density of the deep fluids at the Bruce DGR would also strongly act against vertical mixing because the topographic contrasts are modest. In the opinion of the IEG, the presence of departures from hydrostatic pressure conditions that have been measured at the DGR are of little consequence because of the low porosities and permeability. Their persistence over geological time constitutes further proof that the rocks are of such low permeability that flux rates are likely to remain close to zero indefinitely. It is expected that these departures from hydrostatic pressure at depth in the Ordovician age strata will persist in the future but will have no consequence on flow at the repository level.

Similar general conditions without departures from hydrostatic pressures would be expected at the depth of the repository galleries at a Granite DGR. It is likely that there would be a similar regional height of land some distance away (the IEG was asked to consider a Granite DGR as being in a similar hydrological disposition as the Bruce DGR). There remains one substantial hydrological difference between the two sites: the natural fractures at the Granite DGR site would be expected to have a higher overall fluid transmission potential than the dense, low porosity and low permeability sedimentary rocks at the Bruce DGR site.

Flow Path Length.

Flow path length refers to the distance an element of gas or water has to travel through the rock before it interacts with the surface or with shallow potable groundwater. The greater the flow path length through the rock, the greater is the potential for the adsorption of radionuclides, for dispersion of the flow, and for long flow times leading to more radioactive decay before interactions.

One obvious potential flow path is the sealed post-closure DGR shaft. However, there is no reason to believe that there would be significant differences in the shaft seal performance between the two options, so that discrimination between the two DGR options based on the postulated long-term integrity of the shaft seal cannot be made.

Another potential pathway would be through the rocks from the repository level to the surface. At the level of the Bruce DGR, there is minimal flow of any kind (stagnant conditions). Nevertheless, suppose that at some remote time in the future fluid escape were to take place; the pathway for the exit of this water and the location of the exit region may be speculated upon. It is not possible to be precise as to the location or the length of the pathway, but given the stratigraphic disposition and the gentle dip of the beds to the west, the presence of slow flow in the upper 100-200 m of sediments, and the topographic high to the east, it is expected that any pathway would be approximately from east to west, many kilometers long (almost certainly more than 10 km), and debouching under Lake Huron.

Alternatively, if any radionuclides are transported vertically through diffusion from the repository depth, once the shallower sediments are encountered (the upper 100-200 m), they will be entrained in the westward-flowing formation water and debouche under Lake Huron. Although this pathway is length could be less than 10 km, the first part of the transport pathway, diffusive transport from the 675 m depth to a depth of 100-200 m will be so slow as to preclude this as a genuine concern for radionuclide escape.

These comments include the possibility that current pressure distributions will continue to become slowly modified as the effect of the past glaciation gradually attenuates. Development of strong upward vertical flow for long periods of time is not feasible in the terrane and sediments of the Bruce DGR. Furthermore, even if slow flow of water or gas containing radionuclides did reach the upper 200 m of the strata at the Bruce DGR, groundwater flux, surface dilution with rainfall and stream flow, and previously mentioned effects such as adsorption and dissolution of the gas into the shallow flowing groundwater, followed by geochemical immobilization or attenuation, would take place.

In a Granite DGR of similar hydrological disposition, it is likely that the flow path length would be shorter because of the presence of natural fractures in the granite rock mass. These fractures would allow for radionuclide transport toward the surface, if release from the repository takes place, to be more rapid than for the Bruce DGR case. The exit point could be into a local body of water, or it could be under the adjacent body of water (a "Great Lake"), but the flow path to the surface could conceivably be on the order of a kilometer to ten kilometers in length. It must be clearly stated that this is unlikely because of other features such as the density gradation of the groundwater in the natural fractures in the granite. Nevertheless, the presence of natural fractures in the hypothetical Granite DGR does point to the possibility of more permeable pathways than at the Bruce DGR because of the vertical nature of these fractures and the absence of horizontal bedding of great homogeneity.

In summary, in terms of flow path length, it is impossible to distinguish substantially between the two DGR options on the basis of flow path length alone. Many more important factors such as potential flux rate (gradients and permeability), transport mechanisms (advection versus diffusion), absorption potential and capillary exclusion are more important discriminators between the two DGR options.

Adsorption, Dissolution and Dilution of Radionuclides.

Because of the probable differences in the rock masses between the Bruce DGR and a Granite DGR, the transport capacity for radionuclides is different. The major points are summarized here:

- Many mineral surfaces tend to be surface active, having some amount of unsatisfied surface charges, generally adsorptive of cations. These would absorb, attenuate and disperse any polyvalent dissolved species in the porewater, retarding the rate of radionuclide transport.
- At the hypothetical Granite DGR site, contaminant transport occurs primarily through natural fractures of limited surface area and limited adsorptive capacity. Far less adsorption and less retardation of the flux of radionuclide transport would take place, in comparison to the Bruce DGR site.
- There is a much thinner layer of recent clay-rich sediments in the Granite DGR, compared to the Bruce DGR site where glacial deposits are common and reasonably thick in most places.

In fact, this layer will likely be absent or coarse-grained in much of the region around a Granite DGR, thus there is less adsorptive capacity in the granite site.

- There is expected to be no difference between the two cases in the dissolution tendency of the waters that eventually enter the repository galleries. There may be some geochemical differences in the waters because of the different minerals in the two cases; the Bruce DGR waters would be saline and saturated with $CaCO_3$; the Granite DGR site waters would have far less $CaCO_3$, but still be saline. The nature of the saline phase in the groundwater at the two cases will be different, but it is not considered to be an important issue in this comparison.

The solubility of the great majority of the possible radionuclide sources in the waste materials is low. If water is in contact with the waste materials for some time, there will be dissolution into the water until an equilibrium dissolved value is reached. Given that the invading water will be saline, its capacity to dissolve other materials is limited; since the radionuclides in the low-level and intermediate level wastes are not in the form of highly soluble salts, the capacity of the water to dissolve radionuclides is quite limited. This means that any water that has come into contact with the wastes will have only modest to very small amounts of radionuclides (depending on various chemical factors and the presence of organic compounds), and these radionuclides and any organic compounds in the water would be subject to adsorption and retardation (discussed above) as the water moved through the rock mass.

During transit through a porous rock mass or through a system of interconnected natural fractures that are filled with water, dispersion and dilution will also take place. This arises naturally as flow takes place in any heterogeneous porous system, so that the concentration of the dissolved species in water is gradually reduced, especially as the water comes closer to the surface where there is more rapid water flow and more mixing as the result of rainfall and groundwater flux. In both Granite and Bruce site DGR cases, dispersion and dilution will take place in the subsurface (as well as adsorption and retardation of the transport rate of dissolved species) so that any water exiting near the surface under a body of water will already be diluted by large factors.

Because groundwater exit points would be almost certainly under bodies of water, a further dilution will take place. For a comparison, assume that any plausible exiting flux of water that may have come into contact with radionuclides might be as large as 1000 m^3/year (this is considered highly improbable). The average rainfall onto the 60,000 km^2 area of Lake Huron is more than 700-800 mm/yr, or about 42 billion cubic meters per year (not counting river water flowing into the lake). The amount of water already in Lake Huron, which has an average depth of 60 m, is 100 times larger than the annual rainfall on the Lake, over four trillion cubic meters. Hence, the volumes of the bodies of water available for dilution at the surface are either immense (Great Lake) or actively flowing (rainfall >700 mm/yr, active streams and marshlands), so the dilution capacity is significant. The dilution capacity for a Granite DGR and the Bruce DGR are similar, as we were asked to consider a Granite DGR in a similar hydrological disposition. Differences in rainfall and snowfall exist, but these differences regionally are in the ranges of 10-50%, not orders of magnitude.

If a gas phase manages to reach the surface, dilution with the atmospheric flux will take place rapidly. Given any possible rate of gas escape, this dilution would reduce the concentration of the radionuclides (likely mostly ^{14}C) to vanishingly small levels. There are no apparent differences between the two sites in the capacity for dilution of any gases that might escape to the surface.

Summary of the Differences between a Granite DGR and the Bruce DGR.

At a conceptual level, comparing the Bruce sedimentary rock site with a hypothetical granite site for the disposal of low-level and intermediate level radioactive waste, the following summary points are made:

- The long-term risks of escape of significant amounts or high concentrations of radionuclides at either a properly designed Granite DGR site or the Bruce DGR site are extremely low; in both cases there are many natural barriers and processes that attenuate, retard or dilute dissolved or gaseous species that might be available for transport to the biosphere.

- Granites and other igneous rock masses are naturally fractured, and there is a high probability that a natural fracture system at a Granite DGR in the Canadian Shield has a greater transport potential than the rocks that host and enclose the repository horizon at the Bruce DGR site. A granite site DGR could therefore require more engineered barriers.

- The sediments at the Bruce DGR are homogeneous and thus their properties are quite predictable over substantial distances, and differences in hydraulic properties (permeability and porosity) over these distances (many kilometers) are almost certainly minimal because of the depositional environment and subsequent lack of tectonic deformation in the geological past.

- In a Granite DGR, the distribution of specific natural fractures or fractured zones, their properties and geometry can be complicated, creating challenges for characterisation with high degrees of certainty. The lateral predictability of sub-surface conditions over substantial distances (many kilometers) in granites is poor.

- In the case of possible radionuclide escape from a Granite DGR, the transport mechanism to the biosphere is more likely to be advective transport through natural fractures, whereas from the Bruce DGR, the transport mechanism is more likely to be diffusive transport, for at least several hundred meters of any postulated pathway. Given that diffusive transport is likely to be orders of magnitude slower than advective transport under any postulated escape scenario, the Bruce DGR has a much lower probability of release of a significant concentration of radionuclides to the biosphere.

- Compared to sedimentary rock, granitic rocks have an absence of clay minerals and thus, other factors being equal, have a lower adsorptive capacity for dissolved radionuclides being transported in water.
- Compared to a sedimentary site, the gas entry pressures within fractured crystalline rock is expected to be lower, therefore in a Granite DGR site they would present less of a barrier to gas flow than the extremely low permeability and essentially unfractured rocks above and around the Bruce DGR site.

3 Qualitative Relative Risk Comparison of Four Options

3.1 Overview of the Approach

As requested by the JRP, the IEG conducted a qualitative risk assessment. This approach was designed to address a variety of pathways of harm, including those specified in the Information Requests from JRP. Each of these pathways was considered for each of the four disposal options described in Section 2. In addition, where appropriate, the risk posed by each pathway was separately considered for two different timeframes: the first 100 years (labelled "<100y") and an indefinite period into the future following the first 100 years (labelled ">100y").

The pathways of harm are listed in the Table 1 below. They are intended to be inclusive of all of the pathways of harm that were identified within the charge to the IEG provided by the JRP[4] and further identified and clarified in letters between OPG and the JRP[5,6,7]. The specific types of harm included and excluded from each pathway as well as other assumptions are described briefly in Table 1, with more detail with the risk assessment results below in this section.

The qualitative risk assessment approach included the following four steps:

1. Review of the JRP charge questions, and detailed assumptions underlying the four alternate disposal options.
2. Characterization of pathways of harm to be considered in the qualitative risk assessment.
3. Qualitative relative and absolute risk assessment for each pathway of harm.
4. Development of summary observations.

This section describes the first three of these steps and provides the results of Step 2 and 3. The summary observations of Step 4 are provided in Section 4.

Step 1: Review of Charge and Assumptions.

The IEG was briefed by the proponent on the detailed characterization of each disposal option, during three IEG meetings in Toronto. This included the provision of various documents available on the public record, presentations by proponent staff on the options (see Appendix III), and discussions with internal experts made available by OPG. The IEG reviewed

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[4] JRP letter from Dr. Stella Swanson to Laurie Swami, "Information Request Package #12 from the Joint Review Panel", November 8, 2013.

[5] OPG letter from Laurie Swami to Dr. Stella Swanson, "Acknowledgement of Information Request Package #12", December 4, 2013.

[6] JRP letter from Dr. Stella Swanson to Laurie Swami, "OPG Scope of Work and Proposed Response Dates for Information Request Package #12", December 8, 2013.

[7] OPG letter from Laurie Swami to Dr. Stella Swanson, "Submission of Independent Risk Assessment Expert Group Comments on Relative Risk Analysis of Community Acceptance in IR EIS-12-513", February 20, 2014.

the charge questions in detail, and sought clarification on a number of aspects from the proponent, who then sought clarification from the JRP where appropriate.[7]

Step 2: Characterization of Pathways of Harm.

The charge to the IEG contained a diverse set of issues that were to be included in the alternatives assessment (see Appendix I). They included consideration of specific sources of damage (e.g., extreme weather), specific mechanisms of exposure (e.g., transport of radionuclides, microbial degradation of containers, gas generation), and specific receptors (e.g., public, workers, receiving waters such as Lake Huron). To accommodate the charge and provide an appropriate structure for the relative risk assessment judgements, the IEG sought to create a set of mutually exclusive and exhaustive pathways of harm. These were then reviewed to ensure that they accommodated all of the relevant sources, exposure pathways and other issues identified in the charge from the JRP (see Appendix II).

The list of these identified pathways is provided in Table 1, in Section 3.2 below.

Step 3: Qualitative Relative Risk Assessment.

In order to facilitate the process of reaching an expert group consensus on the relative risk associated with each of the disposal options and for each pathway of harm and timeframe, a set of assessment tools were developed prior to a three-day workshop in which the judgements of relative risk were elicited and recorded. The tools consisted of a relative risk visualization tool and a set of tables that were used to reach consensus and record the final determinations. The results of this assessment are provided in Section 3.3 below.

Step 4: Development of Summary Observations.

The charge provided by the JRP is explicit in calling for a relative risk assessment, while also being explicit in that the IEG is not to attempt to reach or express a conclusion on a preferred alternative among the disposal options. In keeping with the charge, the IEG developed a set of summary observations (provided in Section 4) which were deemed to be inevitable conclusions of the pattern of results found in the pathway-by-pathway relative risk assessment. The observations deliberately do not provide an overall relative risk assessment in which the “net” risk posed by each disposal option is derived or even implied. Such an assessment necessarily involves placing a relative weight on the impacts to different population groups and environmental receptors, impacts of widely different severities, and judgements regarding the importance of nearer-term versus very-long-term impacts that would be faced by different generations.

3.2 Results of Pathway Identification and Characterization

The results of the identification and characterization of pathways of harm are provided in Table 1 below. The table further identifies the timeframes over which each pathway was assessed, pointing out the three exceptions to the overall pattern of assessing each pathway over the near-to-medium term (first 100 years) and the very-long-term (an indefinite period beyond 100 years).

Table 1: Pathways of Harm Evaluated in the Relative Risk Assessment.

Pathway Scenario	Scope of Assessment Pathway Scenario	Timeframe	
		<100 years	>100 years
Worker Health and Safety (WH&S)	• Includes o Normal operations and selected accidents o Accidents during construction (buildings, roads, mines), mining, and decommissioning o Noise, dust, and nuisance o On-site and off-site transportation accidents o Radiological exposures from normal operations • Excludes o Radiological exposures from accidents	✓	✓
Public Health and Safety (PH&S)	• Includes o Transportation on municipal roads and highways o Noise, dust, and nuisance off-site o Construction, operation, decommissioning, and post-closure phases • Excludes o Radiological exposures from normal operations and accidents (for DGR, prior to closure)	✓	✓
Transport of Radionuclides: Advective Water Flow	• Includes o Radionuclide and other contaminants (e.g. metals) transport in the aqueous phase through existing fractures or porous media at depth or near surface o Transport and diffusion in surface waters (including Lake Huron for Cobourg DGR and Great Lake for granite DGR) o Diffusive transport was also considered o Dissolved gases such as carbon dioxide • Excludes o Free gas advection and atmospheric emissions	✓	✓
Transport of Radionuclides: Advective Gas Flow	• Includes o Gas generation from waste and container degradation o Radionuclide transport in the gaseous phase through existing fractures or porous media o Direct emissions to the atmosphere from surface facilities • Excludes o Gas transportation in aqueous dissolved phase o Worker exposures underground	✓	✓

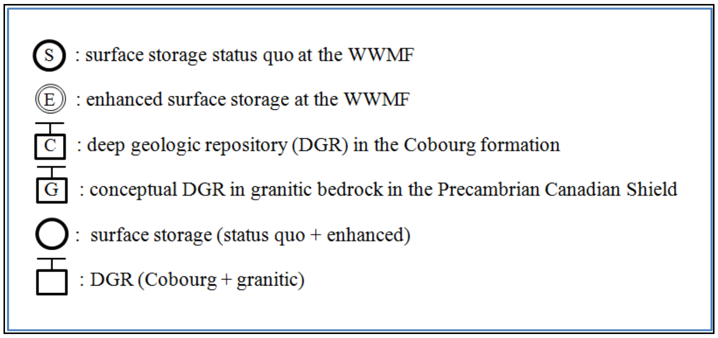
Pathway Scenario	**Scope of Assessment Pathway Scenario**	**Timeframe**	
		<100 years	**>100 years**
Seismic Impairment	• Includes o Any seismic event that is sufficiently large to lead to structural damage of buildings or underground shafts and tunnels o Major geological fracturing associated with any form of seismicity • Excludes o Long term tectonic processes	✓	✓
Structural and Mechanical Impairments	• Includes o Buildings, equipment, impacts on building services (e.g. power loss, ventilation, and pumping equipment failure, fire, flooding) o Rock fall (for DGRs) o Mechanical failures (e.g. hoist way) o Equipment malfunctions • Excludes o Seismic induced failures, severe weather, and glaciation o Failures of packaging	✓	✓
Waste Container Integrity	• Includes o Storage and permanent disposal o Seepage, release rates, and microbial activity o Package handling and breach • Excludes o Waste processing, structural and mechanical integrity of buildings and mine works o Transportation accidents	✓	✓
Radiological Exposure During Transportation Accidents	• Assumes o Additional waste transport (200 – 2,000 km) to a distant granite repository from the WWMF o No transport after 100 years o Identical packaging technology in all transportation scenarios • Includes o Transfers from reactors to WWMF for all options o Accidents and malevolent acts • Excludes o Intra-site transfers (covered under normal operations in WH&S) o Public risk due to physical harm due to transportation accident (covered under PH&S)	✓	✗

Pathway Scenario	**Scope of Assessment Pathway Scenario**	**Timeframe**	
		<100 years	**>100 years**
Severe Weather	• Includes o Extreme wind and hurricane o Tornado o Extreme precipitation o Flooding and surface erosion o Climate change	✓	✓
Glaciation	• Assumes o The possible future re-occurrence of continental glaciation leading to the creation and movement of a thick ice sheet across the site o Glaciation cycle is uncertain; assumes next glaciation in the timeframe of 10,000 - 100,000 years o Cannot assume institutional control • Excludes o Any short-term possibilities (less than 100 years)	✗	✓
Malevolent Acts	• Assumes o Presence of institutional controls in perpetuity • Includes o All intentional acts regardless of motivation o Theft, sabotage, mischief, and politically motivated acts • Excludes o Accidental intrusion	✓	✓
Loss of Institutional Control	• Assumes o Only relevant after 100 years o Very high probability of occurrence after 100 years and up to 100,000 years • Includes o All pathways of harm (natural, operational, accidental, malevolent) that rely on continuous presence of institutional control	✗	✓

3.1 Relative Risk Assessment Method

3.3.1 Visualizing Relative and Absolute Risk

To facilitate the process of reaching a consensus among the expert group on the relative risk associated with the four disposal options for each of the identified pathways, a visualization tool was developed for use during an in-person, three-day meeting (Toronto, Feb. 26-28, 2014). The visualization tool (Figure 2) was developed specifically for the concept of a relative risk assessment. In the absolute and relative risk diagrams, the following symbols were used:



Ⓢ : surface storage status quo at the WWMF
Ⓔ : enhanced surface storage at the WWMF
C : deep geologic repository (DGR) in the Cobourg formation
G : conceptual DGR in granitic bedrock in the Precambrian Canadian Shield
○ : surface storage (status quo + enhanced)
□ : DGR (Cobourg + granitic)

For some pathways of harm, there was thought to be no difference in the consequence and likelihood associated with the surface storage options. When the status quo and the enhanced storage provide the same likelihood and consequence, these two options are represented simultaneously by an unlabelled circle. Similarly, when both DGR options provide the same consequence and likelihood, they will be represented together as an unlabelled repository symbol. For simplicity, the Disposal Option labelled *Status Quo Surface Storage* was established as the baseline for comparison.

The relative risk assessment required the judgement as to the relative likelihood (or, relative probability) of damage scenarios, as well as the relative severity of the consequences of the scenario.

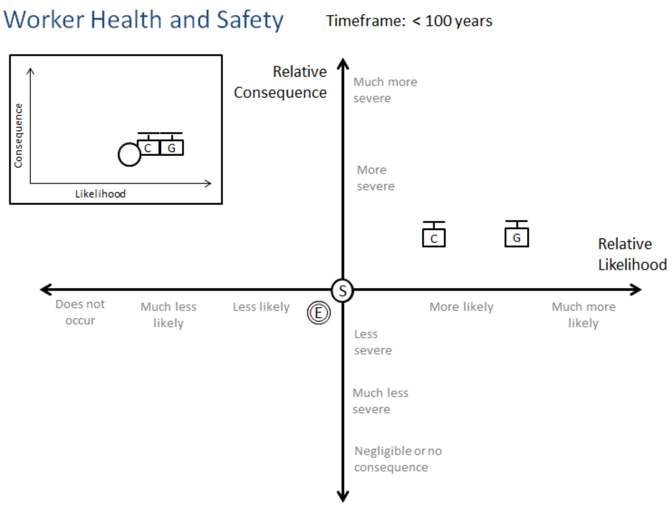


Figure 2: The visualization tool used to judge relative risk associated with the four disposal options, with the example of the Worker Health and Safety pathway of harm. Note: the Status Quo Surface Storage Option was established as the basis of comparison and is therefore always located at the centre of the main diagram. The absolute risk associated with the pathway of harm is characterized in the inset diagram to allow for comparisons of the relative importance of the pathways.

For each of the three other alternate disposal options, judgements were made as to the relative likelihood of harm (along the horizontal dimension), and the relative magnitude or severity of the consequences (along the vertical dimension). The Status Quo Surface Storage Option was established as the basis of comparison (i.e. "more" or "less" in any context is by comparison with the Status Quo Surface Option). This option is always located at the centre of the main, relative risk diagram. It should be noted that the scales are considered to be of a logarithmic nature in that the probabilities involved span many orders of magnitude (e.g., from events that occur on the order of years or decades, to extremely rare events such as glaciation events), and the magnitude of consequences were also thought to span many orders of magnitude (e.g., ranging from minor transportation accidents to scenarios involving significant destruction of the disposal structures). An exception to the "relative" notion of the assessment was provided to allow for the determination that probabilities or consequences are not expected to exist, or are so small as to be negligible. This is represented on the far-left side of the horizontal Likelihood axis as "Does Not Occur." This extreme is represented on the very bottom of the vertical Consequence dimension as "Negligible or No Consequence." An example of the use of this extremely low Consequence characterization is the impact of extreme weather events at the surface for the two Deep Geologic Repository disposal options, for the post-100 year timeframe when they would be expected to be closed and sealed (i.e., "Negligible or No Consequence"). An example of the use of the extremely low Likelihood characterization is for Waste Packaging Handling in the post-100 year timeframe for the DGR options (i.e., "Does Not Occur").

In order to provide important context to the assessment process, in addition to the relative risk characterization, the spectrum of likelihoods and consequences associated with the four disposal options was characterized on an absolute scale. This was conducted separately for each pathway of harm and each of the two timeframes. This was important since the pathways of harm represent such widely varying degrees of probability and consequence that is not evident from the purely relative characterization. This is intended to deliberately avoid any assumption that the pathways of harm should be considered equally important given the great variability among them in terms of the risk that they pose. The absolute risk assessment component is placed on the same diagram, but in an inset box in the upper-left of upper-right as required by the positioning of other symbols.

3.3.2 Interpreting the Relative Risk (RR) and Absolute Risk (AR) Diagrams

The implications of the RR and AR diagrams are best described using an example (Figure 3). Consider Worker Health and Safety as the pathway scenario. Table 1 summarizes the scope of this classification. For this example, interest lies in the timeframe of less than 100 years.

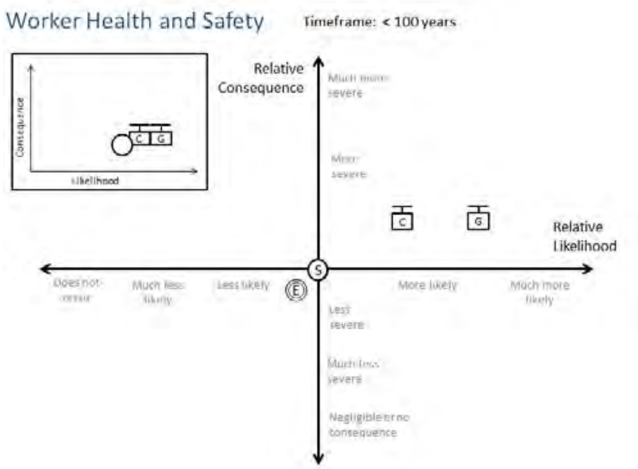


Figure 3: RR and AR diagrams for Worker Health and Safety.

First, consider the main relative risk diagram. Note that the status quo symbol is placed in the middle; the current surface storage facilities at the Bruce site represent the baseline. The remaining three symbols representing the enhanced surface storage, the Cobourg DGR, and the granite DGR, are placed on this diagram relative to the baseline. In comparison to the status quo, any potential harm to workers would occur less frequently during the construction of an enhanced surface storage facility because fewer, stronger storage facilities are built less frequently. Furthermore, wastes are repackaged and moved less frequently. There is a slight reduction in the likelihood and consequences of accidents because there is less construction required. The symbol for enhanced storage is placed slightly leftward of the status quo, because it is slightly less likely, and slightly down from status quo, because the consequences are marginally less severe. As a second illustration of the method, consider the Bruce site DGR. Relative to the status quo, a potential threat to WH & S is more likely to occur at the Bruce site DGR because of the increased construction required to build mineshafts and infrastructure at the new site. The spectrum of accident consequences given this type of construction would be more severe. The symbol for the Bruce site DGR is placed to the right of the status quo, because a worker-involved accident is considered more likely, and upward from the status quo, because the spectrum of consequences would be more severe. A similar argument applies to the granite DGR site, assuming more construction is required for infrastructure at a new site, increasing the likelihood of a worker-related accident.

The absolute risk diagram in the top left-hand corner represents the absolute risk of each disposal method associated with a worker-related incident. An accident is very likely to occur within the next 100 years at both surface storage options; to reflect this judgement, the symbol is placed at some distance from the origin in the horizontal direction. The consequences of a worker-related accident (from a societal perspective, and compared to all possible consequences contemplated in the overall assessment) are not very severe, which are reflected on the AR diagram as a slight shift from the origin in the vertical direction. The extent and nature of construction required at the DGR sites provides for slightly more serious consequences. In the next 100 years, there is also a very high chance that a worker-related accident will occur.

For two or more different pathway scenarios, the relative risk diagrams may look very similar, however, they may represent two very different levels of actual risk. Consider the relative and absolute risk diagrams of two different pathways, displayed below for illustrative purposes (Figure 4).

The relative risk diagrams of these two pathways are identical. However, there is an obvious difference that emerges in the absolute risk (inset) diagrams. The range of consequences for the pathway on the left is quite small relative to the much larger consequences as seen in the absolute risk diagram on the right.

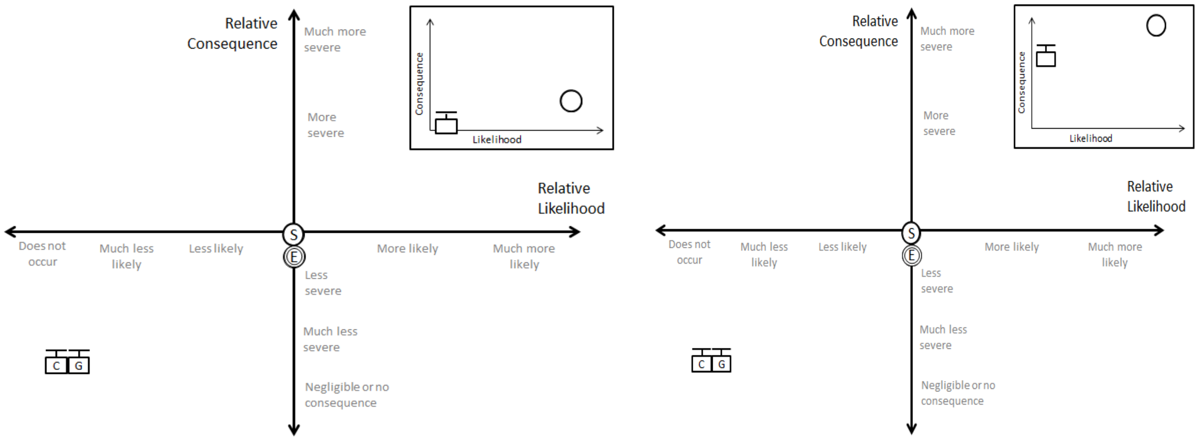


Figure 4: Hypothetical RR and AR diagrams of two different pathways. The consequences for the pathways depicted on the right are much more severe from an absolute risk perspective, though the relative risk patterns are the same.

The illustration above demonstrates that the relative risk assessment on a pathway-by-pathway basis is an incomplete characterization of the overall relative risk, without considering the additional concept of the absolute level of either the likelihood or consequences associated with each pathway.

3.3.3 Tabular Component of Relative and Absolute Risk Assessment

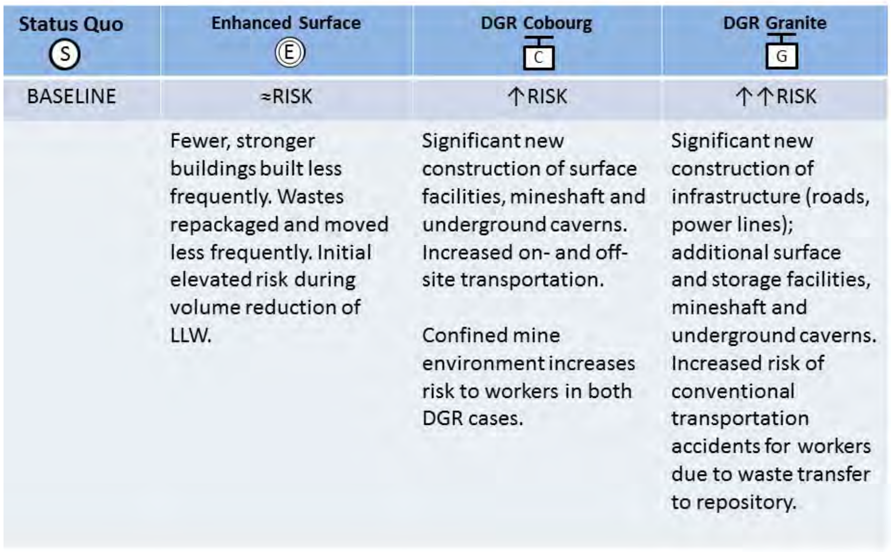
The tabular component contains the evidence and reasoning that supports the diagram. All evidence is written comparatively; alternative options are assessed relative to the baseline. The text in this table provides insight pertaining to the placement of the symbols on the diagrams; the explanations address the consequence(s) of the pathway scope. Furthermore, a relative risk assessment is provided in the second row. These risk characterizations can be summarized in Table 2 as follows:

Table 2: The Risk Characterizations Used in the Relative Risk Assessment.

Symbol	Explanation
↓↓↓ RISK	Alternative option is associated with much less risk than baseline.
↓↓ RISK	Alternative option is associated with less risk than baseline.
↓ RISK	Alternative option is associated with slightly less risk than baseline.
≈ RISK	Alternative option is associated with same risk as baseline.
↑ RISK	Alternative option is associated with slightly more risk than baseline.
↑↑ RISK	Alternative option is associated with more risk than baseline.
↑↑↑ RISK	Alternative option is associated with much more risk than baseline.

Table 3 below represents the evidence and judgement that accompanies the Worker Health and Safety diagrams presented in Figure 2.

Table 3: Table Representing Evidence and Reasoning: Example of Worker Health and Safety.



Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↑RISK	↑↑RISK
	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Initial elevated risk during volume reduction of LLW.	Significant new construction of surface facilities, mineshaft and underground caverns. Increased on- and off-site transportation. Confined mine environment increases risk to workers in both DGR cases.	Significant new construction of infrastructure (roads, power lines); additional surface and storage facilities, mineshaft and underground caverns. Increased risk of conventional transportation accidents for workers due to waste transfer to repository.

In the case of Worker Health & Safety, the enhanced surface storage option has a very similar range of likelihoods and consequences as the status quo surface storage option. For this reason, the risks associated with the enhanced surface storage option are described to be very similar to those belonging to the status quo. The additional construction required at the Bruce and granite sites provides more opportunity for accidents to occur; in comparison to the status quo, there is a slightly higher chance of a worker-related accident, resulting in a slightly increased (depicted by a single arrow denoting an increase) risk relative to the status quo.

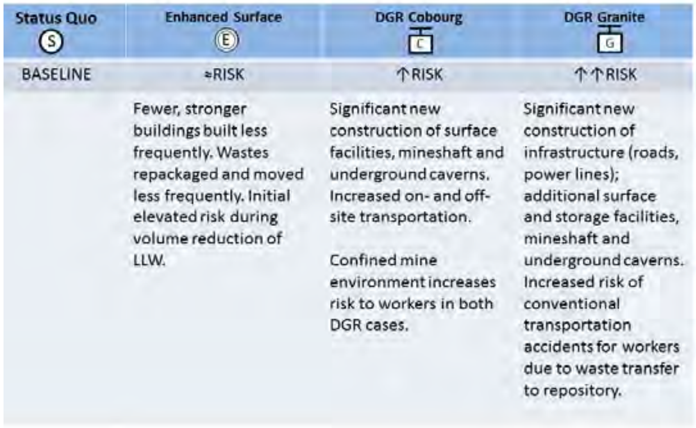
3.2 Relative Risk Assessment Results

The tables and images on the following pages present the results of the relative risk assessment approach conducted by the IEG. There are 12 pathways depicted. Following these 12 pages, there are two pages which extract the absolute risk assessment figures, and summarize them for the 12 pathways grouped by the two timeframes. Section 4 provides some general observations of the IEG based on the patterns of results shown here.

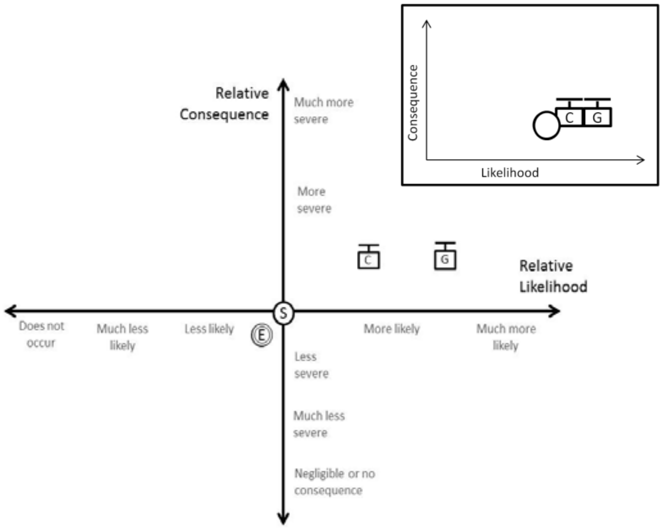
Worker Health and Safety

Includes:	Excludes:
• Normal operations and selected accidents • Construction (buildings, roads, mines) and mining accidents • Noise, dust, nuisance • On-site and off-site transportation accidents • Radiological exposure from normal operations	• Radiological exposures from accidents are assessed in other categories

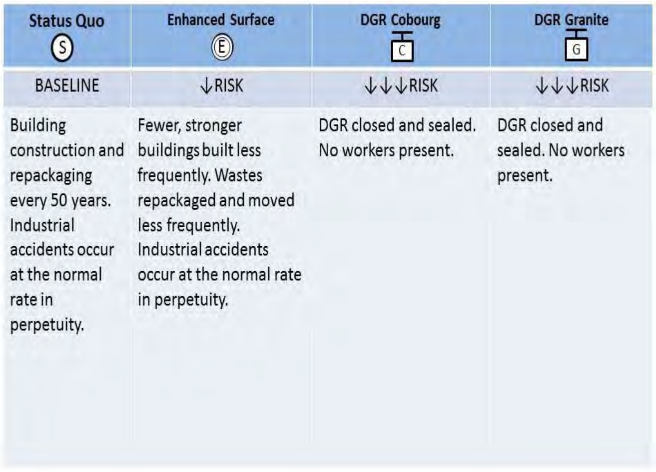
Timeframe: <100 years



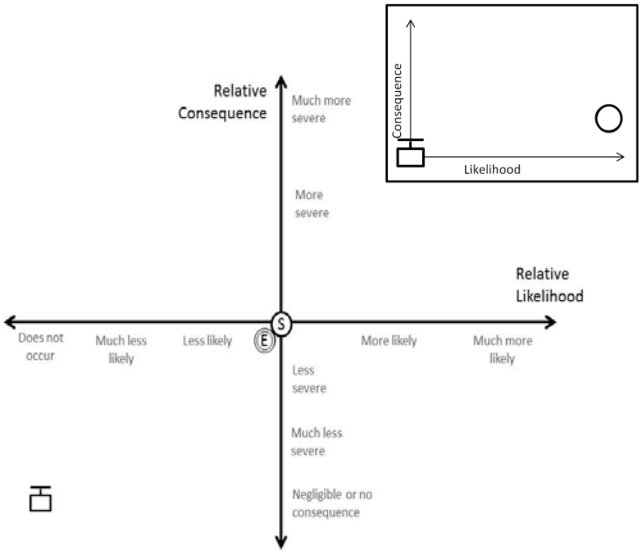
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↑RISK	↑↑RISK
	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Initial elevated risk during volume reduction of LLW.	Significant new construction of surface facilities, mineshaft and underground caverns. Increased on- and off-site transportation. Confined mine environment increases risk to workers in both DGR cases.	Significant new construction of infrastructure (roads, power lines); additional surface and storage facilities, mineshaft and underground caverns. Increased risk of conventional transportation accidents for workers due to waste transfer to repository.



Timeframe: >100 years



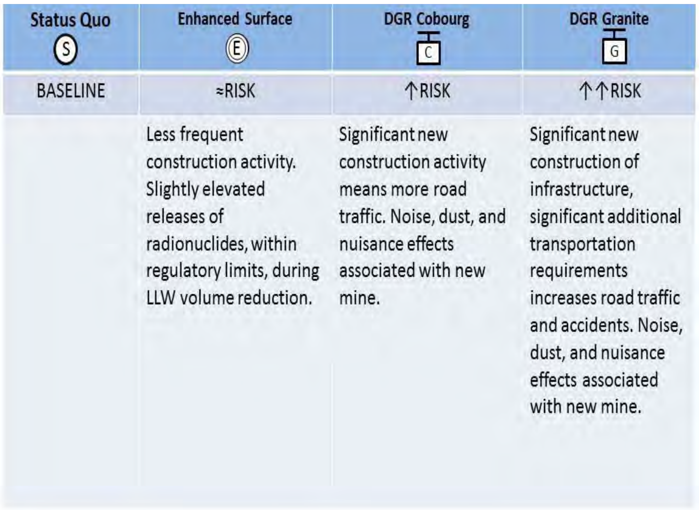
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Building construction and repackaging every 50 years. Industrial accidents occur at the normal rate in perpetuity.	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Industrial accidents occur at the normal rate in perpetuity.	DGR closed and sealed. No workers present.	DGR closed and sealed. No workers present.



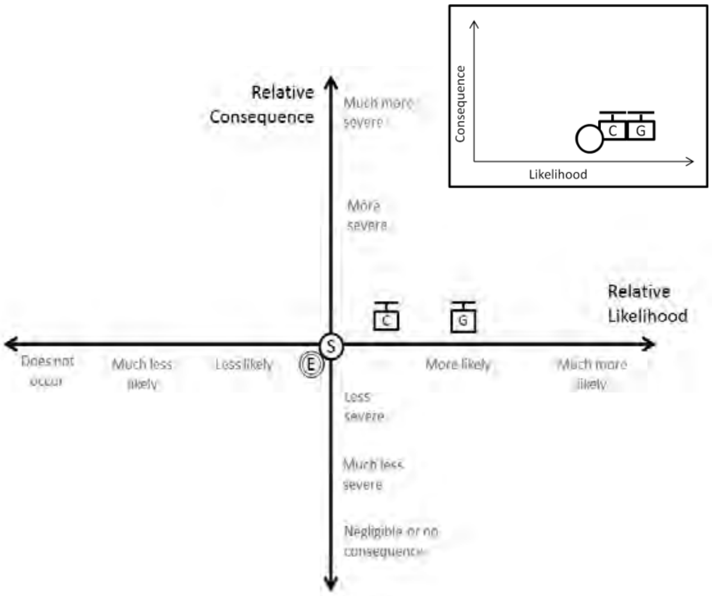
Public Health and Safety

Includes:	Excludes:
• Transportation on municipal roads and highways • Noise, dust, and nuisance off-site • Construction, operation, decommissioning, and post-closure phases	• Radiological exposures from normal operations and accidents

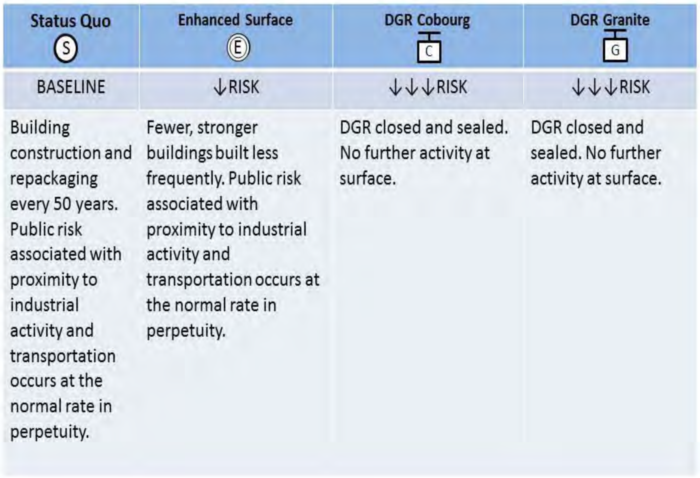
Timeframe: <100 years



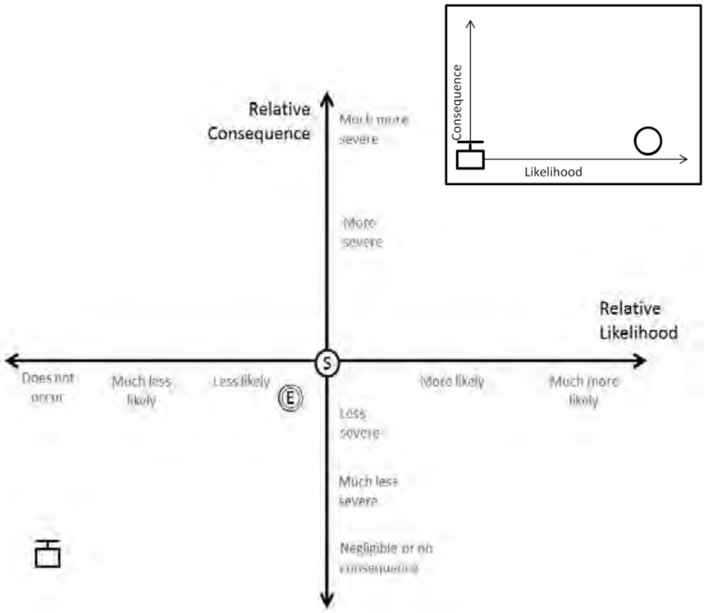
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↑RISK	↑↑RISK
	Less frequent construction activity. Slightly elevated releases of radionuclides, within regulatory limits, during LLW volume reduction.	Significant new construction activity means more road traffic. Noise, dust, and nuisance effects associated with new mine.	Significant new construction of infrastructure, significant additional transportation requirements increases road traffic and accidents. Noise, dust, and nuisance effects associated with new mine.



Timeframe: >100 years



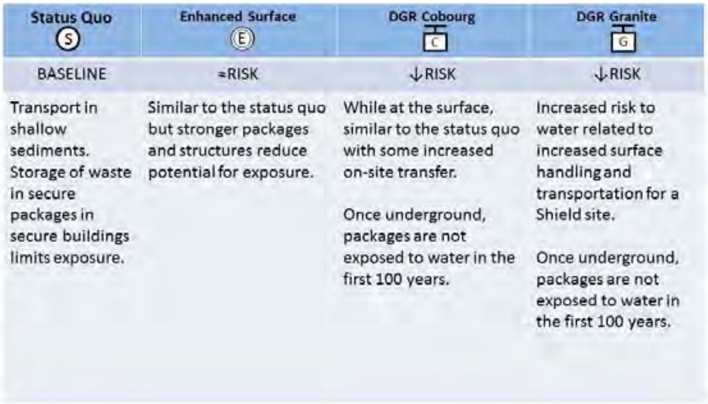
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Building construction and repackaging every 50 years. Public risk associated with proximity to industrial activity and transportation occurs at the normal rate in perpetuity.	Fewer, stronger buildings built less frequently. Public risk associated with proximity to industrial activity and transportation occurs at the normal rate in perpetuity.	DGR closed and sealed. No further activity at surface.	DGR closed and sealed. No further activity at surface.



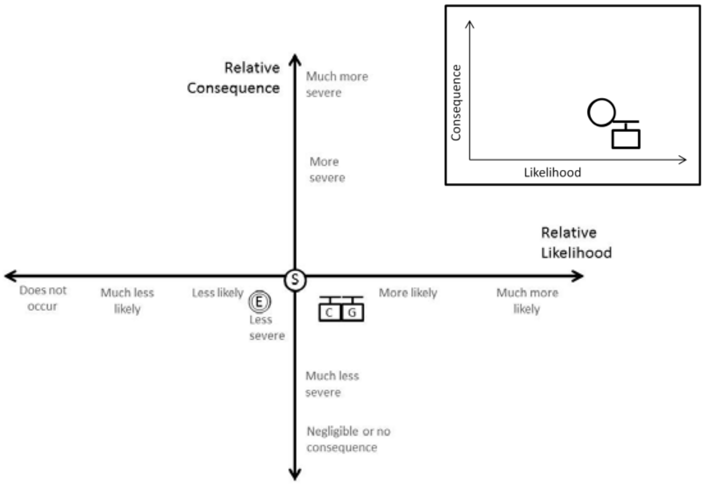
Transport of Released Radionuclides – Advective Water Flow

Includes:	Excludes:
- Radionuclide and other contaminants (e.g. metals) transport in the aqueous phase through existing fractures or porous media at depth or near the surface - Dissolved gases such as carbon dioxide	- Free gas advection and atmospheric emissions are covered elsewhere

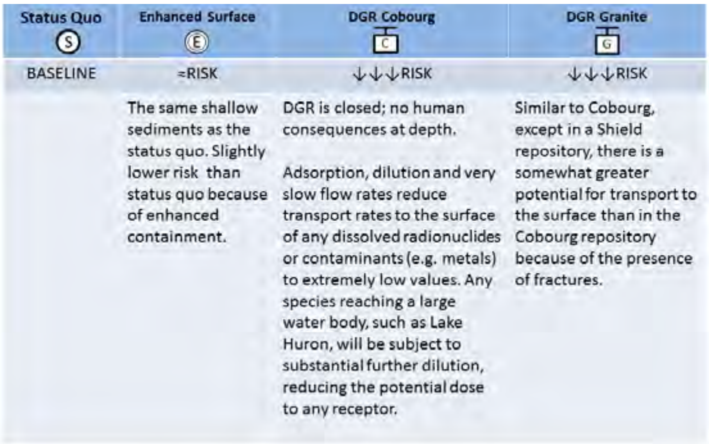
Timeframe: <100 years



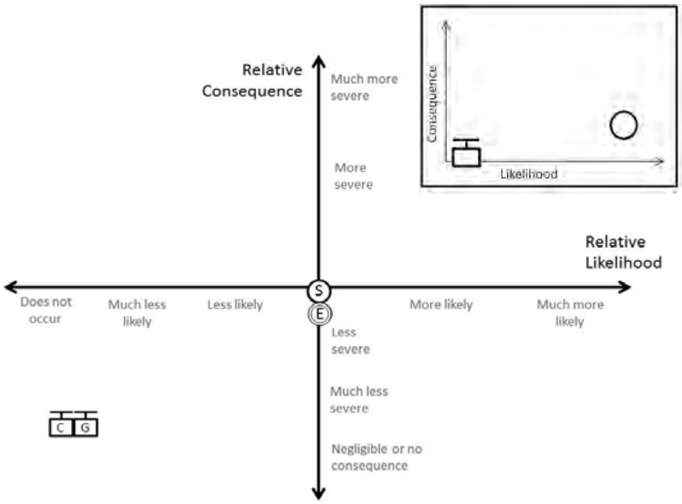
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↓RISK	↓RISK
Transport in shallow sediments. Storage of waste in secure packages in secure buildings limits exposure.	Similar to the status quo but stronger packages and structures reduce potential for exposure.	While at the surface, similar to the status quo with some increased on-site transfer. Once underground, packages are not exposed to water in the first 100 years.	Increased risk to water related to increased surface handling and transportation for a Shield site. Once underground, packages are not exposed to water in the first 100 years.



Timeframe: >100 years



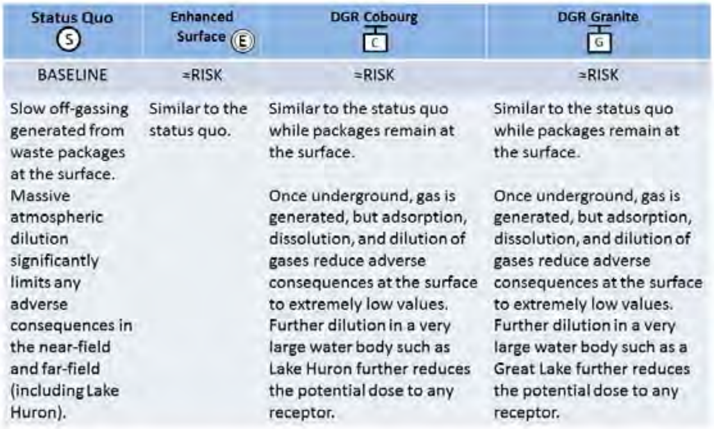
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	The same shallow sediments as the status quo. Slightly lower risk than status quo because of enhanced containment.	DGR is closed; no human consequences at depth. Adsorption, dilution and very slow flow rates reduce transport rates to the surface of any dissolved radionuclides or contaminants (e.g. metals) to extremely low values. Any species reaching a large water body, such as Lake Huron, will be subject to substantial further dilution, reducing the potential dose to any receptor.	Similar to Cobourg, except in a Shield repository, there is a somewhat greater potential for transport to the surface than in the Cobourg repository because of the presence of fractures.



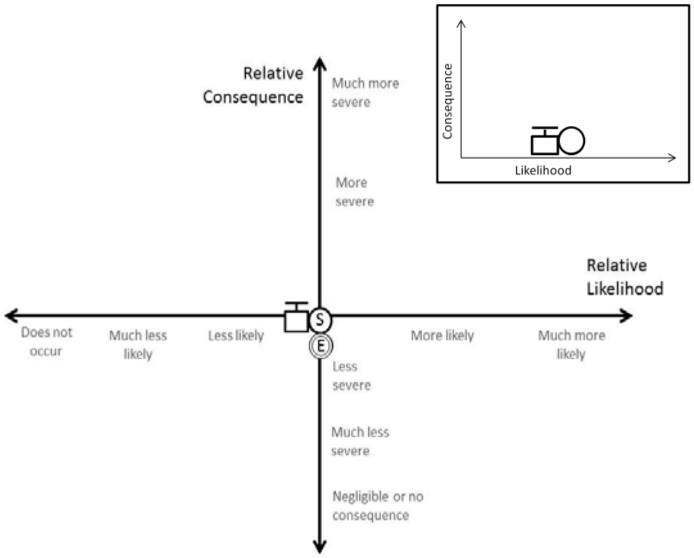
Transport of Released Radionuclides – Advective Gas Flow

Includes:	Excludes:
- Radionuclide transport in the gaseous phase through existing fractures or porous media - Gas generation from waste off-gassing and degradation products - Direct emissions to the atmosphere from surface facilities	- Gas transportation in aqueous dissolved phase - Worker exposures underground

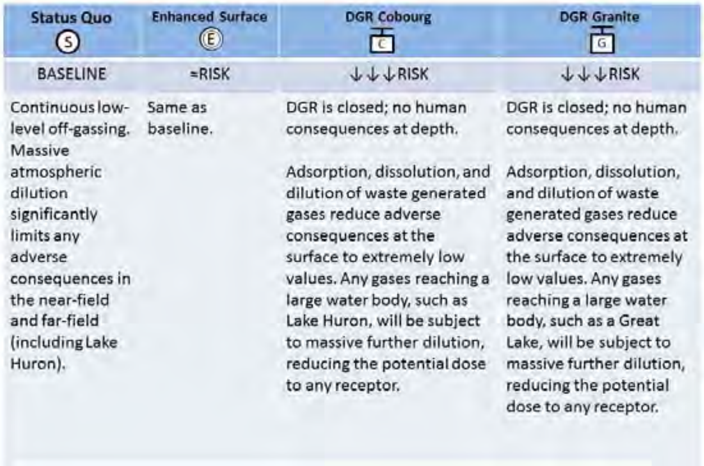
Timeframe: < 100 years



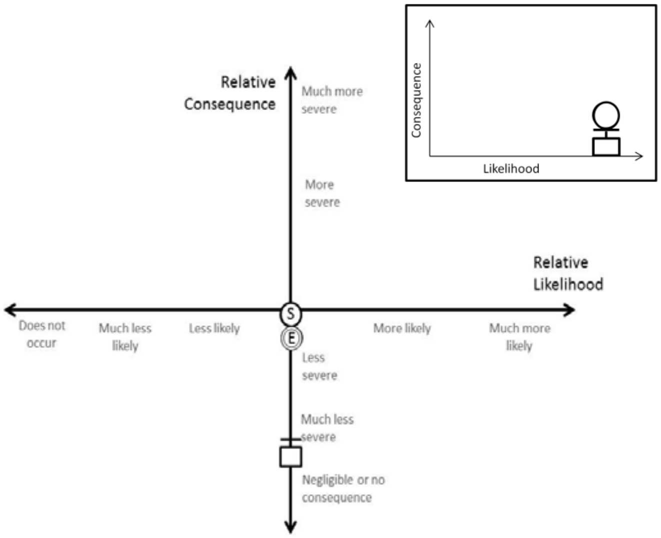
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg 🄲	DGR Granite 🄶
BASELINE	≈RISK	≈RISK	≈RISK
Slow off-gassing generated from waste packages at the surface. Massive atmospheric dilution significantly limits any adverse consequences in the near-field and far-field (including Lake Huron).	Similar to the status quo.	Similar to the status quo while packages remain at the surface. Once underground, gas is generated, but adsorption, dissolution, and dilution of gases reduce adverse consequences at the surface to extremely low values. Further dilution in a very large water body such as Lake Huron further reduces the potential dose to any receptor.	Similar to the status quo while packages remain at the surface. Once underground, gas is generated, but adsorption, dissolution, and dilution of gases reduce adverse consequences at the surface to extremely low values. Further dilution in a very large water body such as a Great Lake further reduces the potential dose to any receptor.



Timeframe: > 100 years



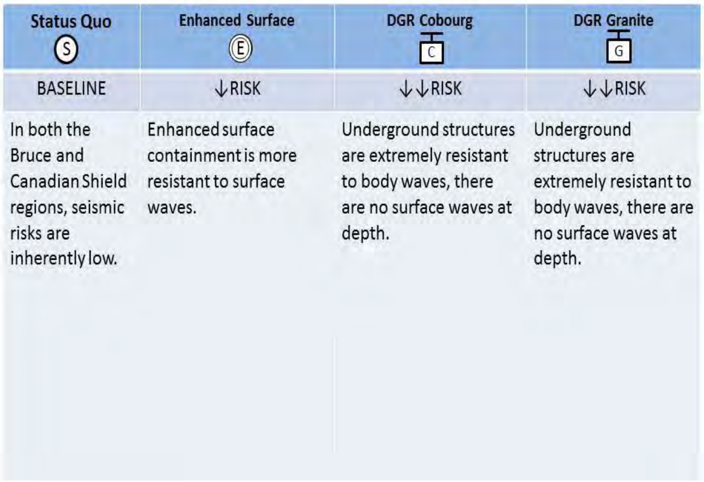
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg 🄲	DGR Granite 🄶
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
Continuous low-level off-gassing. Massive atmospheric dilution significantly limits any adverse consequences in the near-field and far-field (including Lake Huron).	Same as baseline.	DGR is closed; no human consequences at depth. Adsorption, dissolution, and dilution of waste generated gases reduce adverse consequences at the surface to extremely low values. Any gases reaching a large water body, such as Lake Huron, will be subject to massive further dilution, reducing the potential dose to any receptor.	DGR is closed; no human consequences at depth. Adsorption, dissolution, and dilution of waste generated gases reduce adverse consequences at the surface to extremely low values. Any gases reaching a large water body, such as a Great Lake, will be subject to massive further dilution, reducing the potential dose to any receptor.



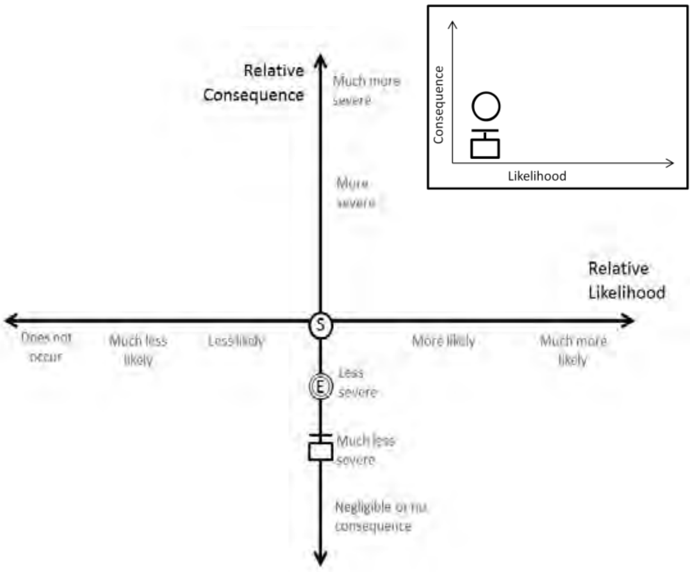
Seismic Impairment

Includes:	Excludes
• Any seismic event that is sufficiently large to lead to structural damage of buildings or underground shafts and tunnels • Major geological fracturing associated with any form of seismicity	• Long term tectonic processes

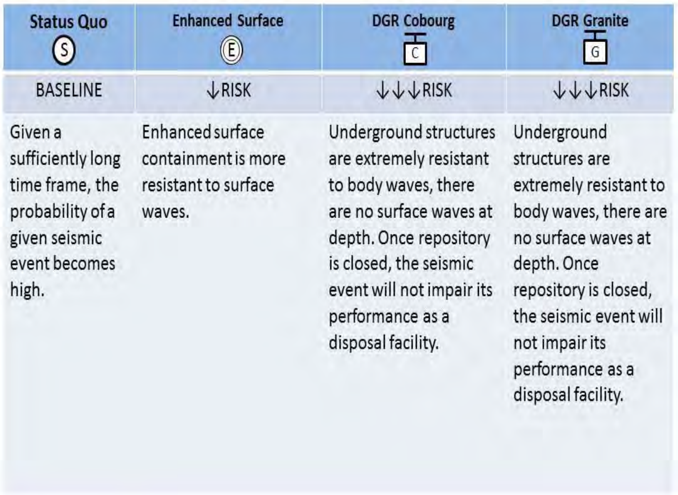
Timeframe: < 100 years



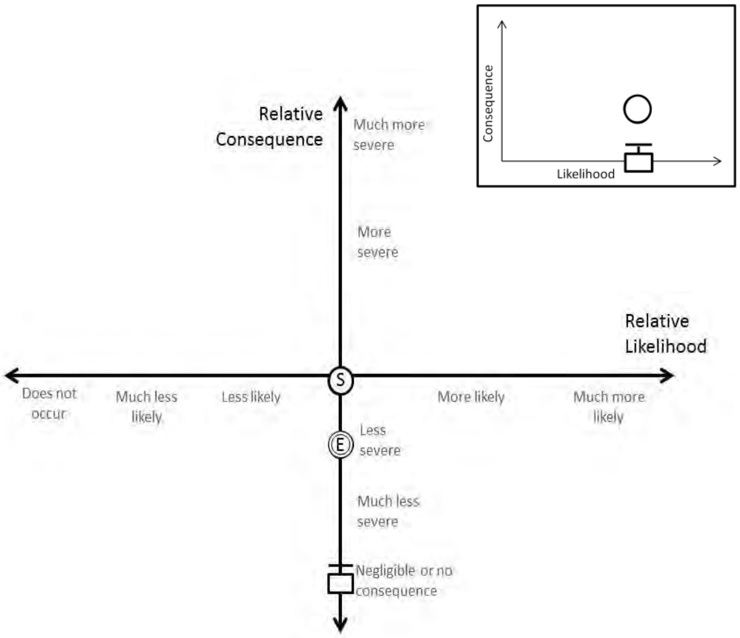
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓RISK	↓↓RISK
In both the Bruce and Canadian Shield regions, seismic risks are inherently low.	Enhanced surface containment is more resistant to surface waves.	Underground structures are extremely resistant to body waves, there are no surface waves at depth.	Underground structures are extremely resistant to body waves, there are no surface waves at depth.



Timeframe: >100 years



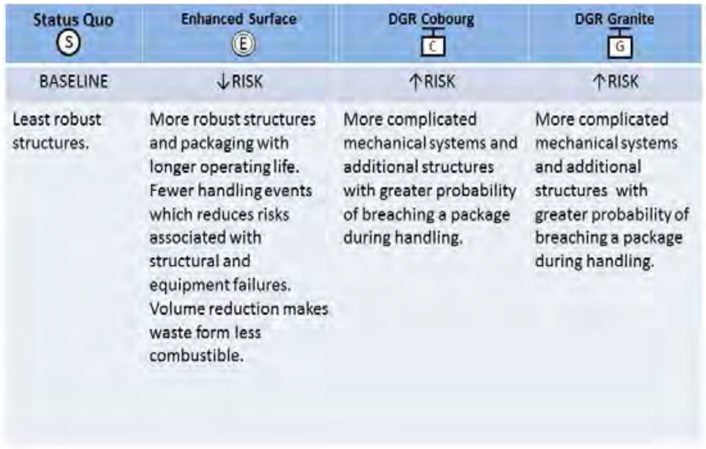
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Given a sufficiently long time frame, the probability of a given seismic event becomes high.	Enhanced surface containment is more resistant to surface waves.	Underground structures are extremely resistant to body waves, there are no surface waves at depth. Once repository is closed, the seismic event will not impair its performance as a disposal facility.	Underground structures are extremely resistant to body waves, there are no surface waves at depth. Once repository is closed, the seismic event will not impair its performance as a disposal facility.



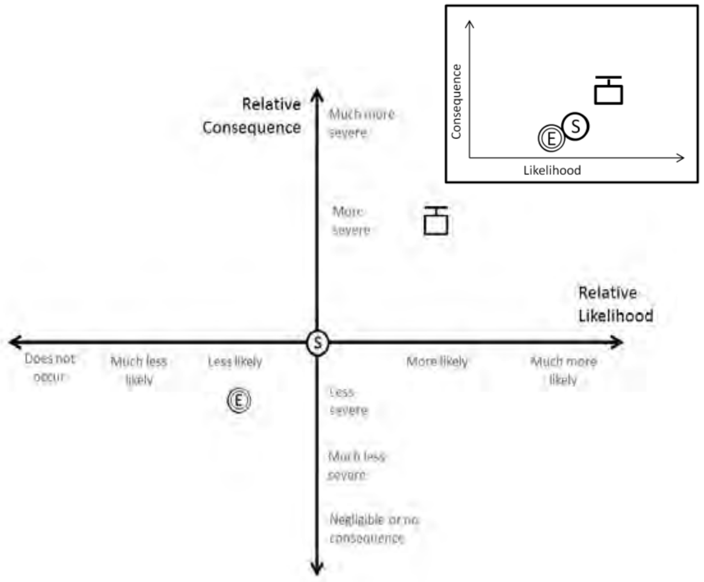
Structural and Mechanical Impairments

Includes:	Excludes:
- Buildings, equipment, impacts on building services, e.g. power loss, ventilation and pumping equipment failure, fire, flooding, rock fall - Mechanical failures (e.g. hoist way) - Equipment malfunctions	- Seismic induced failures, severe weather, and glaciation - Failures of packaging

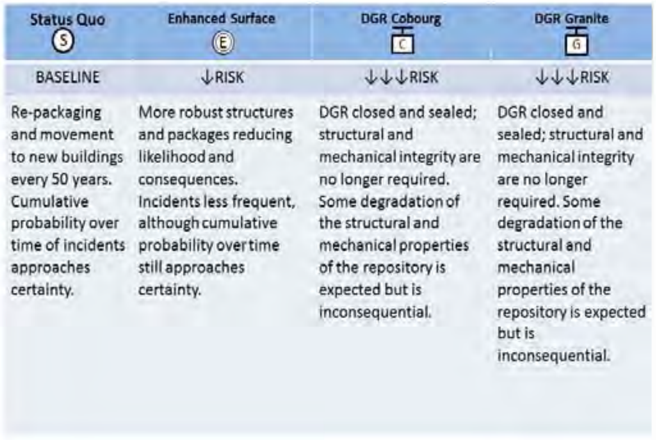
Timeframe: <100 years



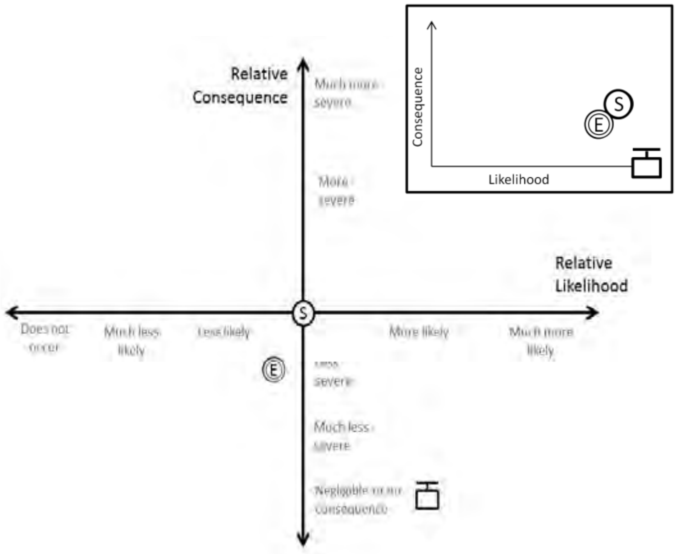
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↑RISK	↑RISK
Least robust structures.	More robust structures and packaging with longer operating life. Fewer handling events which reduces risks associated with structural and equipment failures. Volume reduction makes waste form less combustible.	More complicated mechanical systems and additional structures with greater probability of breaching a package during handling.	More complicated mechanical systems and additional structures with greater probability of breaching a package during handling.



Timeframe: >100 years



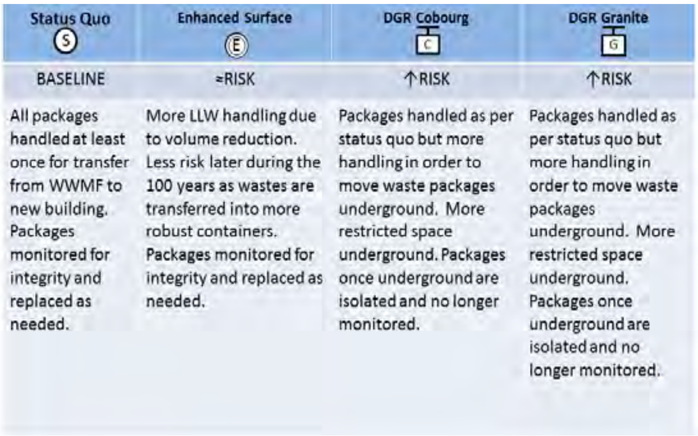
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Re-packaging and movement to new buildings every 50 years. Cumulative probability over time of incidents approaches certainty.	More robust structures and packages reducing likelihood and consequences. Incidents less frequent, although cumulative probability over time still approaches certainty.	DGR closed and sealed; structural and mechanical integrity are no longer required. Some degradation of the structural and mechanical properties of the repository is expected but is inconsequential.	DGR closed and sealed; structural and mechanical integrity are no longer required. Some degradation of the structural and mechanical properties of the repository is expected but is inconsequential.



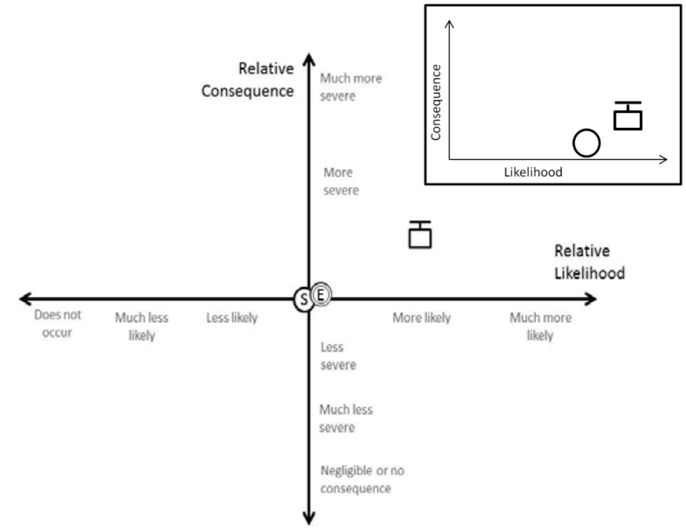
Waste Container Integrity

Includes:	Excludes:
- Storage and permanent disposal - Seepage, release rates, microbial activity - Package handling and breach	- Waste processing, structural and mechanical integrity of buildings and mine works - Transportation accidents

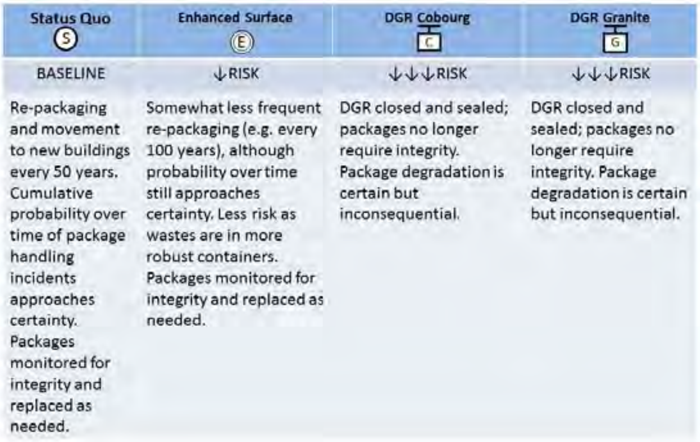
Timeframe: <100 years



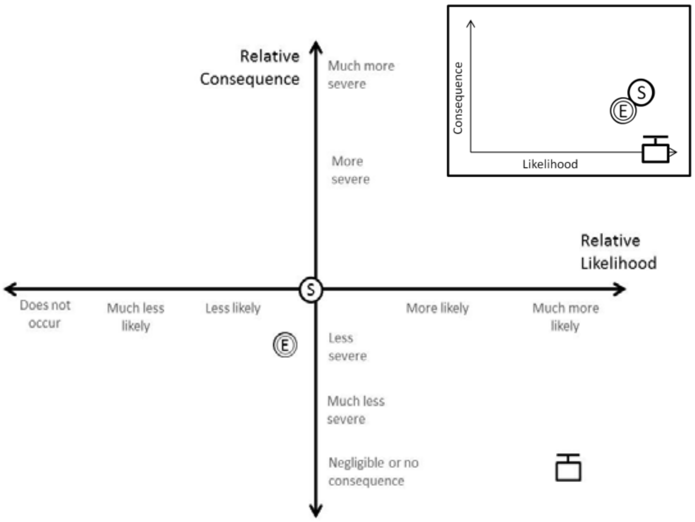
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↑RISK	↑RISK
All packages handled at least once for transfer from WWMF to new building. Packages monitored for integrity and replaced as needed.	More LLW handling due to volume reduction. Less risk later during the 100 years as wastes are transferred into more robust containers. Packages monitored for integrity and replaced as needed.	Packages handled as per status quo but more handling in order to move waste packages underground. More restricted space underground. Packages once underground are isolated and no longer monitored.	Packages handled as per status quo but more handling in order to move waste packages underground. More restricted space underground. Packages once underground are isolated and no longer monitored.



Timeframe: >100 years



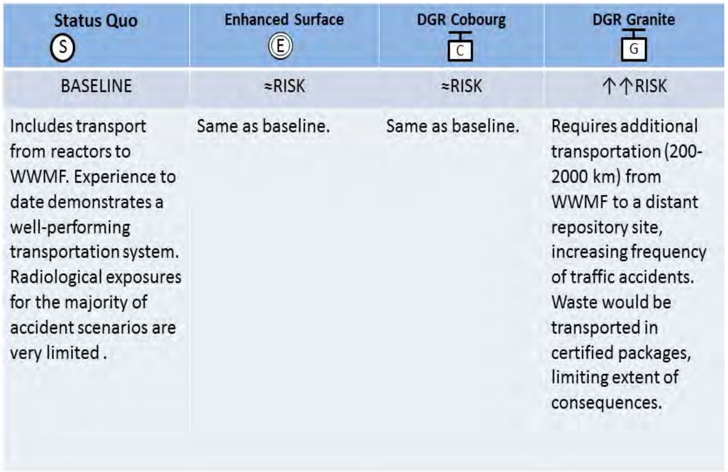
Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Re-packaging and movement to new buildings every 50 years. Cumulative probability over time of package handling incidents approaches certainty. Packages monitored for integrity and replaced as needed.	Somewhat less frequent re-packaging (e.g. every 100 years), although probability over time still approaches certainty. Less risk as wastes are in more robust containers. Packages monitored for integrity and replaced as needed.	DGR closed and sealed; packages no longer require integrity. Package degradation is certain but inconsequential.	DGR closed and sealed; packages no longer require integrity. Package degradation is certain but inconsequential.



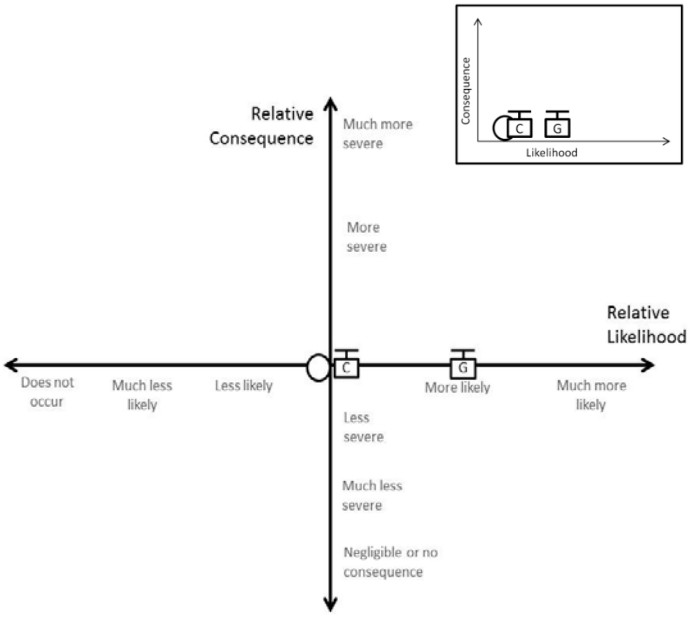
Radiological Exposure During Transportation Accidents

Assumes:	Includes:	Excludes:
• Additional waste transport (200-2000 km) to a distant granite repository from the WWMF • No transport after 100 years • Identical packaging technology in all transportation scenarios	• Transfers from reactors to WWMF for all options • Accidents	• Intra-site transfers covered under normal operations in WH&S • Public risk due to physical harm due to transportation accident • Malevolent acts

Timeframe: < 100 years



Status Quo S	Enhanced Surface E	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	≈RISK	↑↑RISK
Includes transport from reactors to WWMF. Experience to date demonstrates a well-performing transportation system. Radiological exposures for the majority of accident scenarios are very limited .	Same as baseline.	Same as baseline.	Requires additional transportation (200-2000 km) from WWMF to a distant repository site, increasing frequency of traffic accidents. Waste would be transported in certified packages, limiting extent of consequences.



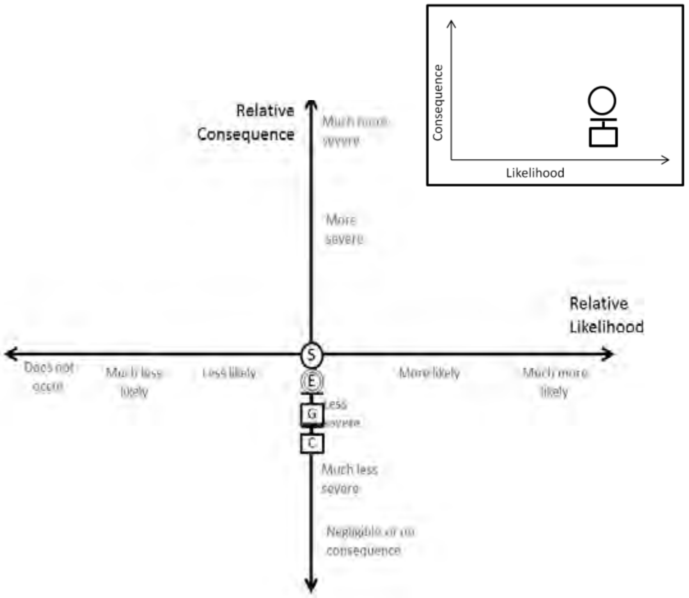
Severe Weather

Includes:

- Extreme wind and hurricane
- Tornado
- Extreme precipitation
- Flooding and surface erosion
- Climate change

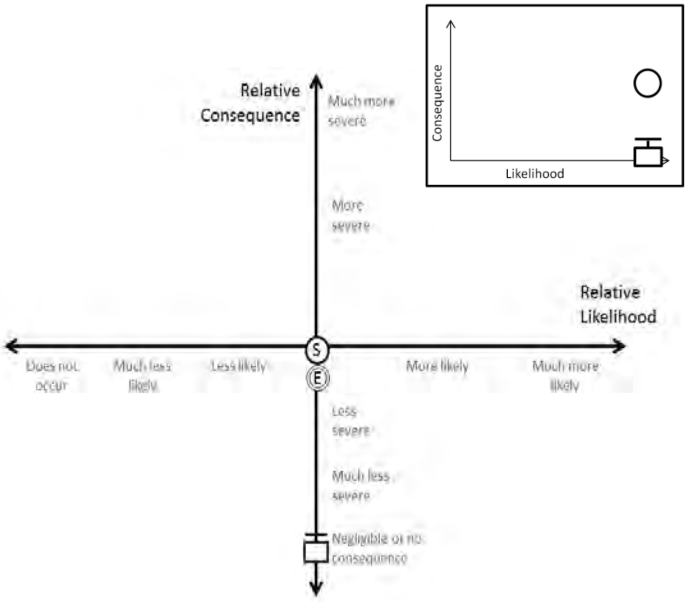
Timeframe: < 100 years

Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓RISK	↓RISK
	Higher degree of structural protection lowers consequence for each severe weather event, probability of events remains the same	In first 100 years, DGR is being built and commissioned, followed by a gradual transition of the stored waste to the underground repository. Waste remaining at the surface will be vulnerable at the same level as the baseline; wastes that are moved underground will be unaffected , probability of events remains the same	Same as DGR Cobourg with the addition that there is a transportation program underway in which some waste may be in transit plus an additional temporary surface storage facility on-site.



Timeframe: >100 years

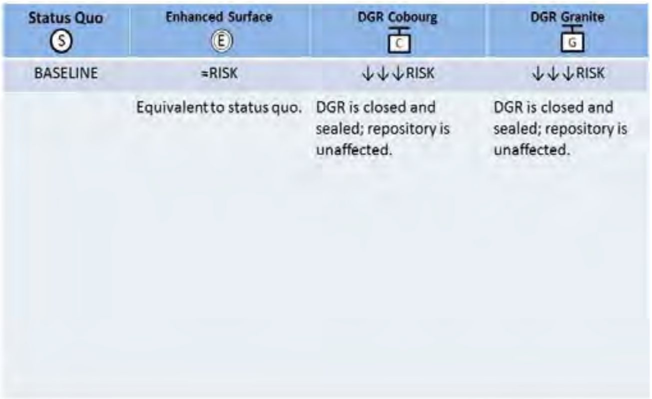
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈ RISK	↓↓↓RISK	↓↓↓RISK
	For surface storage in perpetuity, major events are inevitable. The enhanced structural quality in this scenario may marginally reduce the consequences.	No event impacts after closure and sealing.	No event impacts after closure and sealing.



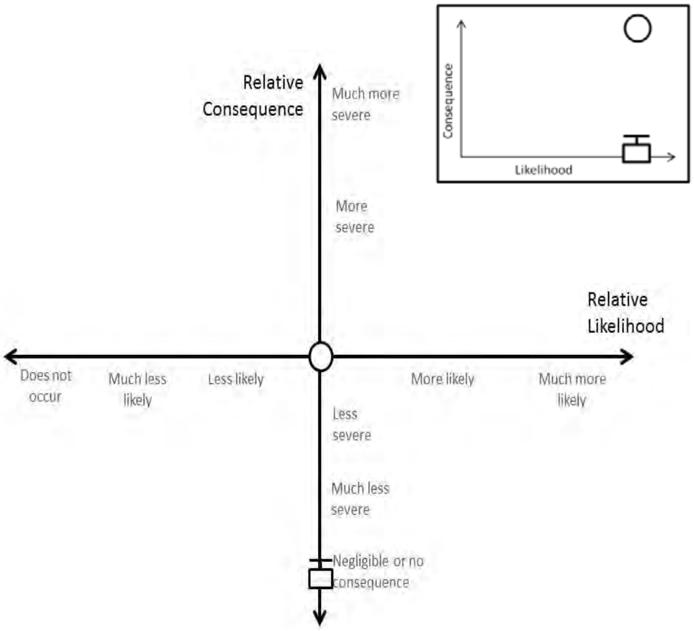
Glaciation

Assumes:	Excludes:
• The possible future re-occurrence of continental glaciation leading to the creation and movement of a thick ice sheet across the site • Glaciation cycle is uncertain; assumes next glaciation in the timeframe of 10,000 – 100,000 years • Cannot assume institutional control	• Any short-term possibilities (less than 100 years)

Timeframe: >100 years



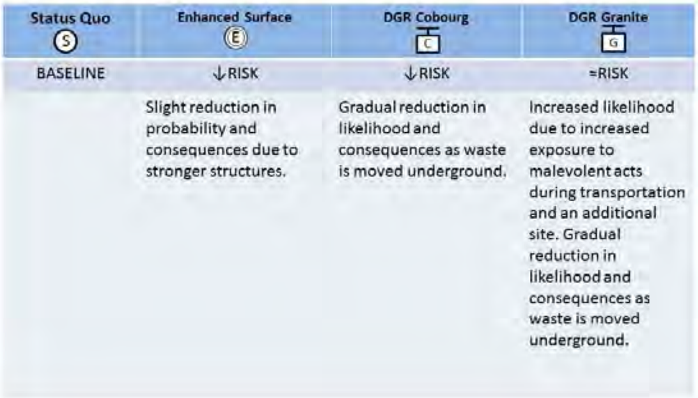
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	=RISK	↓↓↓RISK	↓↓↓RISK
	Equivalent to status quo.	DGR is closed and sealed; repository is unaffected.	DGR is closed and sealed; repository is unaffected.



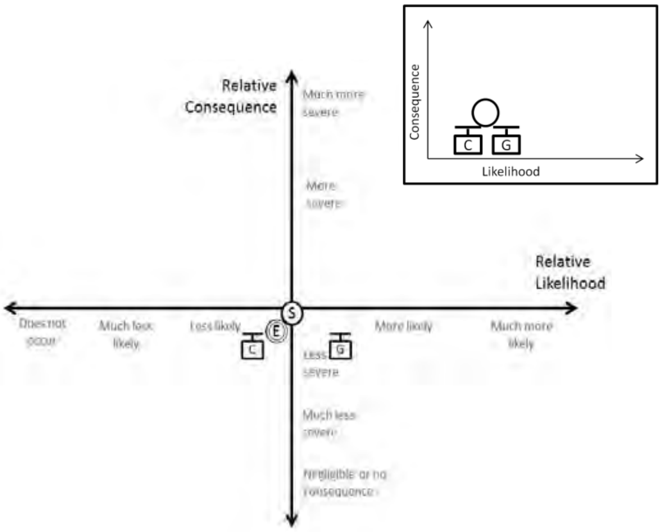
Malevolent Acts

Includes:	Excludes:
- All intentional acts regardless of motivation - Theft, mischief, politically motivated acts - Assumes presence of institutional controls in perpetuity	- Accidental intrusion

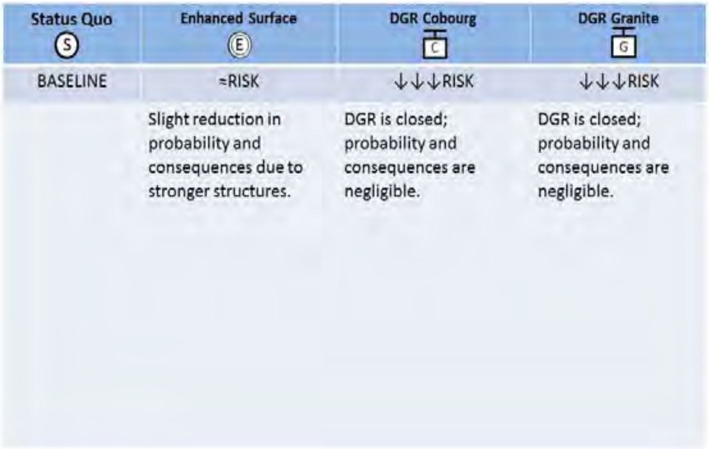
Timeframe: <100 years



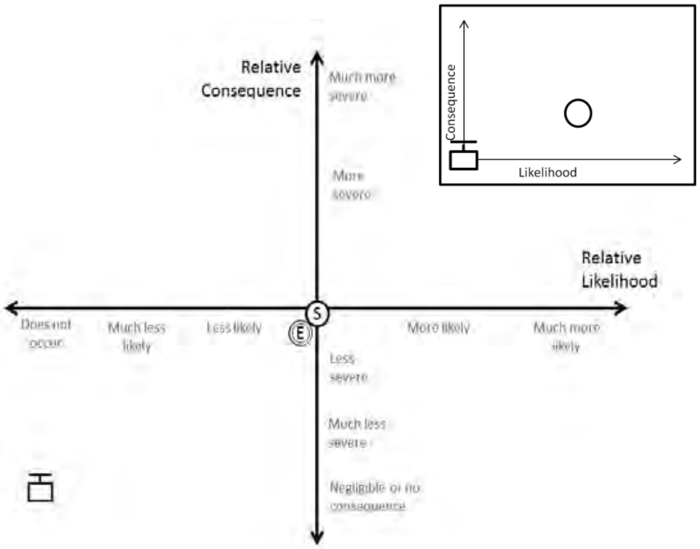
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	↓RISK	↓RISK	≈RISK
	Slight reduction in probability and consequences due to stronger structures.	Gradual reduction in likelihood and consequences as waste is moved underground.	Increased likelihood due to increased exposure to malevolent acts during transportation and an additional site. Gradual reduction in likelihood and consequences as waste is moved underground.



Timeframe: >100 years



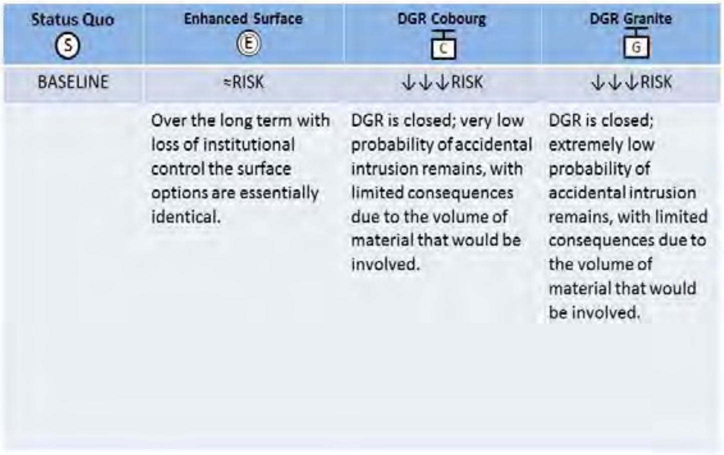
Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	Slight reduction in probability and consequences due to stronger structures.	DGR is closed; probability and consequences are negligible.	DGR is closed; probability and consequences are negligible.



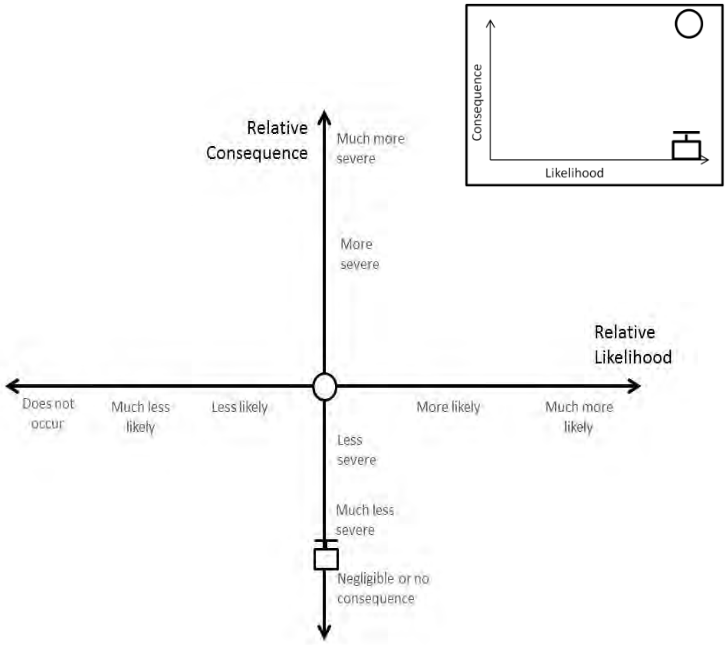
Loss of Institutional Control

Assumes:	Includes:
- Only relevant after 100 years - Very high probability of occurrence at least once after 100 years and up to 100,000 years - No changes in surface storage options over that same timeframe	- All pathways of harm (natural, operational, accidental, malevolent) that rely on continuous presence of institutional control

Timeframe: >100 years

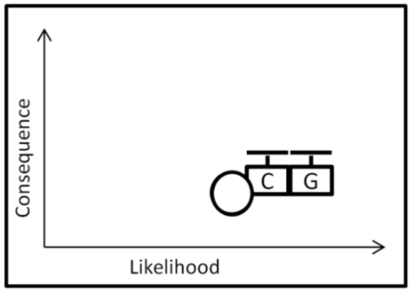


Status Quo Ⓢ	Enhanced Surface Ⓔ	DGR Cobourg C	DGR Granite G
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	Over the long term with loss of institutional control the surface options are essentially identical.	DGR is closed; very low probability of accidental intrusion remains, with limited consequences due to the volume of material that would be involved.	DGR is closed; extremely low probability of accidental intrusion remains, with limited consequences due to the volume of material that would be involved.

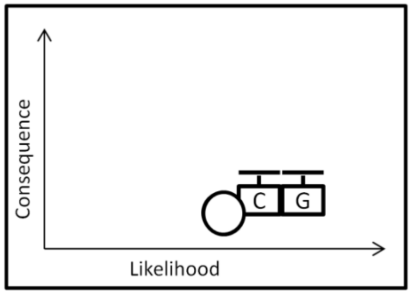


Timeframe: <100 years

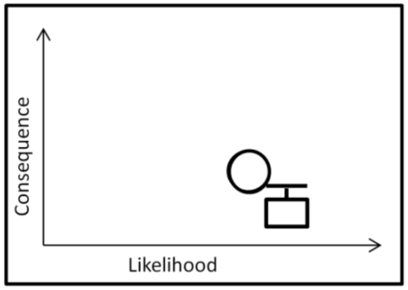
Worker Health and Safety



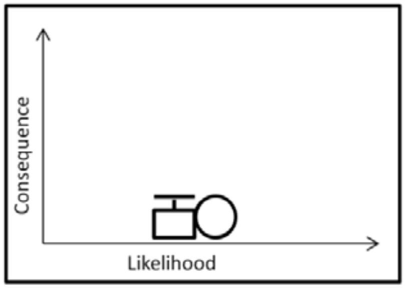
Public Health and Safety



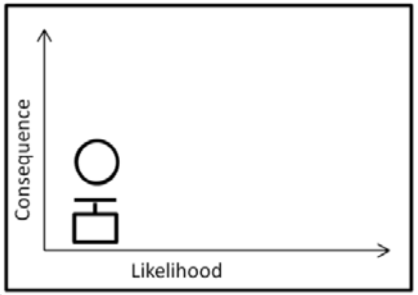
Transport of Radionuclides: Advective Water Flow



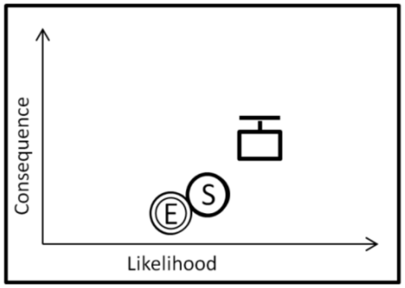
Transport of Radionuclides: Advective Gas Flow



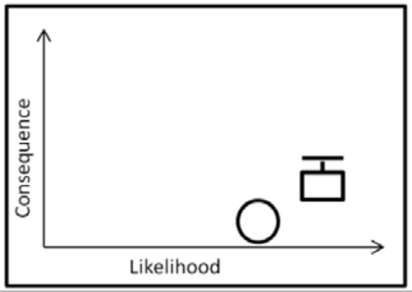
Seismic Impairment



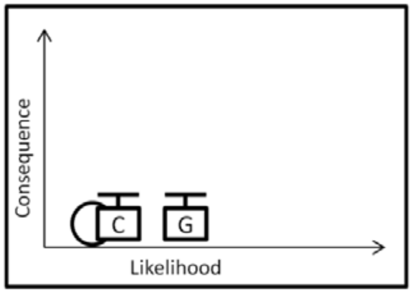
Structural and Mechanical Impairments



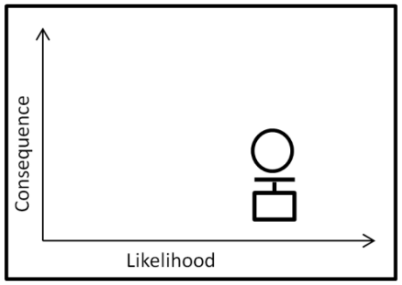
Waste Container Integrity



Radiological Exposure During Transportation Accidents



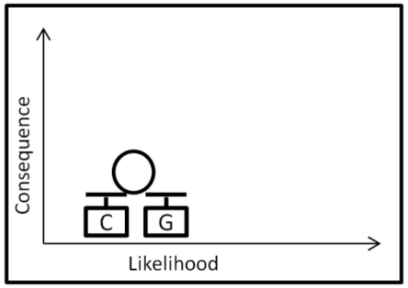
Severe Weather



Glaciation

Will not occur in the next 100 years.

Malevolent Acts

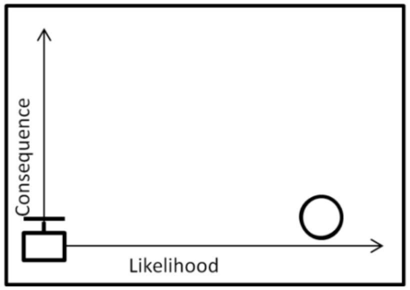


Loss of Institutional Control

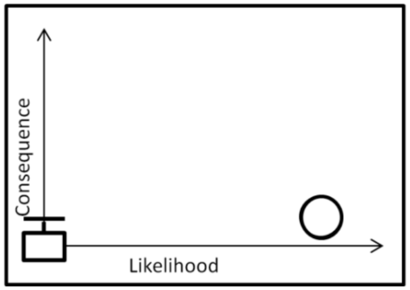
Will not occur in the next 100 years.

Timeframe: >100 years

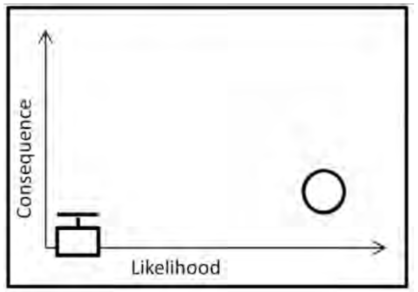
Worker Health and Safety



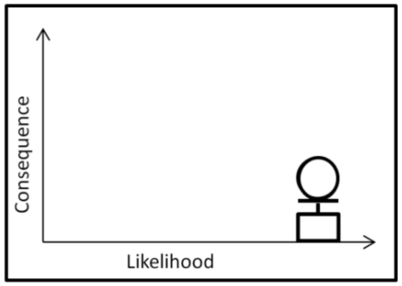
Public Health and Safety



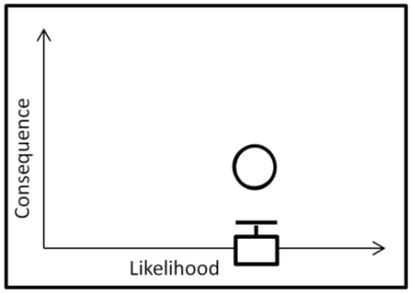
Transport of Radionuclides: Advective Water Flow



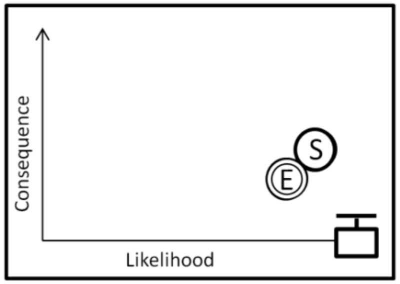
Transport of Radionuclides: Advective Gas Flow



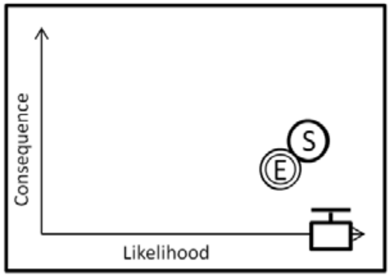
Seismic Impairment



Structural and Mechanical Impairments



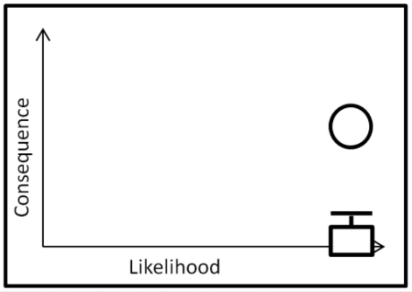
Waste Container Integrity



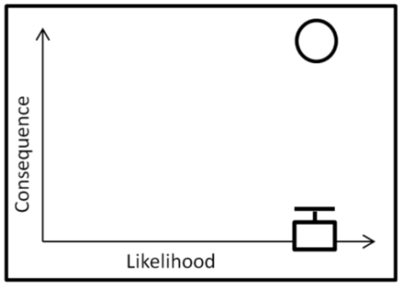
Radiological Exposure During Transportation Accidents

Will not occur after 100 years.

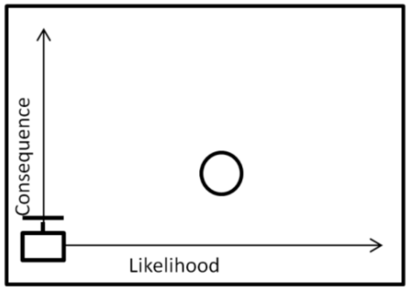
Severe Weather



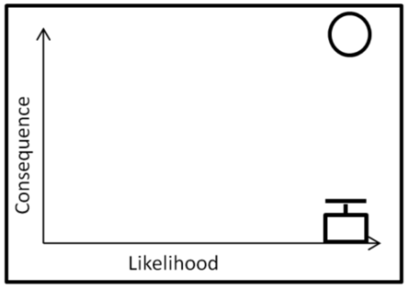
Glaciation



Malevolent Acts



Loss of Institutional Control



4 Results and Observations for the Qualitative Risk Comparison

The JRP has asked that four options be compared: the status quo of surface storage maintained into the indefinite future; an enhanced surface storage program then maintained into the indefinite future; geologic disposal in the sedimentary Cobourg Formation at the Bruce site as currently proposed; and disposal into a conceptual geologic formation in the granitic Canadian Shield.

The IEG identified the important features for comparing the options, assuring that all the elements in the JRP assignment were part of the assessment. The team identified twelve key features for comparison and evaluated each of them for the near term (<100 years) and long term (>100 years). In a few cases, only one of the time periods made sense (e.g., a comparison of the impacts of glaciation only makes sense for the long term). In each case, the IEG assessed two aspects for each element in the comparisons: (1) How did the four options compare to one another in expected performance? (2) How important was the feature in achieving the overall performance objectives of the waste management program as illustrated in the absolute risk charts in Section 3?

This careful evaluation is particularly necessary since the diagrams are populated on a log-log scale to be able to capture differences that may be one or more orders of magnitude. As an example, a feature that scores very high in likelihood or consequence or both may be a factor of 100 or 1000 or more different than one that scores low.

While there are a number of important factors in comparing these options, there are two fundamental issues among the options that were ascertained to be of the greatest consequence in the assessment: (a) the implications of indefinite surface storage versus permanent disposal in a deep geologic repository for the long term; and (b) the implications of choosing a granite repository site for geologic disposal at some distance away from the current waste management storage location, rather than in the sedimentary-rock Cobourg formation located adjacent to the current storage site, for the wastes.

Indefinite long term storage versus geologic disposal.

The principal issue with regard to storage versus disposal is the degree of confidence one has in the very long term (many thousands of years) availability and operation of the active management required for both surface storage options. While low-level and some fraction of intermediate level wastes will decay in relatively short time periods, much of the intermediate level wastes remain potentially hazardous for much longer time periods. That has been the driver for the decisions made in many countries to provide for ultimate geologic disposal with the view being that once the wastes are emplaced deep underground in a suitable location, active management is no longer necessary.

The comparative assessment of the likelihood and consequences of the ultimate loss of institutional controls necessary to maintain assurance of protection of public and worker health and safety, security, and the environment becomes a key factor in comparing the surface and repository options. The assessment team judged that long term institutional controls (including the capacity, resources, expertise, political and societal will) cannot be guaranteed or even expected over the many thousands of years that the wastes remain potentially hazardous. The long term consequences of such a postulated eventual loss of institutional control are judged to be extremely high on very important elements such as protection against long term severe weather, glaciation, inadvertent intrusion, and malevolent acts.

Climate change and glaciation. The major consideration is that surface facilities will be more vulnerable to climate change and glaciation in the very long term. Even with assumed active institutional controls into the long term, severe weather would provide a significant challenge to surface facilities and if active controls were to cease at some point, the degradation of the facilities and waste packaging would make severe weather a much greater risk than in the repository options where deep emplacement would make the wastes safe from weather and climate considerations. Whenever a new glaciation period occurred, it may eventually be necessary to move the storage options to a new location where active controls can be maintained. Such glaciation implications would not affect the repository options.

Inadvertent intrusion. Intrusion in the future is a serious risk and must be precluded to the extent possible. In the storage options, as long as there is active control a security program would be kept in place to preclude inadvertent (or deliberate) intrusion. Should active controls be lost in the long term, the potential for intrusion would increase substantially and increase the risk accordingly. Once the wastes are emplaced in a deep geologic formation, the probability of inadvertent intrusion would decrease markedly, even though it is assumed that knowledge of the location of the repository is eventually lost. Siting of a repository requires an assessment finding that there are no significant known deposits of minerals or other materials that might credibly invite exploration into the repository at some time in the future.

Malevolent acts. While the probability and consequences of potential malevolent acts far into the future are unknown, the expectation is that disposal of the wastes into a deep geologic repository would make access much more unlikely and difficult to accomplish. As long as institutional controls are maintained, security (and its costs) would be an important component of the on-site responsibility. If institutional controls are eventually lost, access to the site and the wastes would be considerably easier and the probability of the malevolent use of the wastes would accordingly become higher, though over time the hazard would diminish somewhat as the wastes decay.

The shorter term consequences of moving to geologic disposal are in some cases higher than for storage options as the construction and operation of a geologic repository will have short term consequences. These are anticipated to be limited much like the consequences of other modern mining operations and of much less consequence than the longer term differences described above. The shorter term consequences of a repository sited in granite are expected to be greater than those for a repository at the Bruce site since siting at a granite site will require additional handling and transportation steps with their attendant worker and public safety consequences. These are judged to be similar to those associated with the transport of hazardous wastes in other industries.

Finally, while worker and public health and safety are anticipated to be low while institutional controls are maintained into the future, once the wastes have been emplaced into a deep geologic repository in either the Cobourg Formation at the Bruce site or a granite site, and the site then closed, the anticipated impacts on worker and public health and safety are judged to become lower. While the enhanced surface storage option provides some improvements over the status quo, these were judged to be valuable but of limited consequence when considering the long term implications of a loss of institutional control.

Geologic disposal in the Cobourg Formation at the Bruce site versus a granitic repository.

The second key issue relates to the assessment of differences in building the geologic repository in the sedimentary Cobourg Formation at the current storage site for the wastes versus siting a repository in granite somewhere in the Canadian Shield. The IEG reads the description provided for the granitic repository to suggest that such a site in a hydrologic setting comparable to the proposed sedimentary site at Bruce should be considered.

Differences in a number of individual risks between the Cobourg Formation at the Bruce site and the generic granite site are described in the comparative evaluations in Section 3. Both would be expected to perform well within the regulatory requirements for long term safety and environmental protection. The need for additional handling and transportation steps influences the comparison between the two repository options. The additional step of moving the wastes off of the Bruce site, where the wastes are presently processed and stored, requires substantially more handling and more miles of waste transportation. Longer distances will increase the risk of more conventional transportation accidents. However, the potential for radiological exposure is judged to be quite low for both handling and transportation.

In conclusion: The Independent Expert Group was tasked by the Joint Review Panel to review and compare four specific management options for the safe management of low- and intermediate-level waste in Canada. The directive indicated that the IEG should address the comparisons in terms of the relative risks. Risk is the product of the probability and consequences for a number of factors that must be comparatively evaluated for the four management options. The IEG developed a framework for consistently and transparently evaluating the comparative risks, on a qualitative basis, for each of the four options against the important individual features that can discriminate among their safety performance. This analysis is intended to be inclusive of all of the pathways of harm that were identified within the charge to the IEG provided by the JRP.

Appendices

Appendix I: Thematic Requests to the Expert Group

A. JRP, EIS-12-513 Alternatives Review:

Provide a renewed and updated analysis of the relative risks of siting alternatives under alternative means requirements of the EIS Guidelines. This analysis should be undertaken by independent risk assessment experts. The analysis is to be qualitative, transparent, defensible, and repeatable.

Options to be analyzed:

1. "As is" facility at the WWMF (the status quo).

2. Enhanced surface storage at the WWMF ("hardened" storage).

3. Proposed DGR in the Cobourg Formation at the Bruce Power site.

4. A conceptual DGR in granitic bedrock of the Precambrian Canadian Shield. Information required for the qualitative analysis of a conceptual DGR in granite bedrock should be based primarily upon the extensive data and analyses available within the environmental assessment performed by Atomic Energy of Canada Limited (AECL) for the Environmental Assessment Panel for Nuclear Fuel Waste Management and Disposal Concept (known as the Seaborne Panel).

Analysis of risks to socio-economic factors (such as physical, social and financial assets) is not required because the conceptual DGR in granite is not located in a specific geographic location.

The relative risk of each alternative should be assessed for normal operations and for selected accidents, malfunctions and malevolent acts. The accidents, malfunctions and malevolent acts that were assessed in the EIS can be used for the risk analysis.

Effects of the environment on relative risk must also be included; specifically, the relative risk associated with severe weather events – particularly under climate change scenarios.

The relative risk analysis should include the following:

- Worker Health and Safety: construction, operation and decommissioning
- Public Health and Safety: construction, operation, decommissioning and post-closure
- Risks to Safety Case:
    - advective water flow around and through the facility
    - gas generation
    - physical disruption
        - seismic
        - structural failures
        - major fracturing
    - chemical/physical degradation of waste containers (assuming containers are as described in the EIS and further described in IR responses and during the Hearing):
        - seepage
        - release rates
        - microbial activity

- transport of released radionuclides
    - sources
    - travel times to nearest receptor (radionuclides and other constituents of concern such as metals)
        - near-field and far-field risks (including Lake Huron)
- air emissions
    - sources
    - near-field and far-field risks (including Lake Huron)
- waste transportation to and on the site
- requirements for institutional controls, short and long term
    - passive and active
- contribution to sustainability
    - add the conceptual granite bedrock location to the results of Table 1 in the OPG response to IR EIS-06-273 and Table 1 OPG response to IR EIS-06-278
- community acceptance
    - in the Local and Regional Study Area
    - outside of the Regional Study Area

B. Detailed Scope of Work for OPG Responses to Information Requests (Letter of 4 December 2013):

OPG will provide a qualitative analysis (narrative) of the relative risks of the four specified siting alternatives. The assessment will be conducted by a group of independent experts with relevant expertise including risk assessment. The experts will review relevant information assembled from the literature by OPG on these alternatives, including the Independent Assessment Study, or prepared by OPG in response to requests from the experts.

Key assumptions OPG has made in the development of the scope of work to respond to this IR include:

- The result will be a description of the relative risks of the four siting alternatives against several criteria, not an overall recommendation of a preferred siting alternative.
- The alternatives would accommodate 200,000 m3 of Low and Intermediate Level Waste, as per the Environmental Impact Statement [2].
- All wastes are assumed to be first transported to the Western Waste Management Facility (WWMF) for processing and temporary storage as may be needed before transfer to the DGR.
- All four alternatives are assumed to be in place indefinitely. Implications will be assessed considering a reference case with indefinite institutional control, as well as the implications of loss of institutional control after 300 years, of severe weather events particularly under near-term climate change, and of long-term glaciation. All four alternatives will be assessed for normal or expected conditions, and for selected accidents, malfunctions and malevolent acts.

Characterization of the four siting alternatives is as follows:

- Status Quo: Under this alternative, it is assumed that the wastes continue to be conditioned and stored at WWMF as per present practice with respect to processing (i.e., incineration and compaction), containers and storage facilities. The WWMF area would be expanded onto the proposed DGR site as needed for additional storage volume. In the future, as the design life of the current buildings and containers is reached (approximately 50 years), the wastes would be transferred to similar new buildings and containers on the site. After 300 years, the Low Level Waste (LLW) will be assumed to have decayed sufficiently that it can be transferred to a conventional waste disposal site.

- Enhanced Surface Storage: Under this alternative, it is assumed that wastes continue to be conditioned and stored at WWMF. Additional effort would be undertaken to reduce the volume of wastes, in particular segregation and compaction of LLW. Wastes would be stored either above ground or in-ground, in containers and facilities similar to current structures but more robust (design life of approximately 100 years). In the future, as the design life of the buildings and containers is reached, the wastes would be transferred to new buildings and containers on the site. After 300 years, the LLW will be assumed to have decayed sufficiently that it can be transferred to a conventional waste disposal site.

- DGR in Cobourg Formation: This alternative is the reference proposal as described in the Environmental Impact Statement [2], the Preliminary Safety Report [3] and supporting documents.

- DGR in Granite: Under this alternative, it is assumed that a repository would be located in a granite environment representative of Canadian Shield conditions. Normally a repository would be purpose-designed for a specific site. OPG does not have a granite site nor a design for a DGR for L&ILW in granite. For this qualitative assessment, it is assumed that the DGR repository concept can be transferred to a granite location. As there is no proposed location, a range of distances from the current DGR will be assumed where needed in the qualitative risk assessment. Where needed, site conditions described in the NWMO Fourth Case Study [4] will be used. This hypothetical crystalline rock site is preferred over that presented to the Seaborn Panel in 1994 as this site has been extensively used by NWMO and OPG for the past 10 years as a framework for conducting geoscience and safety case studies.
- Some additional analyses will be undertaken to support the conceptual description of these alternatives and the assessment of relative risk, but a full safety assessment would not be undertaken for the added alternatives.

C. Letter from JRP to OPG, 6 December 2013:

The Panel has one comment on the detailed scope of work for the OPG IR responses. Regarding EIS-12-513, the “DGR in granite” alternative should include analysis of distinctly different surface water receiving environments, including a boreal wetland, a stream system with several stream orders, and a large lake system (analogous to a Great Lake).

Appendix II: Concordance Table

JRP Issues	IEG Pathway
• Normal operations and selected accidents, malfunctions and malevolent acts	• Worker Health and Safety, Public Health and Safety, Malevolent Acts
• Severe weather events, particularly under climate change scenarios	• Severe Weather, Glaciation
• Worker Health and Safety: construction, operation, and decommissioning	• Worker Health and Safety
• Public Health and Safety: construction, operation, decommissioning and post-closure	• Public Health and Safety
• Risks to Safety Case:	
o advective water flow around and through the facility	• Transport of Released Radionuclides: Advective Water Flow
o gas generation	• Transport of Released Radionuclides: Advective Gas Flow
o physical disruption	
▪ seismic	• Seismic Impairment
▪ structural failures	• Structural and Mechanical Impairments
▪ major fracturing	• Seismic Impairment
o chemical/physical degradation of waste containers (assuming containers are as described in the EIS and further described in IR responses and during the Hearing):	
▪ seepage ▪ release rates ▪ microbial activity	• Waste Container Integrity
o transport of released radionuclides ▪ sources ▪ travel times to nearest receptor (radionuclides and other constituents of concern e.g. metals) • near-field and far-field risks (including Lake Huron)	• Transport of Released Radionuclides: Advective Water Flow
o air emissions	
▪ sources ▪ near-field and far-field risks (including Lake Huron)	• Transport of Released Radionuclides: Advective Gas Flow
o waste transportation to and on the site	• Worker Health and Safety, Radiological Exposure During Transportation Accidents
o Requirements for institutional controls, short and long term	• Loss of Institutional Control
▪ passive and active	

Notes on the Concordance Table

The consolidated set of twelve risk pathways developed by the IEG, as set out in greater detail in Section 3, Table 1 of the Report, is as follows:

1. Worker Health and Safety
2. Public Health and Safety
3. Transport of Released Radionuclides - Advective Water Flow
4. Transport of Released Radionuclides - Advective Gas Flow
5. Seismic Impairment
6. Structural and Mechanical Impairment
7. Waste Container Integrity
8. Radiological Exposure During Transportation Accidents
9. Severe Weather
10. Glaciation
11. Malevolent Acts
12. Loss of Institutional Control

Notes:

A. WH&S and PH&S include the activities of construction, operation, decommissioning, and post-closure, as well as the non-radiological impacts of transportation accidents.
B. Transport of Released Radionuclides includes major fracturing.
C. Advective gas and water flow includes off-gassing and package degradation, transport times of radionuclides via gas and water.
D. Sub-surface pathways affecting Lake Huron and are addressed as part of advective gas and water flow.
E. Malfunctions are considered as part of Structural and Mechanical Impairment.
F. Contribution to Sustainability is dealt with separately in Appendix III.
G. Community acceptance is commented on in a letter to OPG (see Appendix IV).
H. Near-term climate change is considered part of severe weather.
I. Analysis of distinctly different surface water receiving environments for the DGR in granite option will be found in Section 2 of the Report.
J. Air emissions are included in “Transport of Released Radionuclides – Advective Gas Flow.”

Appendix III: Contributions to Sustainability and the Precautionary Approach

EIS-06-273 Sustainable Development. Table 1: Contribution of Alternative Means to Sustainability

Alternative Means		**Contribution to Sustainability**		
	Consumption of Energy Resources	**Impact on Ecosystems**	**Production of Wastes**	**Impact on Economy**
Location of site				
On the Bruce nuclear site	Avoids transportation of waste	Avoids emissions from transport	N/A	Avoids consuming productive land
DGR in granite at a site on Canadian Shield distant from WWMF	Increased use of fossil fuels for transportation.	Some impact since it is likely a green field site.	Similar to DGR on Bruce site	No effect on mineral resources. Loss of some forestry or hunting land use during operations. Significant impact on local economy.

EIS-06-278 Precautionary Approach. Table 1: Rationale for Selection of Alternative Means in Light of Risk Avoidance, Adaptive Management Capacity and Preparation for Surprise

Alternative Means Category	**Preferred Alternative**	**Rationale**		
		Risk Avoidance	**Adaptive Management Capacity**	**Preparation for Surprise**
DGR in Granite in the Canadian Shield	N/A	Requires off-site transportation of wastes Local community support must be obtained	Location requires development of knowledgeable and experienced staff	Emergency response plans would have to be implemented after choice of site. Increased transport risk would have to be managed.

Appendix IV: Letter to the JRP on the Matter of "Community Acceptance"

February 18, 2014

Laurie Swami
Vice-President, Nuclear Services
Ontario Power Generation
889 Brock Road
Pickering, ON L1W 3J2

Dear Ms. Swami:

The undersigned are members of the independent risk assessment expert group established by OPG in response to the request of the Joint Review Panel for OPG's Deep Geologic Repository Project for Low and Intermediate Level Waste [hereafter JRP]. Among the tasks stipulated for the expert group is a relative risk analysis of four specific waste options as specified by the JRP. In addition, the charge to the expert group further stipulates: "The relative risk analysis should include the following:… Community acceptance in the Local and Regional study area [and] outside of the Regional Study area."

By this letter we are asking you to forward to the JRP the following set of comments on that part of the relative risk analysis which deals with the concept of "community acceptance."

1. The charge to the expert group further states: "The [relative risk] analysis is to be qualitative, transparent, defensible, and repeatable." We interpret this charge, specifically the terms defensible and repeatable, as also encompassing the notion that our analysis must be "evidence-based."

2. We are aware of the following 2003 study that surveyed the local communities on some options for the management of low and intermediate level radioactive waste at the WWMF site:

   a. "Public Attitudes towards Long Term Management of Low and Intermediate Level Radioactive Wastes at the Western Waste Management Facility [WWMF]." This is a consultants' report prepared by Intellipulse for Golder Associates and Gartner Lee Limited; it is dated September 2003 and is 120 pages in length.

   b. The purpose of this study included an attempt to "gauge awareness of the existing WWMF and the long term waste management options under consideration." The study results were based on a telephone survey which polled 751 residents of Bruce County, including residents of the Municipality of Kincardine and neighbouring municipalities.

   c. Those surveyed were read the following statement: "There are three options currently being considered for long-term waste management. They are: (1) Enhanced Processing, Treatment and Long-Term Storage; (2) a long-term management facility using Covered Above-Ground Concrete Vault technology; and (3) a long-term management facility using Deep Rock Cavern Vault technology. All three can be safely constructed and operated at the Western Waste Management Facility."

   d. We note that these options correspond to two of the four waste management options specified by the JRP in the charge to our expert group. Option (1) is similar to Enhanced Surface Storage; Option (3) is the Bruce site DGR. Option (2) does not correspond to any of the four options we have been asked to consider, since it was a surface disposal concept suitable for LLW but not for all ILW.

   e. The study results indicated (pages 25-26) that a clear majority of respondents – between 63% [Neighbouring Municipalities] and 77% [Kincardine] – *did not* believe that the operations of the WWMF, *regardless of what waste management option were to be chosen,* would have any adverse effect on the attractiveness of Kincardine as a tourist destination, as a place to establish and operate a business, or as a place to live.

   f. The 2003 study results did not ask about community views on an off-site granite DGR, which is part of our task.

3. Subsequent to this study, there were decisions made by the local municipal councils favoring a DGR at the Bruce site. There was also a survey in 2009 on public attitude with respect to the proposed DGR project at the Bruce site, notably:

   a. Municipal council decision in Kincardine and letters of support from neighbouring communities of Saugeen Shores, Huron-Kinloss, Arran-Elderslie and Brockton in 2004 supporting the DGR option, and reaffirmed by the mayors at the JRP Hearings in 2013.

   b. "Deep Geologic Repository: Public Attitude Research," prepared by Intellipulse for AECOM Canada in 2009/2010, 178 pages in length.

   c. These provide an indication of community acceptance for the Bruce site DGR option. They do not provide information on community acceptance of the other three options we have been charged to assess.

4. We are aware that the JRP has received input from individuals and groups for and against various options over the course of the 2-year public review, including indefinite on-site storage, Bruce site DGR, and a granite site DGR. However we were not present throughout this extensive process, and we are not aware of a systematic survey of views on the four options that we have been asked to assess.

5. We are aware that NWMO carried out extensive research on Canadian public attitudes toward the management of high-level radioactive waste (HLW) during the period 2002 to 2005. This included a deep geologic repository option as well as a centralized indefinite storage option. NWMO concluded that there was a general acceptance for an option that involved a deep geologic repository as its technical end point, in either sedimentary or crystalline rock. However, we do not believe that the findings of this research are directly relevant to the tasks before the independent expert group, which deal only with LLW and ILW.

6. We do not believe that information drawn from any other jurisdictions, either in Canada or elsewhere, pertaining to the siting of LL and IL radioactive waste storage and disposal facilities,

would be directly relevant to the issue of local and regional community acceptance of the four options we have been charged with assessing.

7. Therefore, in the evidence we have before us, there is insufficient information directly relevant to the issue of local and regional community acceptance, based on research having to do with *discriminating* among the four specific options listed in the charge to the expert group.

8. For these reasons we will be unable to comment on the issue of community acceptance in our relative risk analysis.

Sincerely yours,
Members of the Independent Expert Group:
    Maurice Dusseault
    Tom Isaacs
    William Leiss, Chair
    Greg Paoli

Signed on behalf of the Expert Group:

<original signed by>

____
William Leiss, Chair

Appendix V: OPG: Description of Alternative Options

Section 1.
Introduction

Information Request EIS-12-513 requests a qualitative assessment of the relative risks of four potential options for the long-term management of low & intermediate level waste (L&ILW). The options to be analyzed are:

1. "As is" facility at the WWMF (the status quo);
2. Enhanced surface storage at the WWMF (“hardened” storage);
3. Proposed DGR in the Cobourg Formation at the Bruce Power site;
4. A conceptual DGR in granitic bedrock of the Precambrian Canadian Shield. Information required for the qualitative analysis of a conceptual DGR in granite bedrock should be based primarily upon the extensive data and analyses available within the environmental assessment performed by Atomic Energy of Canada Limited (AECL) for the Environmental Assessment Panel for Nuclear Fuel Waste Management and Disposal Concept (known as the Seaborn Panel).

Of these options, Option (1) is essentially an extension of the existing WWMF facility, and there is information available on present performance. Option (3) is also a well-defined project with quantitative information on potential risks and impacts (OPG 2011a,b). The other two options are conceptual. OPG/NWMO has developed descriptions of the four options as input to the relative risk assessment. These descriptions are presented in this document. These descriptions are intended to provide a balance between providing too narrow a definition of each option, while providing enough detail to inform judgment about the relativity of risks.

Each of these options is described based on a capacity to provide long-term (indefinite) management of the approximately 200,000 m^3 (packaged) volume of L&ILW arising from operations and refurbishment of OPG owned or operated nuclear reactors. Figure 1.1 summarizes the reference total radioactivity as a function of time accounting for radioactive decay (Figure 8-21, OPG 2011b). 80% of the waste volume is LLW and decays in about 300 years, but most of the activity is in the ILW. Refurbishment waste consists of steam generators, classed as LLW, and reactor retube components, classed as ILW.

Figure 1.1 shows that carbon-14 is an important radionuclide initially based on inventory. It is also important because it is relatively volatile. It has a 5700 year half-life, so largely decays within 60,000 years. Most of the very long-lived radioactivity is Zr-93, which is a relatively immobile radionuclide, initially contained in the zirconium alloy pressure tubes. This figure illustrates that the options need to provide isolation and containment for a timeframe of at least 100,000 years.

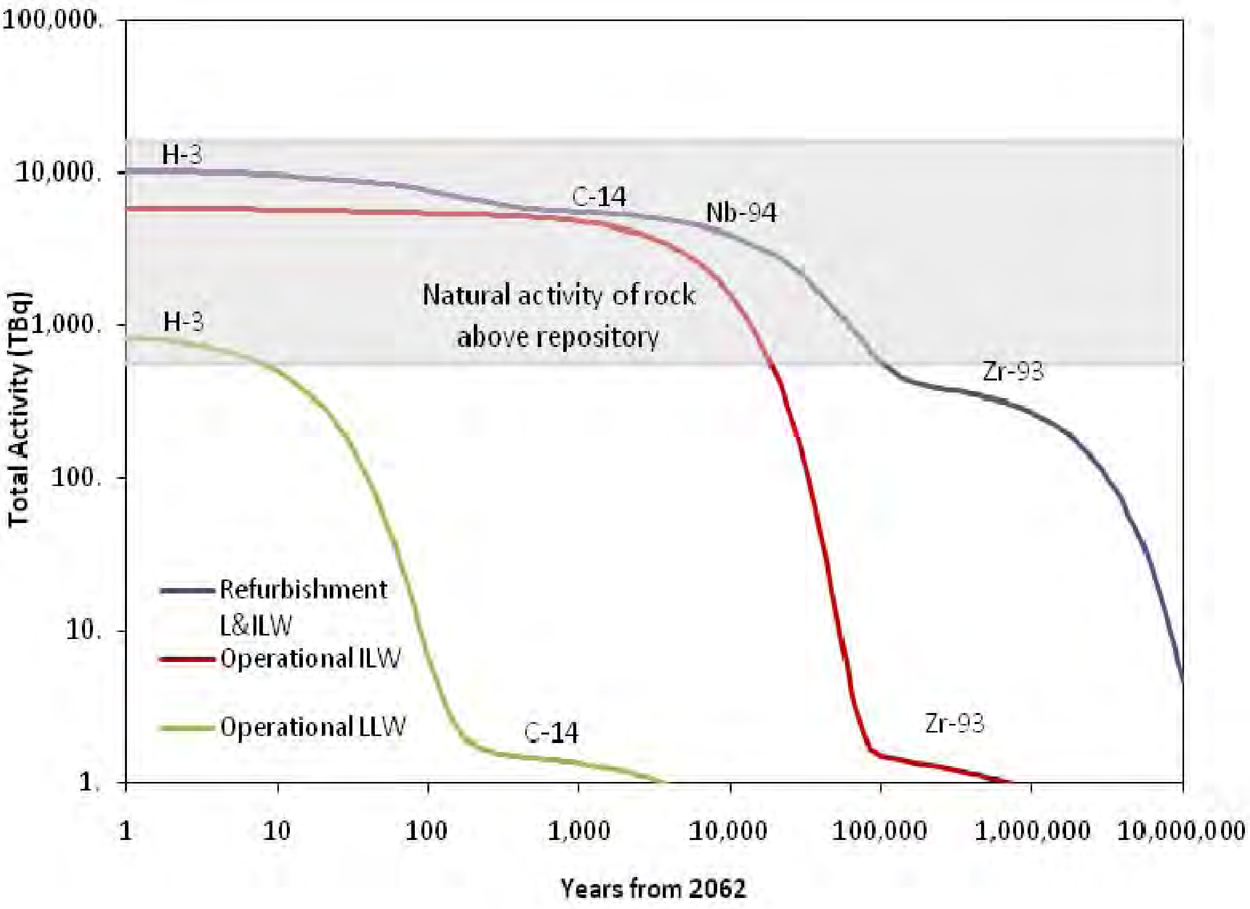


Figure 1.1: Reference inventory characteristics. Note that the shaded area represents the natural activity of the rock above the repository, with the range corresponding to a range of areas from repository footprint to Bruce site.

Section 2.
Description of Existing WWMF

The Western Waste Management Facility (WWMF) was established in 1974 as a centralized site for processing and storage of all OPG's L&ILW. The site also hosts the Western Used Fuel Dry Storage Facility for dry storage of used fuel from the Bruce nuclear stations. This used fuel facility is not part of the current risk assessment. Figure 2.1 shows the WWMF site.

WWMF (L&ILW) currently consists of:

- LLW waste incinerator
- Low-force compactor
- 14 Low Level (waste) Storage Buildings (LLSBs)
- In-ground structures for LLW (trenches) and ILW (tile holes, ICs)
- Above ground structures for ILW (quadricells)
- 1 Steam Generator Storage Building (SGSB)
- 1 Retube Component Storage Building (RCSB)
- Other service buildings.

WWMF stores on average about 3500 m^3 of LLW and ILW each year from the Pickering, Darlington and Bruce nuclear stations. There is presently about 95,000 m^3 of L&ILW in storage at WWMF.

WWMF has an excellent safety record, and routinely operates well below its regulatory limits. It is a minor contributor to public doses from all facilities on the Bruce nuclear site. In 2009, the maximum public dose from all facilities on the Bruce site was 0.0044 mSv/a (Bruce Power 2010). That year, WWMF contributed 4% of the Bruce nuclear site airborne tritium releases, 0.2% of the site C-14 airborne releases; 0.01% of waterborne tritium and 3% of the waterborne gross beta/gamma (Bruce Power 2010). Therefore the WWMF component of the maximum public dose in 2009 can be roughly estimated as 4% of 0.0044 mSv/a or 0.0002 mSv/a. (Similar values would apply in other recent years.) This is much lower than the CNSC limit for public dose rate of 1 mSv/a, and the Canadian natural background dose rate of around 1.8 mSv/a.

The LLSBs provide storage capacity for low level wastes. The structural design of the building utilizes pre-fabricated pre-stressed concrete. The concrete panels are joined in an overlapping configuration to prevent radiation streaming between the panels. The walls are approximately 38 cm thick, and the roof is approximately 16 cm thick. The buildings are provided with services such as fire protection, ventilation, lighting and drainage. A geomembrane is provided under the building.

The SGSB provides capacity for sealed steam generators and similar wastes. Shielding is provided as required to limit radiation fields both within and outside the building. The structural design of the building utilizes prefabricated pre-stressed concrete. A geomembrane is provided below the building similar to the LLSBs. The RCSB provides storage capacity for retube component waste containers from retubing of reactor units. The retube component wastes are stored at the WWMF in shielded containers. The building is provided with services such as ventilation, lighting and drainage. These are similar to LLSBs although not as tall. A geomembrane is provided below the building similar to LLSBs.

The Quadricells are above-ground concrete storage structures for intermediate level wastes. The structure provides mechanical strength and shielding. Concrete trenches provide storage capacity for low level wastes. The trenches are in-situ reinforced structures with a concrete thickness of 38 cm. This provides shielding at the top for operational personnel. The exterior surfaces of the concrete walls and joints of the trenches are waterproofed before backfilling. The joint between the walls and surface asphalt is periodically recaulked with sealant. Tile holes are an early (1970's) design for the storage of intermediate level wastes. Shielding is provided by the surrounding backfill. Monitoring for the release of contamination is also provided for the tile holes.

In-ground containers (ICs) provide storage capacity for intermediate level wastes and have a minimum design life of 50 years. The diameter and depth of the containers can be altered to suit any special waste storage needs. The in-ground container design utilizes the natural shielding provided by the surrounding till. The possible release of radioactivity from the ICs is prevented by the provision of two steel barriers with a monitored interspace between the barriers. Periodic sampling for water ingress is provided for the containers.

OPG has a robust Radiation Protection Program in place that supports the WWMF to ensure that its operations adhere to both the prescribed CNSC occupational dose limits and the internal OPG occupational dose targets. There have been no instances of individuals working at the WWMF receiving radiation doses above the CNSC or OPG limits. During the last 5 years there has been no release of contamination from the WWMF radiological zones in excess of licensed limits. Additionally, it has been over 2 years since the last WWMF lost-time accident (IRI 2013a, p.20). The transportation of waste to the WWMF from Darlington and Pickering is managed by experienced drivers. Over the last 3 million kilometers travelled, there have been no preventable collisions (IRI 2013a, p.20). In 40 years, OPG has not had a transportation accident involving low and intermediate level waste which has resulted in the release of radioactive materials (IRI 2013b, p.164).

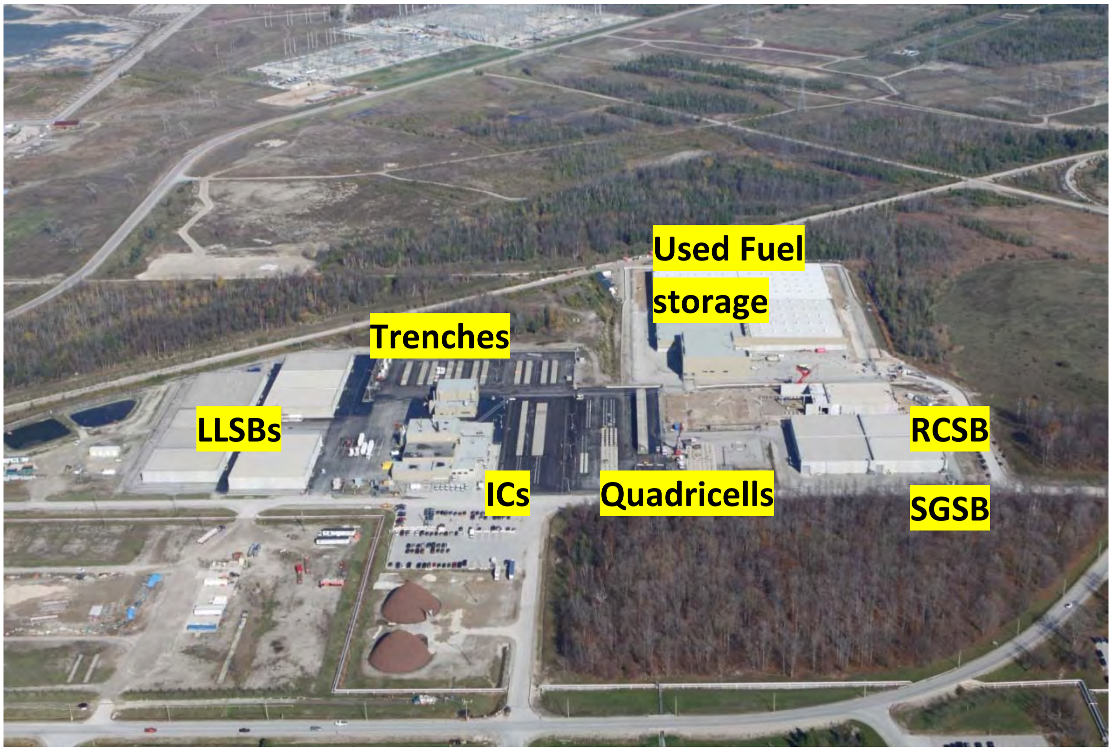


Figure 2.1: (a) Location of WWMF on the Bruce nuclear site. (b) Layout of facilities at WWMF.

Section 3.
Alternative Option 1: Status Quo Option

3.1 Basis: The existing WWMF surface storage continues, but would be expanded to accommodate a total of 200,000 m^3 of operational and refurbishment L&ILW using waste containers and storage structures similar to those presently in use. Incineration and low-force box compaction would continue to be used for LLW as is present practice.

3.2 Summary:

The existing WWMF surface storage practices would continue indefinitely. In particular, LLW would be placed in steel containers for LLW, and stored in surface Low-Level Storage Buildings (LLSBs). Steam generators would be placed as-is in the LLSBs. ILW retube wastes would be placed in steel-and-concrete Retube Waste Containers, and stored above ground in Retube Waste Storage Buildings (RWSBs).

ILW operational wastes are presently stored in a variety of in-ground and above-ground containers, with in-ground containers as the present preferred storage structure. In this option, the ILW from operations would eventually be transferred into steel containers and placed inside concrete in-ground containers similar to current IC-18s.

In the future, as the current containers and buildings or containment structures reach their design life, the wastes would be transferred to new containers and buildings. The current design life ranges from about 30 years to 50 years. For simplicity, it can be assumed that all future containers and structures have a 50-year design life; this represents a modest extension of current practice. In this option, over a 50 year period, all wastes would need to be transferred to new containers and storage structures. This would continue indefinitely.

However, after about 300 years, it can be assumed that much of the LLW would have decayed to the point where it could be disposed as industrial landfill, leaving mainly the ILW to be handled on an ongoing basis.

Canadian society is assumed to remain intact in the Normal Evolution Scenario. This means that there would be the capability to transfer wastes to new containers and structures as needed, and in general to maintain and monitor the site. It is assumed that land use around the site would be controlled. For risk assessment purposes, a 0.75 km radius around the site could be assumed where public access would be restricted; this is approximately the current closest distance from WWMF to the Bruce site boundary.

3.3 Location: WWMF site, with enlarged footprint extending onto DGR area.

3.4 Transportation: All wastes are trucked to WWMF. No additional off-site transportation is required.

3.5 Design Assumptions:

Consistent with current practice at WWMF, and the OPG DGR project basis, it is estimated that the complete inventory would ultimately have approximately 45,000 LLW and 7,400 ILW packages (Table 5-7, OPG 2011b).

Using current storage structure volumes, this would require:

- LLW stored in approx 25 LLSBs.
- Retube ILW stored in approx 7 RCSBs; these are similar to LLSBs although not as tall.
- Operational ILW stored in approx. 600 IC-18s.

A potential site layout with these structures is illustrated in Figure 3.1. This shows how the site might look in 100 years, after all the wastes had been received at WWMF and also existing wastes had been transferred into these structures. (26 LLSBs shown assuming one is always under construction.)

In order to maintain this option, ongoing work would be needed that would initially include:

- constructing one new surface building and demolishing one old building at a rate of roughly (32 buildings)/(50 years) = 0.64 per year,
- constructing (600 IC-18s)/(50 years) = 12 IC-18s per year,
- transferring the LLW from old to new containers at a rate of 45,000/50 = 900/yr
- transferring the ILW from old to new containers at a rate of 7,400/50 = 150/yr.

Note that these are the effective annual rates. It may be more practical to operate on a different schedule, e.g. replacing 2 buildings every 3 years.

3.6 Worker Health and Safety:

Conventional safety would be related to the amount of construction activities and by the amount of package handling. Nuclear safety would also be roughly related to the rate of waste package handling. After the initial processing (incineration and compaction) which is common to all options, the wastes are largely in storage, with infrequent transfer to new containers and structures. This option would have the most package handling beyond the first 100 years.

The radiation will decrease with time due to radioactive decay. Worker dose will likely be primarily affected by gamma-emitting species, of which Co-60 is the main contributor in the near-term. After approximately 50 years, most of the Co-60 will have decayed, and the remaining gamma fields will likely be due to Cs-137 and Nb-94.

3.7 Public Health and Safety:

The public safety risk from current normal operations is very low due to the low emissions from the facility. Emissions are routinely measured and are always well below the approved CNSC Derived Release Limits. Maintaining the status quo is not expected to result in any substantial change to these emissions in the near term. Initially, there would be more packages stored at the site (about half of the wastes are presently in storage at WWMF). In the longer term, there would be no incinerator emissions, just low levels of primarily H-3 and C-14 off-gassing from the packages. These releases would decrease with time as the source of the releases is lost due to radioactive decay and off-gassing. (Radon gas releases from uranium in the wastes would increase over time, but would remain small.)

3.8 Loss of Stewardship / Institutional Control:

At some time in the future, it is possible that there would be loss of stewardship or institutional control of the site. This would require some significant event, such as war or epidemic outbreak or severe climate change. In this scenario, it is assumed that the site would no longer be maintained, and the buildings and containers left to degrade.

As these structures degrade, rainwater would eventually percolate through the structures and either runoff onto adjacent land or infiltrate through the till and into the groundwater aquifer beneath the site. Due to the low permeability of the till, it is more likely to runoff the surface. In either case, radioactivity would be released, which could lead to dose consequences. The potential consequences are assessed using simple models in Section 8, Addendum. Simple estimates suggest that if stewardship was lost at 300 years after closure (assumed 2062), and people moved on site immediately, the dose consequences to someone growing crops on land that was contaminated by runoff would be much higher than the current public dose limit, while the dose impacts to someone living near shore and obtaining water and fish from Lake Huron would be below the dose limit.

If it is assumed that human intrusion occurs once stewardship is lost, then the worst case would be for excavation directly into the structures. It is expected that the dose consequences would be very high for intrusion into ILW, and below the public dose criteria for intrusion into LLW. The consequences of loss of stewardship to persons living on the site would remain very high for tens of thousands of years due to the long life of some of the radionuclides in retube ILW, notably Nb-94.

3.9 Sustainability:

Sustainability may be assessed through several factors, notably energy usage and materials usage. This option requires the ongoing construction of 0.6 concrete buildings per year for 300 years (LLW and ILW), and 0.14 buildings per year thereafter (for ILW); and 12 IC-18's per year. It also requires 900 LLW steel containers per year for 300 years; and 150 steel-and-concrete ILW containers per year indefinitely.

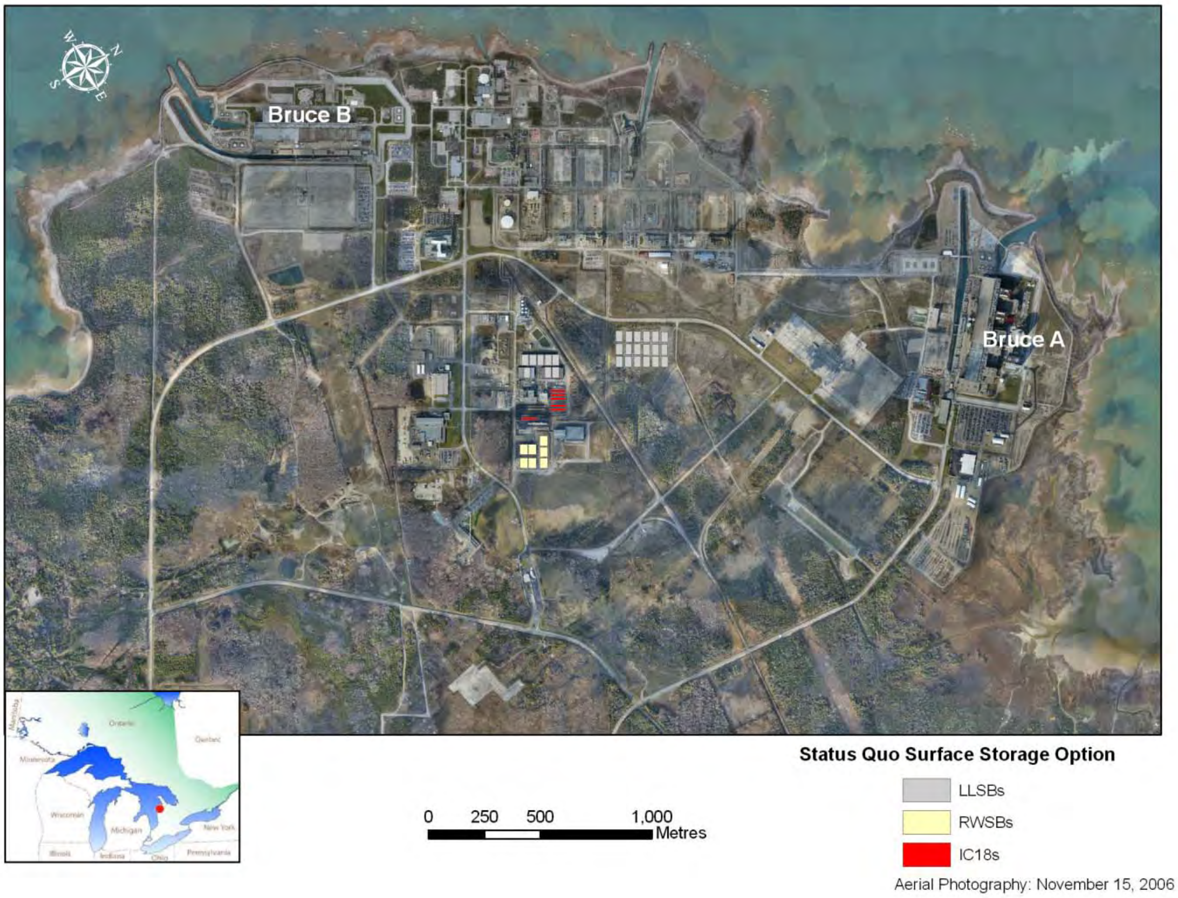


Figure 3.1: Illustrative layout of Status Quo option in 100 years, with all wastes transferred to LLSBs, IC18s and RWSBs placed on current WWMF and proposed DGR site.

Section 4.
Alternative Option 2: Enhanced Surface Storage

4.1 Basis: This description is based on assuming that surface storage at WWMF is selected as the reference option for indefinite long-term management of the L&ILW. It is assumed that significant efforts are undertaken to minimize the stored waste volumes, and to use more robust storage systems (containers and structures) than current WWMF practice.

4.2 Summary:

The existing WWMF surface storage continues, but would be expanded to accommodate a total of 200,000 m^3 of operational and refurbishment L&ILW. Furthermore, the containers and storage structures would be made more robust.

There are no equivalent L&ILW indefinite surface storage facilities in operation around the world. The closest example is the COVRA facility in the Netherlands, which has facilities for long-term management of L&ILW and of used fuel (Figure 4.1). These facilities have a 100-year design life (Codee 2002).

Presently, incineration and low-force box compaction are used at WWMF for LLW volume reduction. In this *Enhanced Surface Storage* option, significant additional effort is assumed to reach an aggressive target of 50% LLW volume reduction. The specific approach is not defined, but could consist of some combination of increased waste segregation and incineration, supercompaction, and metal melting. No additional volume reduction would be undertaken with ILW, due to its smaller total volume, the limited options for further volume reduction, and the public and worker dose implications from processing and conditioning ILW.

In this option, it is assumed that the containers and storage structures are designed for longer life than current *Status Quo* structures. In particular, a 100-year design life is assumed for both, rather than the current 30-50 year design life. This is consistent with the 100-year design life for the COVRA long-term L&ILW storage facility in the Netherlands (Codee 2002). The specific changes needed to achieve longer-life are not defined, but could include a combination of thicker walls, more durable materials, and active control of storage conditions (e.g. control of humidity).

In the future, as the containers and buildings or containment structures reach their design life, the wastes would be transferred to new containers and buildings. Therefore, over a 100 year period, all wastes would need to be transferred to new containers and storage structures. This would continue indefinitely. However, after about 300 years, it can be assumed that much of the LLW would have decayed to the point where it could be disposed as industrial landfill, leaving mainly the ILW to be handled subsequently.

Note that the structures in this option would be more robust (or "hardened") compared with *Status Quo* option due to: (a) the volume reduction of the LLW resulting in a more solid and low-combustible waste form; (b) the more robust longer-life containers; and (c) the more robust storage structures. In addition, it may be assumed that the structures are emplaced further apart than is current practice; this could limit the extent of releases from a single accident or malevolent act. The in-ground storage of operational ILW would also continue to provide hardened storage.

Canadian society is assumed to remain intact in the Normal Evolution Scenario. This means that there would be the capability to transfer wastes to new containers and structures as needed, and in general to maintain and monitor the site. It is assumed that land use around the site is controlled. For risk assessment purposes, a 0.75 km radius around the site could be assumed where public access is restricted; this is approximately the current closest distance from WWMF to the Bruce site boundary.

4.3 Location: WWMF site, with enlarged footprint extending onto DGR area. Although there are fewer surface buildings in this scenario, they would be spaced farther apart so a similar area would be needed as in the *Status Quo* option.

4.4 Transportation: All wastes are trucked to WWMF. No additional off-site transportation is required. This is the same as *Status Quo* option.

4.5 Design Assumptions:

- Enhanced container concepts to support a longer (100-yr) design life.
- Approximately 23,000 LLW and 7,400 ILW packages, based on a 50% LLW volume reduction.
- LLW stored in 13 enhanced LLSBs. (Half as many as *Status Quo* option due to reduced volume. Enhanced LLSBs would be more robust structures for longer life.)
- Retube ILW stored in 7 enhanced RWSBs. (Same number as *Status Quo* option since same waste volume, but more robust structure for longer life.)
- Operational ILW stored in approx. 600 enhanced IC-18s. (Same number as *Status Quo* option since same waste volume, but more robust structure for longer life.)

A potential site layout with these structures is illustrated in Figure 4.2. This shows how the site might look in 100 years, after all the wastes had been received at WWMF and also existing wastes had been transferred into these structures.

In order to maintain this system, there would need to be:

- construction of one new surface building and demolish one old building at rate of roughly (13+7 buildings)/(100 yrs) = 0.2 per year (or 1 every 5 years),
- construction of 600/100 = 6 enhanced IC-18s per year,
- transfer the LLW from old to new containers at a rate of 23,000/100 = 230/yr
- transfer the ILW from old to new containers at a rate of 7,400/100 = 74/yr.

4.6 Worker Health and Safety:

Conventional safety would be related to the amount of construction activities and by the amount of package handling. Nuclear safety would also be related to the rate of waste package handling.

In this option, after the standard initial processing on arrival at WWMF, the impact would initially (within 50 years) be somewhat higher than in the *Status Quo* option due to the handling of all the LLW packages to support the volume reduction effort. This could result in approximately double the amount of waste package handling compared to the *Status Quo* option in this period.

In the longer term, the amount of package handling would be much less than in the *Status Quo* option due to the more robust structures and fewer packages, and therefore lower waste transfer rates.

The radiation will decrease with time due to radioactive decay. Worker dose will likely be primarily affected by gamma-emitting species, of which Co-60 is the main contributor in the near-term. After approximately 50 years, most of the Co-60 will have decayed, and the remaining gamma fields will likely be due to Cs-137 and Nb-94 decay.

4.7 Public Health and Safety:

The public safety risk under normal operations would be very low due to the low routine emissions from the facility.

Initially these emissions would be approximately similar to the *Status Quo* option (Section 3.7). However, the assumed volume reduction effort in the first 100 year period in the *Enhanced Storage* option would likely result in some increase in releases since the containers would be opened and the wastes actively handled. In the longer term, since about the same inventory is present, the release rate due to waste handling would be lower than with the *Status Qu*o option due to the longer-lived containers, while the off-gassing term would be about the same since the total inventory was similar.

4.8 Loss of Stewardship / Institutional Control:

At some time in the future, it is possible that there would be loss of stewardship or institutional control of the site. This would require some significant event, such as war or epidemic outbreak or severe climate change. In this scenario, it is assumed that the site would no longer be maintained, and the buildings and containers left to degrade.

As these structures degrade, rainwater would eventually percolate through the structures and either runoff onto adjacent land, or infiltrate through the till and into the groundwater aquifer beneath the site. In either case, radioactivity would be released, which could lead to dose consequences. The potential consequences are assessed using simple models in Section 8, Addendum. Simple estimates suggest that if stewardship was lost at 300 years after closure, and people moved on site immediately, the dose consequences to someone growing crops on land that was contaminated by runoff would be much higher than the current public dose limit, while the dose impacts to someone living near shore and obtaining water and fish from Lake Huron would be below the dose limit.

Since the structures are more robust in this *Enhanced Surface Storage* option, the rate of degradation of the structures would be slower than in the *Status Quo* option. However, while this might delay significant rainfall contact for several decades, it is unlikely to make much of a difference to releases since the key remaining radionuclides would have much longer half-lives and not decay significantly. Overall, the impacts would likely be similar to those for the *Status Quo* option.

If it is assumed that human intrusion occurs once stewardship is lost, then the worst case would be for excavation directly into the structures. In general, the consequences would be similar to the *Status Quo* option. It is expected that the dose consequences would be very high for intrusion into ILW, and below the public dose criteria for intrusion into LLW.

The consequences of loss of stewardship to persons living on the site would remain very high for tens of thousands of years due to the long life of some of the nuclides in retube ILW.

4.9 Sustainability:

Sustainability may be assessed through several factors, notably energy usage and materials usage. This option requires the ongoing construction of 0.2 concrete buildings per year for 300 years (LLW and ILW), and 0.07 buildings per year thereafter (for ILW); and 6 IC-18's per year. It would also require 230 LLW steel containers per year for 300 years, and 74 steel-and-concrete ILW containers per year indefinitely. Note that these containers would be more robust than in the Status Quo option, so would likely use more materials.

Figure 4.1: Photos of the long-term L&ILW storage building and containers at COVRA in Netherlands. Each building has a capacity for about 5000 m^3 of waste, has 40-cm thick concrete walls and a design life of 100 years.

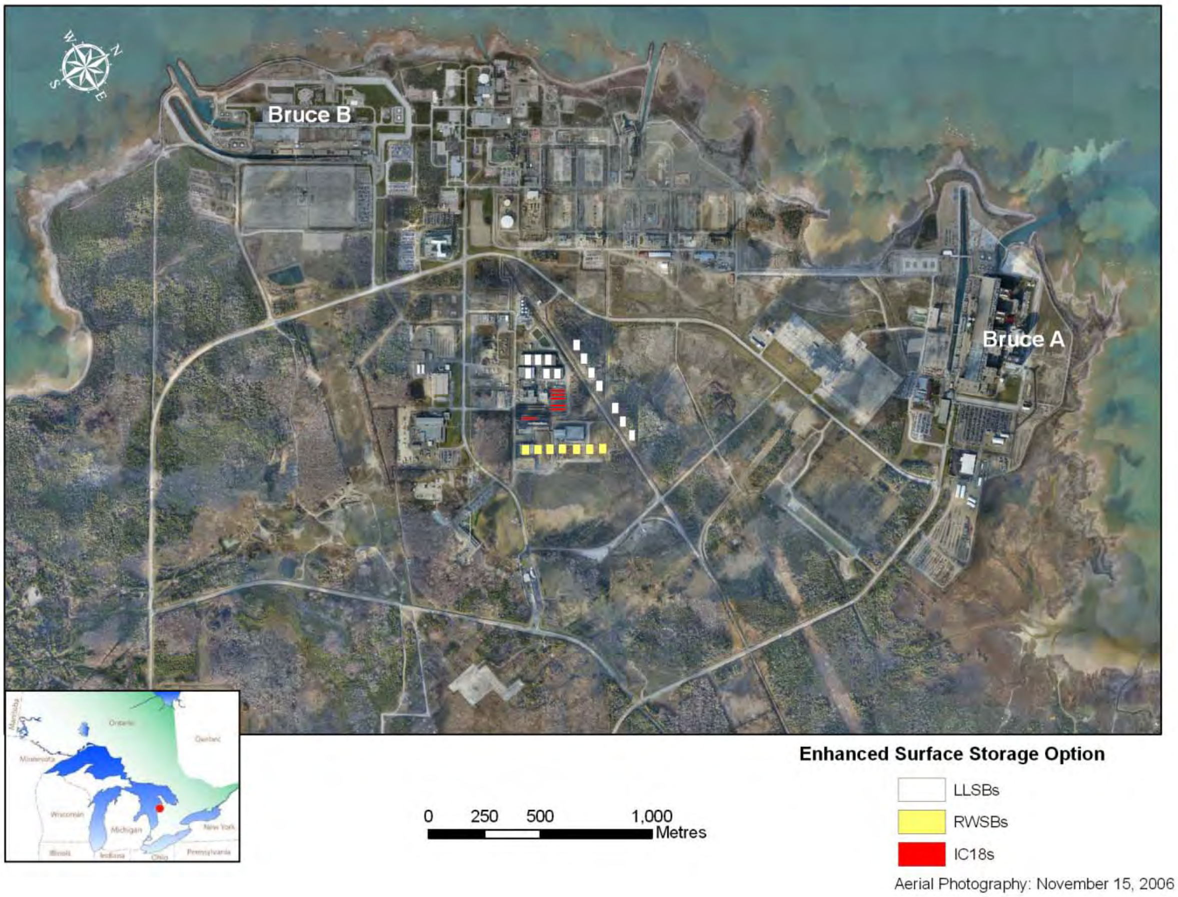


Figure 4.2: Illustrative layout of Enhanced Surface Storage option in 100 years, with all wastes transferred to LLSBs, IC18s and RWSBs placed on current WWMF and proposed DGR site. Structures are also spaced apart compared to Status Quo option.

Section 5.
Alternative Option 3: DGR in Cobourg Formation at the Bruce Site

5.1 Basis: This is the reference option as described in the DGR Project Description and related documents, including the EIS (OPG 2011a) and PSR (OPG 2011b).

5.2 Summary:

In this *Bruce Site DGR* option, a deep geologic repository would be constructed at a nominal depth of 680 m in the Cobourg Formation at the Bruce nuclear site (Figure 5.1 and Figure 5.2). This is a very-low-permeability limestone formation, surrounded by thick low-permeability rock formations including 200-m of shale caprock. The DGR would be sized to accommodate 200,000 m^3 of operational and refurbishment L&ILW using waste containers similar to those presently in use. Incineration and low-force box compaction would continue to be used for LLW as in present practice. No other new significant volume reduction efforts would be undertaken.

The waste packages would be placed in rooms located underground (Figure 5.3). The space around the packages would not be backfilled. As “panels” containing emplacement rooms are filled, the panels would be isolated with closure walls. After all the emplacement rooms are filled, there would be a period of monitoring to ensure that the repository is behaving as expected. Eventually the facility would be backfilled around the shaft area, and the shafts filled with an extensive low-permeability seal. Surface facilities would be removed. Within the emplacement rooms, the containers would degrade over years to decades. The low permeability of the surrounding rock and shaft seals will limit the rate of water movement into the repository, as well as the movement of radionuclides from the repository. Furthermore, slow degradation of metals and organics will result in the production of gas, which will also be mostly retained in the repository by the low-permeability rock, forming an unsaturated volume in the repository. The repository is also designed through a combination of depth, layout and rock properties to be robust under earthquake and glacial loads. The net result would be that most activity decays within or near the repository.

Canadian society is assumed to initially remain intact, providing site monitoring and land use restrictions which ensure that there are no activities or events that would damage the repository. Since the repository is not dependent on active maintenance, it would continue to perform as intended.

5.3 Location: Adjacent to WWMF on the Bruce nuclear site.

5.4 Transportation: All wastes are trucked to WWMF as per the *Status Quo* option. They are then moved approximately 200-m to the Main Shaft at the DGR. No additional off-site transportation would be required.

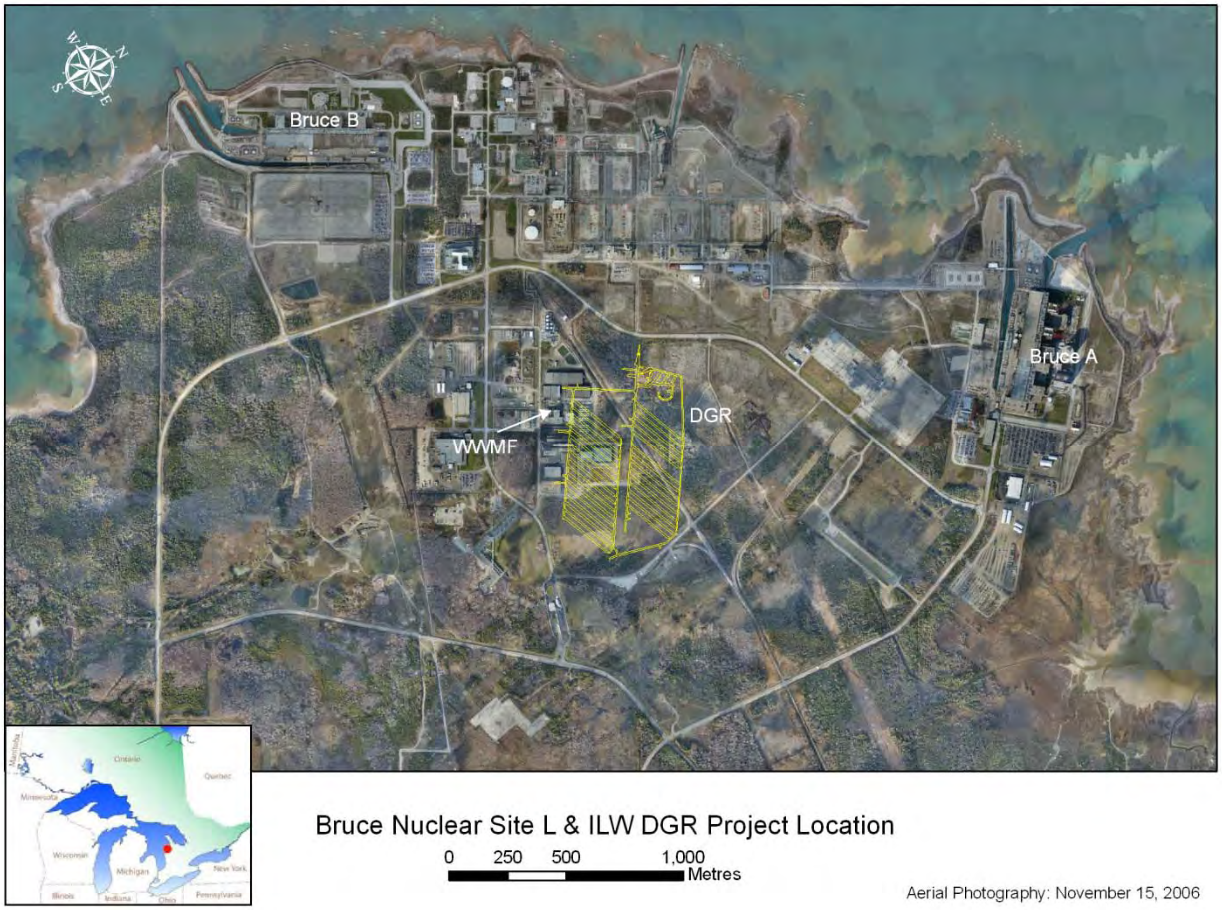


Figure 5.1: Illustration of footprint of DGR at Bruce nuclear site.

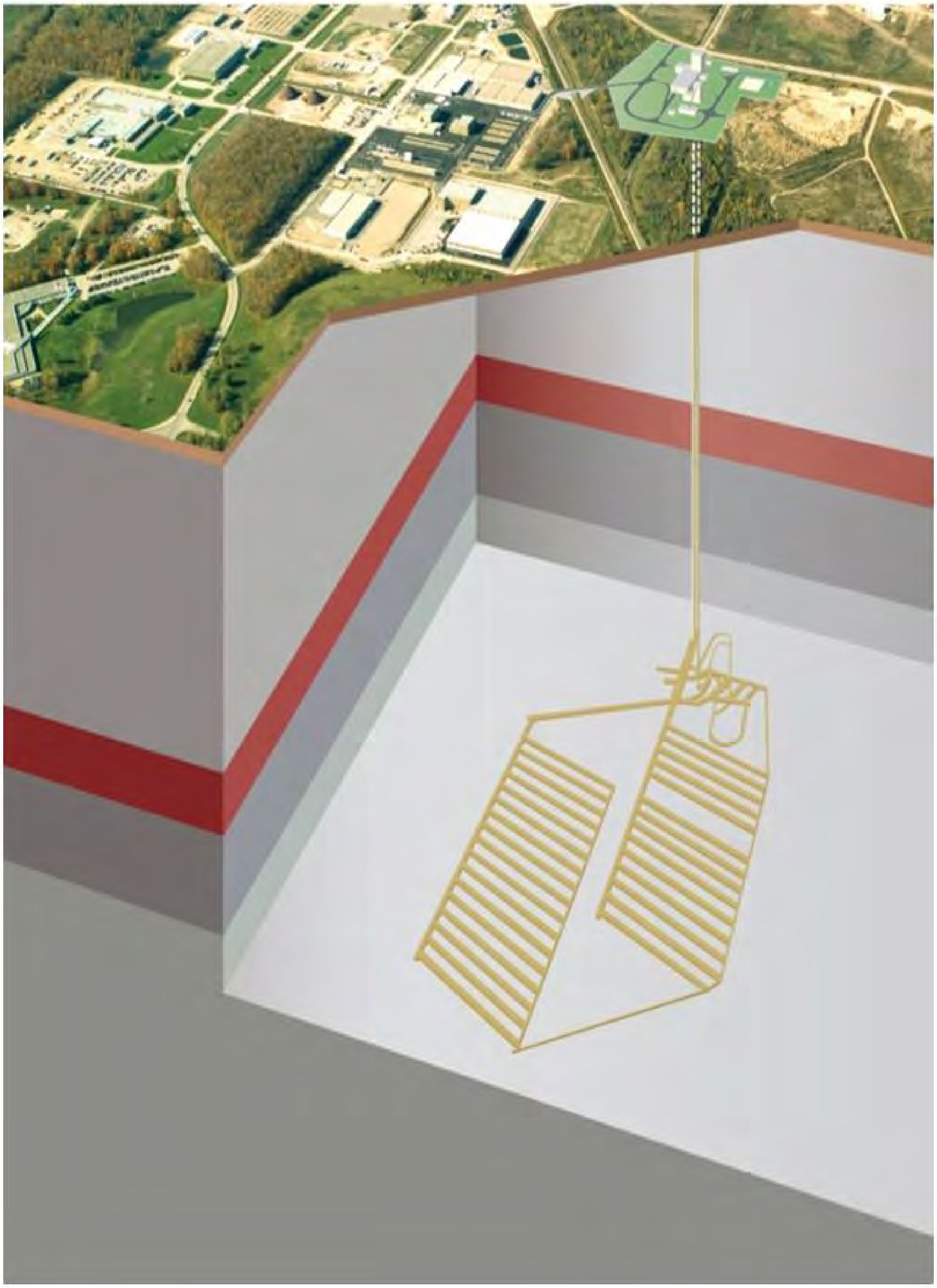


Figure 5.2: Perspective view of DGR at Bruce site.

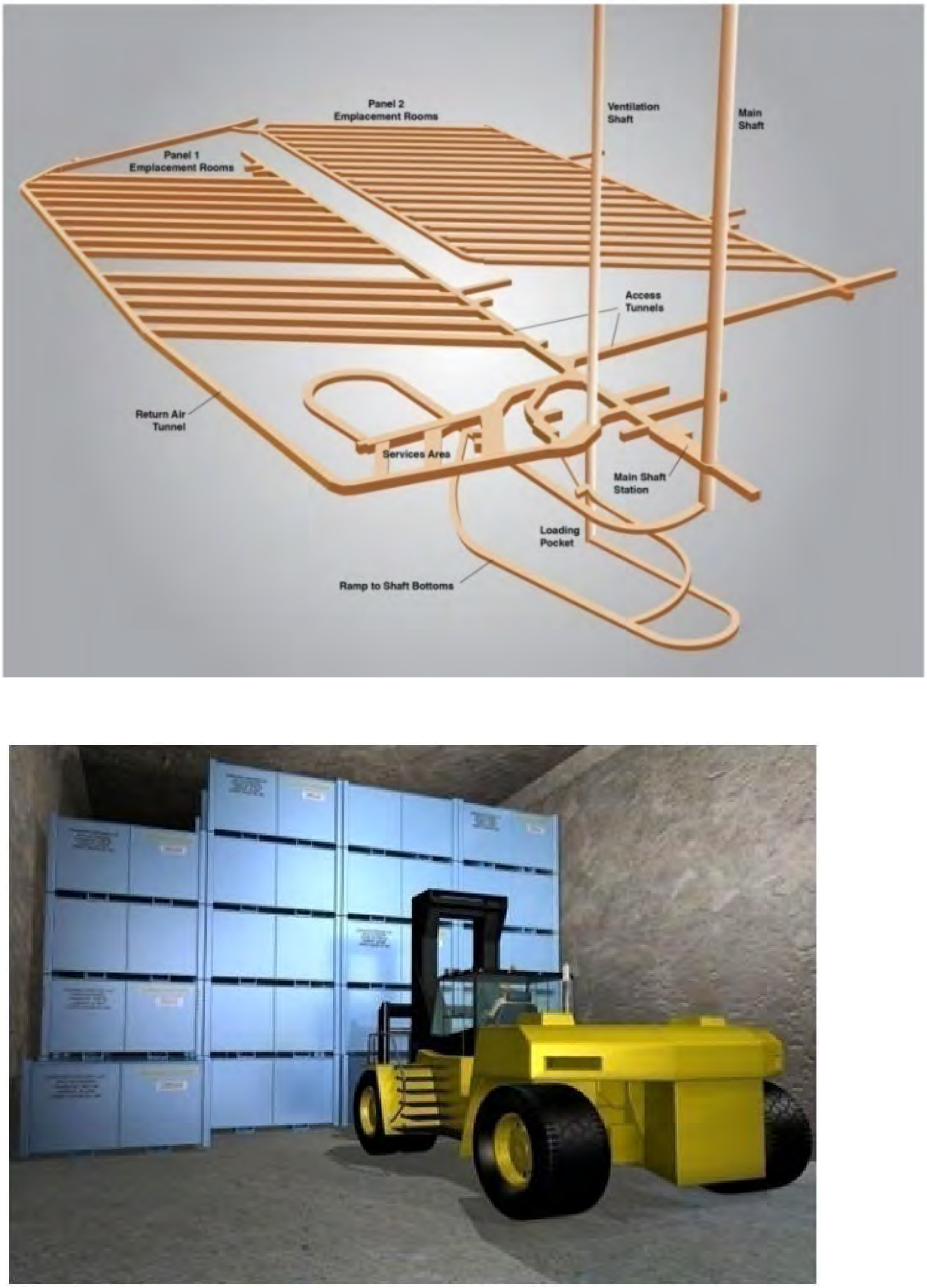


Figure 5.3: Illustration of (a) underground layout and (b) emplacement of LLW packages. Wastes are emplaced in 31 rooms in 2 panels. Rooms are 250 m long, 7 m x 8.5 m wide.

5.5 Site Characteristics:

The sedimentary rock formations beneath the Bruce nuclear site have been characterized as part of the OPG L&ILW DGR project. The assessment is described in various technical reports, and summarized in the PSR (OPG 2011b).

Figure 5.4 summarizes the geological formations below the Bruce nuclear site, and also illustrates the depth range of the deep boreholes used to study the area.

Figure 5.5 summarizes some features of the rock formations. Figure 5.5a shows the salinity profile. The upper 170 m is a permeable freshwater aquifer, but at lower depths there is a sharp transition to brine. This and other studies of the water chemical composition indicate that the deep groundwaters are ancient.

Figure 5.5b shows the hydraulic head profile. The measured profile shows a significant underpressure in the Middle Ordovician rock formations, and an overpressure in the lower Cambrian Formation. The underpressures in particular are indicative of a very low permeability system, as they would not remain if the system was hydraulically connected.

More generally, the information from the site characterization program supports the following characteristics of the Bruce site:

- **Predictable**: horizontally layered, undeformed sedimentary shale and limestone formations of large lateral extent.
- **Multiple Natural Barriers**: multiple low permeability bedrock formations enclose and overlie the DGR.
- **Contaminant Transport Diffusion Dominated**: deep groundwater regime is ancient with low permeabilities, and shows no evidence of glacial perturbation or cross-formational flow.
- **Natural Resource Potential Low**: commercially viable oil and gas, salt, and base metal reserves not present.
- **Seismically Quiet**: located in a seismically quiet portion of the craton; comparable to stable Canadian Shield setting.
- **Geomechanically Stable**: selected DGR limestone formation will provide stable, virtually dry openings.
- **Shallow Groundwater Resources Isolated**: near surface groundwater aquifers isolated from the deep saline groundwater system.

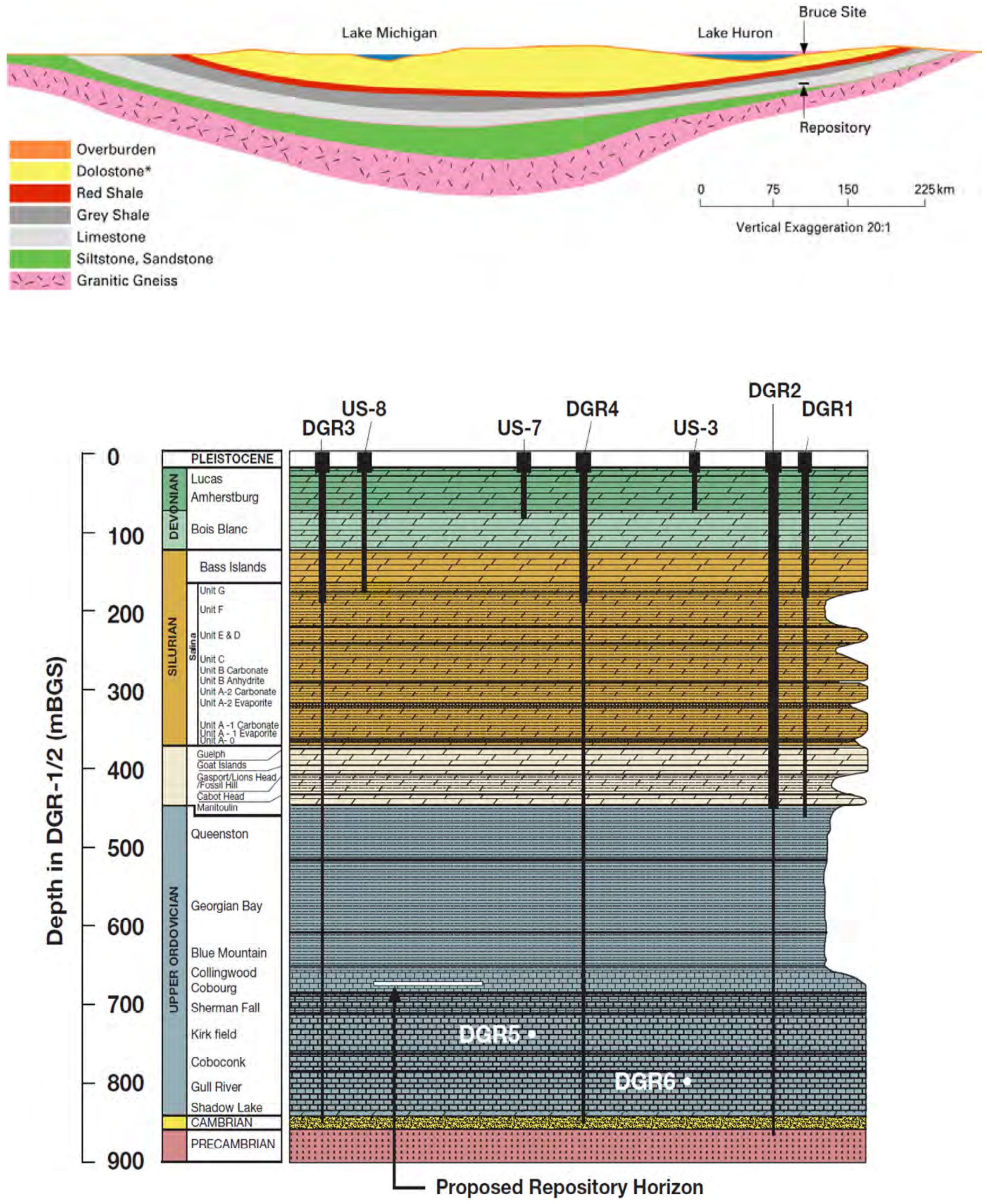


Figure 5.4: Rock formations beneath the Bruce nuclear site at the (a) Michigan Basin scale, and (b) DGR site. Repository would be located in the Cobourg Formation at about 680 m depth.

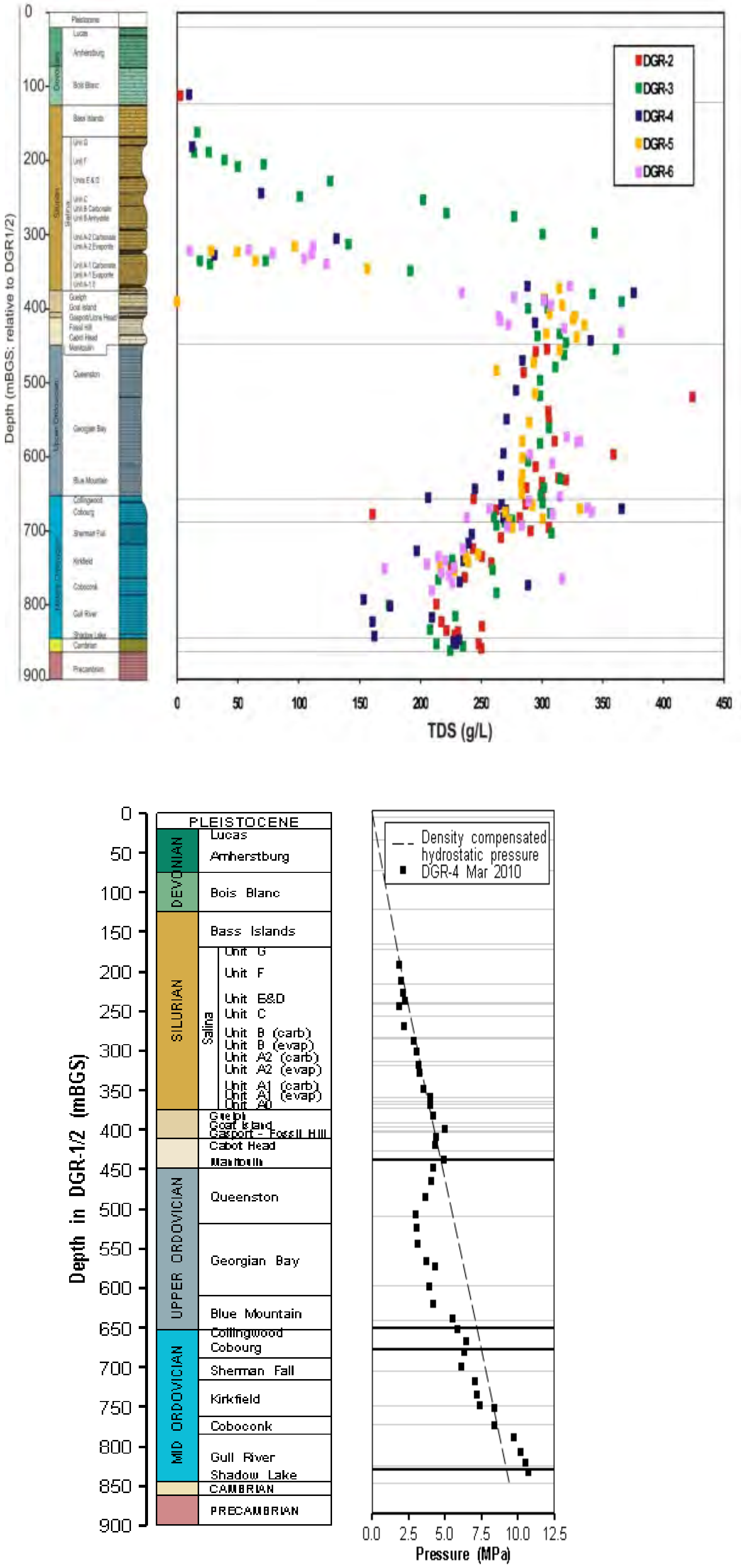


Figure 5.5: Properties of the rock formations beneath the Bruce nuclear site: (a) salinity profile; (b) hydraulic pressure profile. These profiles are indicative of low-permeability conditions at depth.

5.6 Design Assumptions:

- Existing container concepts with approximately 30 to 50 year design life.
- Approximately 45,000 LLW and 7,400 ILW packages (Table 5-7, OPG 2011b).
- L&ILW stored in 31 emplacement rooms in two panels.
- No future waste handling required after the repository has been sealed.

5.7 Worker Health and Safety:

Conventional safety will be related to the amount of construction or excavation activities and by the amount of package handling. These risks will be managed through good mining and conventional safety practices.

Nuclear safety during the operations period is described in more detail in Ch. 7 of the PSR (OPG 2011b). Worker nuclear safety would be related in part to the rate of waste package handling. This will occur during the initial 40 year period while waste packages are transferred from the WWMF to the DGR. After this one-time transfer, and the DGR is closed, there would be no further worker exposure.

5.8 Public Health and Safety:

During the DGR's operational phase, the main impact on public safety from normal operations would be from the low routine emissions from the facility. This would be essentially H-3 and C-14 off-gassing from the packages, and either released to atmosphere or as condensate water within the ventilation shaft. The total releases would initially be similar to those from the *Status Quo* option. However, the DGR releases would decrease with time as panels are closed off and the repository sealed.

Following closure, any releases under normal evolution conditions would have to occur by diffusion through the surrounding rock or shaft seals as dissolved species or gaseous species. These processes are very slow, and there would be radioactive decay, dispersion and dilution before any materials would reach surface. The dose impacts to persons living even on the site would be much less than 10^{-6} mSv/a (Ch. 8, OPG 2011b). If institutional controls were in place, it is likely that people would not be living directly on top of the repository, and the dose impacts to persons living off the site would be even smaller.

5.9 Loss of Institutional Control:

At closure of the DGR, it is expected that the shafts would be sealed, surface facilities removed, and institutional controls put in place. These could include local, provincial and national records, land use controls, fencing and markers. The intent would be to preserve the knowledge that the repository was placed at that location. There might also be some ongoing level of monitoring at surface. The details would be developed with the regulator and community at that time, based upon the knowledge and technologies 50 years from now.

At some time in the future, it is possible that there would be loss of stewardship or institutional control of the site. This could be due to some significant event, such as war or epidemic outbreak or severe climate change. Since the repository is also very passive, it could also be due to simple passage of time since nothing significant would be observed to change at surface. However, even in this case, societal memory could preserve knowledge of the site for a long time. In the worst case, it may be assumed that eventually all records, markers and memory of the repository location is lost.

As part of the *Bruce Site DGR* safety assessment (Ch. 8, OPG 2011b), it is assumed that institutional control is not effective 300 years from closure of the repository, including even memory of the nature of the site. It is further assumed that people move onto the site, and are therefore directly exposed to any releases from the facility. However since the repository is not dependent on active maintenance, it would continue to perform as intended. This is the Normal Evolution Scenario. Any impacts from the repository are expected to be many orders of magnitude below current regulatory criteria. The impacts would be even smaller for someone living further distant, such as someone living near shore and obtaining water and fish from Lake Huron.

If it is assumed that inadvertent human intrusion occurs once stewardship is lost, then the worst case would be for unintended intersection of the repository during exploratory drilling. This would be unlikely because of the lack of mineral resources in these rocks, the depth of the repository, and its small footprint. Inadvertent intrusion could bring materials to surface and create a pathway for gas and groundwater release. The consequences of intrusion were assessed for the *Bruce site DGR* using simple models, and are summarized in Section 8, Addendum. These consequences assume that the wastes brought to surface during drilling are left on surface at site, and also that people live near and on the site after the drilling. The consequences of loss of institutional control to persons living on the site would remain at similar levels for tens of thousands of years due to the long life of some of the radionuclides in ILW.

5.10 Sustainability:

Sustainability may be assessed through several factors, notably energy usage and materials usage. This option requires the ongoing construction, operation and closure of the DGR. As a general estimate, there would be about $6\text{x}10^5$ m^3 of rock excavated, about $2\text{x}10^8$ kg of concrete, about $3\text{x}10^6$ kg of steel, and about $7\text{x}10^7$ kg of bentonite/sand seal used in the DGR construction and closure (Section 4, Quintessa and Geofirma 2011). Once closed, there would be no significant further use of resources.

Section 6.
Alternative Option 4: L&ILW DGR in Granite

6.1 Basis: In this option, the L&ILW is emplaced in a deep geologic repository constructed in granite at a location on the Canadian Shield. There is, however, no such site identified, nor is there an informed reference design for a L&ILW DGR in the crystalline rocks of the Canadian Shield. As a conceptual design basis, it is therefore simply assumed that the Bruce site L&ILW DGR concept could be transferred to a granite site. That is, a similar depth, layout and engineered barrier approach is adopted.

6.2 Summary:

DGRs are purpose-designed to match the characteristics of their particular site. Existing L&ILW repositories in granite in Sweden, Finland and Hungary are illustrated in Figure 6.1; these are all different designs, adapted to their waste characteristics and to local conditions.

In the absence of a specific site for optimization, and for the purpose of developing a basis for a relative risk assessment, it is assumed that the reference *Bruce site L&ILW DGR* concept can be transferred to a granite site. That is, a similar depth and layout is adopted. This may not be optimal but is plausible. For example, granite should be at least as strong as Cobourg Formation rock, and that in-situ stress levels are such that a similar Bruce site layout could be achieved.

Granite sites would generally have a range of fractures in the vicinity of a potential site. The repository rooms would therefore be positioned to avoid all major fracture zones, and to minimize contact with minor fractures. Given the relatively small footprint of the L&ILW repository, it is assumed that it would fit within the major fractures without significant adjustment. As with the *Bruce Site DGR,* this *Granite Site DGR* would accommodate 200,000 m^3 of operational and refurbishment L&ILW using waste containers similar to those presently in use. Incineration and compaction would continue to be used for LLW as in present practice.

The waste packages would be placed in rooms located underground. Depending on the specific site conditions, an additional engineered barrier may be provided by backfilling the space within or around the packages with cement or bentonite. This would need to be assessed in the context of a real granite site.

As “panels” containing emplacement rooms are filled with waste packages, the panels would be isolated with closure walls. After all emplacement rooms are filled, there would be a period of monitoring to ensure that the repository is behaving as expected. Eventually the area around the shafts would be filled with a concrete monolith, and the shafts filled with low-permeability seals. Surface facilities would be removed.

Within the emplacement rooms, the containers would eventually degrade. The slow degradation of metals and organics will result in the production of gas, which will also be restrained by the low-permeability rock, forming an unsaturated volume in the repository. However in general, a granite site would in comparison provide more water to the repository, and more gas released from the repository, than is expected at the Bruce site sedimentary rock.

The repository would be designed through combination of depth, layout and rock properties to be robust under earthquake and glacial loads. The net result would be that most radioactivity decays within or near the repository.

Canadian society is assumed to initially remain intact, providing site monitoring and land use restrictions which ensure that there are no activities or events that would damage the repository. Since the repository is not dependent on active maintenance, it would continue to perform as intended.

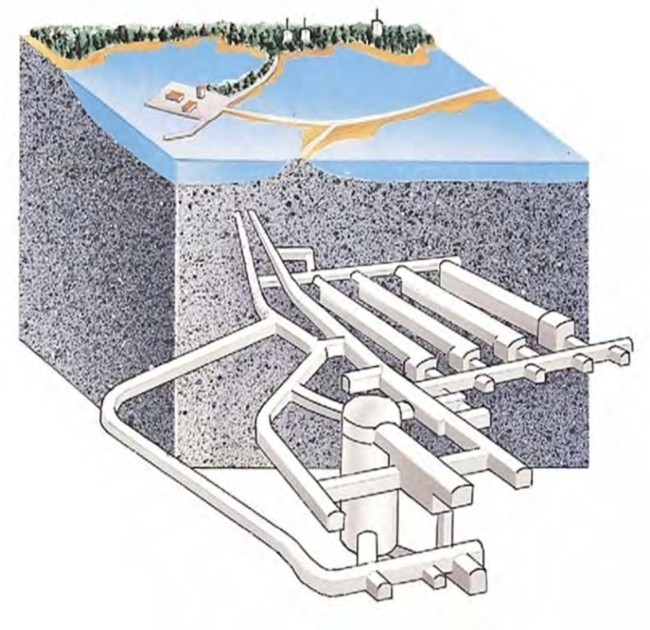
6.3 Location: Unspecified Canadian Shield site. For context, the nearest edge of the Canadian Shield is about 200 km by road from WWMF, while the Canadian Shield at the Manitoba/Ontario border is about 2000 km distant.

6.4 Transportation: All wastes are trucked to WWMF as per current practice, for initial processing and storage. Processing includes incineration and compaction. Approximately half of the waste packages are already stored at the WWMF.

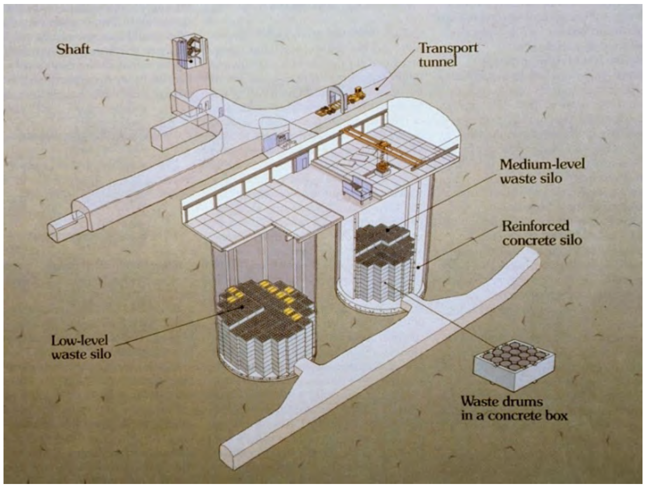
This option requires additional offsite transport compared to all of the other options. The amount of additional transportation depends on the granite site location. The current distance from the stations to WWMF is about 300 km by public roads from Pickering and Darlington stations, and about 1 km on site roads from the Bruce stations. All waste packages initially go to WWMF for processing. A granite site within Ontario is likely to be in the range of 200 to 2000 km distant by road from the WWMF. This indicates that the *Granite Site DGR* would require from double to several times as much road transportation of waste packages compared to the other three options.

6.5 Design Assumptions:

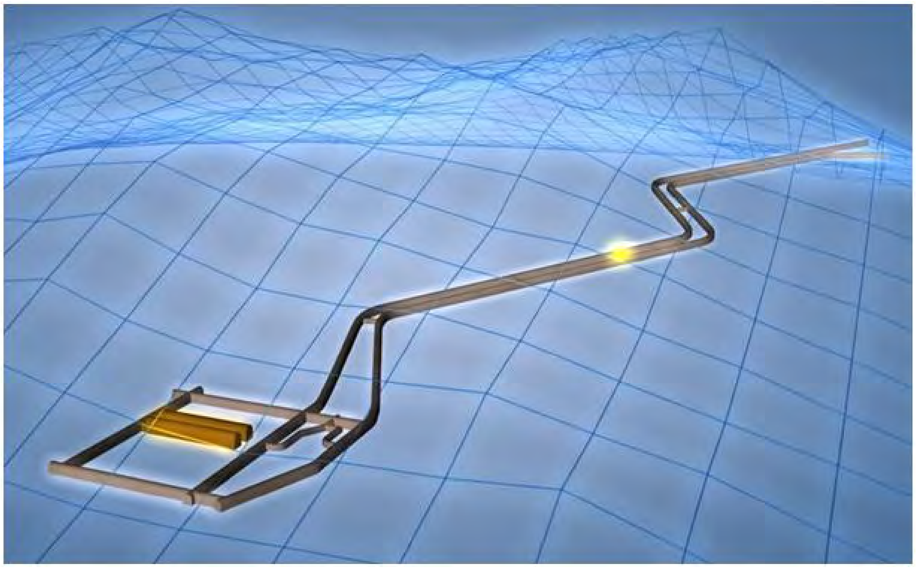
- Existing container concepts with approximately 30 to 50 year design life.
- Approximately 45,000 LLW and 7,400 ILW packages (Table 5-7, OPG 2011b).
- Repository layout same as *Bruce Site DGR.* L&ILW stored in 31 emplacement rooms in two panels.
- No future waste handling required after the repository has been sealed.



(a) SFR, Sweden



(b) VLJ, Finland



(c) Baatapati, Hungary

Figure 6.1: Illustrations of L&ILW repositories in granitic rock. (a) SFR in Forsmark, Sweden at 80 m depth. (b) VLJ in Finland at around 80 m depth, and (c) Baatapati, Hungary at 250 m depth.

6.6 Site Characteristics:

Granitic rocks are generally more fractured and permeable than the Bruce site sedimentary rock. In granite rocks, fractures are very site specific; and at a real site, the repository would be positioned to take best advantage of conditions to achieve passive safety (i.e., respect distance to large layout-determining fractures).

Within the Canadian Shield, three granite sites have had some characterization relevant to siting of a deep geologic repository - Whiteshell/Pinawa, Atikokan and East Bull Lake. However, these were research areas and never intended as candidate sites for a repository. At present several communities located on the Canadian Shield have expressed interest in learning more about hosting an NWMO used fuel repository. However none of these communities have indicated interest in a L&ILW repository, nor has there been underground rock characterization near these communities. Therefore there is no characterized potential Canadian Shield granite site for an L&ILW DGR.

The site information from Whiteshell/Pinawa was used for illustrative purposes as part of the AECL Environmental Impact Statement for a used fuel repository (AECL 1994) presented to the Seaborn Panel. Recognizing the variability in Canadian Shield sites, a similar site but with an assumed approximately 100x higher rock permeability was considered in the AECL Second Case Study (AECL 1996), also presented to the Seaborn Panel. Subsequently, the Canadian used fuel repository program has considered a hypothetical site within the Canadian Shield in the Third Case Study (OPG 2004) and Fourth Case Study (NWMO 2012) and related published reports. These latter two studies used a hypothetical site that was constructed to be representative of Canadian Shield site that could be of interest for a repository. It included typical Shield topography, fracture distribution and geometry, and hydraulic conductivities.

This site is shown here as an illustration of the potential nature of candidate granite sites within the Canadian Shield. In particular, Figure 6.2(a) illustrates the regional topography around the illustrative site, showing the generally subdued topography typical of the Canadian Shield. Figure 6.2(b) illustrates the nature of major fractures that could occur at a Canadian Shield site.

Figure 6.2(a) also illustrates the range of surface water features that could occur at a real site, ranging from small lakes and streams, to larger rivers and (not shown) lakes. The larger water bodies generally have a larger catchment area, so would be more likely to collect any radionuclides released from a DGR. However, they also would have higher water flow volumes.

The site may be assumed to be in a seismically quiet portion of the Canadian Shield craton; the seismicity of the *Bruce Site DGR* region is comparable to such a setting.

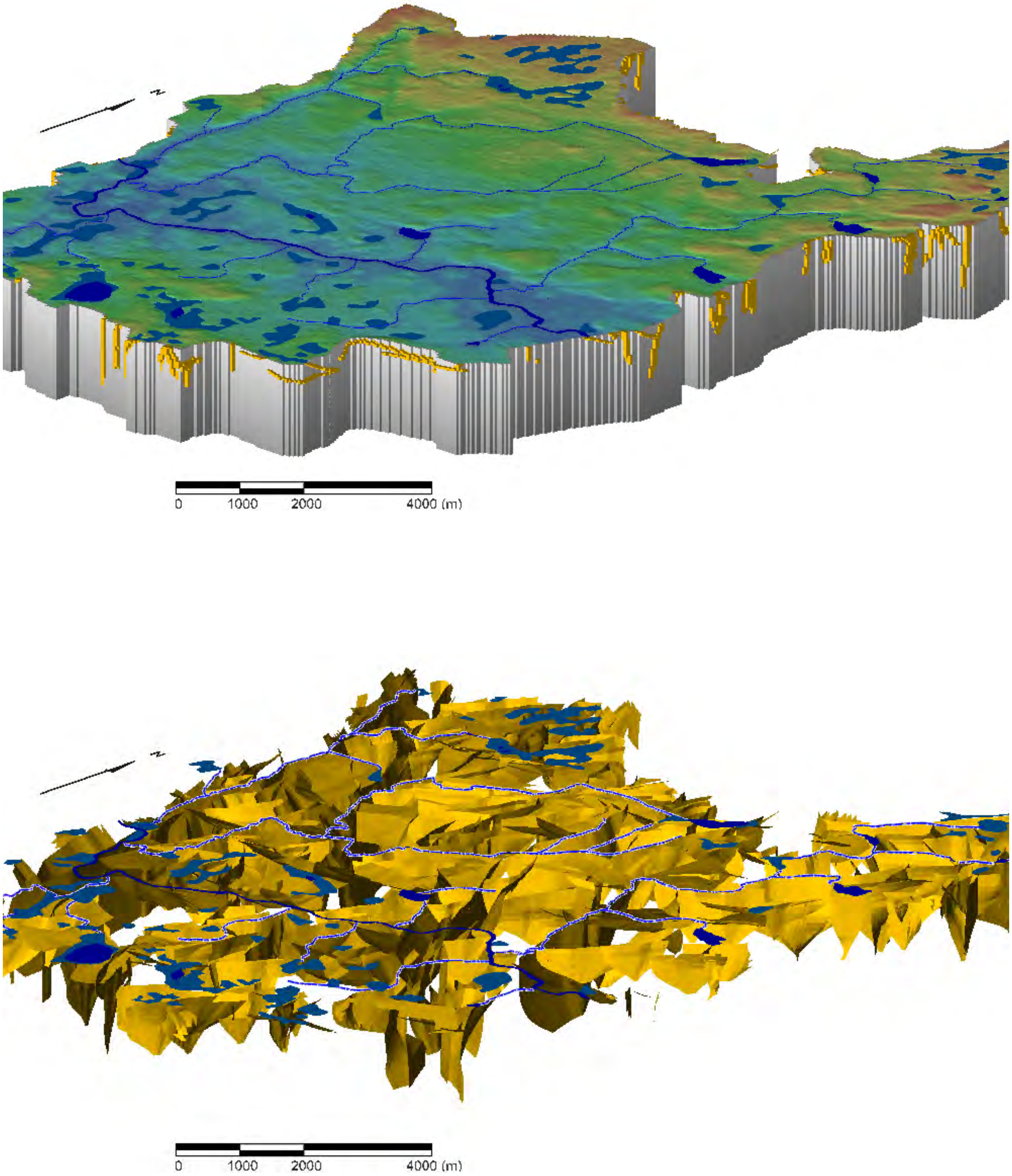


Figure 6.2: (a) Topography for hypothetical area in Canadian Shield. (b) Fracture network for hypothetical area of Canadian Shield.

In addition to the nature of the fractures in the rock, another important characteristic is the effective hydraulic conductivity and porosity of the rock mass between the fractures. Figure 6.3(a) shows the hydraulic conductivity measured in the granitic rock at the Whiteshell and Atikokan sites, and the reference effective rock mass hydraulic conductivity profiles used for various Canadian used fuel repository case studies in crystalline rock. (The major fracture zones were assigned high hydraulic conductivities; not shown.)

Figure 6.3(b) shows the Whiteshell and Atikokan site hydraulic conductivity data, and the reference Bruce site hydraulic conductivity profile based on measurements. It can be seen that the rock mass hydraulic conductivity around the repository horizon (680 m depth) at the Bruce site is very low; lower than that in the various granitic rock sites considered. Figure 6.3(b) also identifies two model granite rock mass hydraulic conductivities - Low K and High K - consistent with the range of data. The Low K case is similar to the rock properties used in the EIS submitted in support of the Seaborn Panel (as referenced in the IR EIS-12-513 context). It is an optimistic case for Shield granite.

Permeable rock occurs in all cases near surface. At the Bruce nuclear site, there are no permeable subvertical faults in the area, but there are relatively thin, permeable, near-horizontal rock formations about 200-m above and below the DGR host rock horizon. In a granite site, there would be fracture zones in the vicinity that would most likely be permeable.

Figure 6.4 illustrates the groundwater velocities in a plane of the repository at the hypothetical granite site. These velocities are shown for three different hydraulic conductivity profiles, as shown in Figure 6.3(b). Velocity arrows are not shown below 0.0001 m/a; in such regions contaminant transport is effectively diffusion controlled. Although the details are specific to this hypothetical site, the results illustrate two more general points: (a) the importance of the local fracture network geometry in governing groundwater migration rather than regional gradients; and (b) the general decrease in groundwater movement with depth.

Canadian Shield granite sites likely have low levels of salinity, possibly on the order of 10-50 g/L at repository horizons. This would be much lower than that at the Bruce site, where the water is essentially brine (about 300 g/L) below about 200 m depth. The lower salinity in granite rocks would have various effects on the repository behavior and radionuclide mobility. For example, there could be less chemical corrosion but more microbial corrosion under lower salinity water. At a generic site level, highly saline conditions indicate that the site likely has very old or stagnant groundwater.

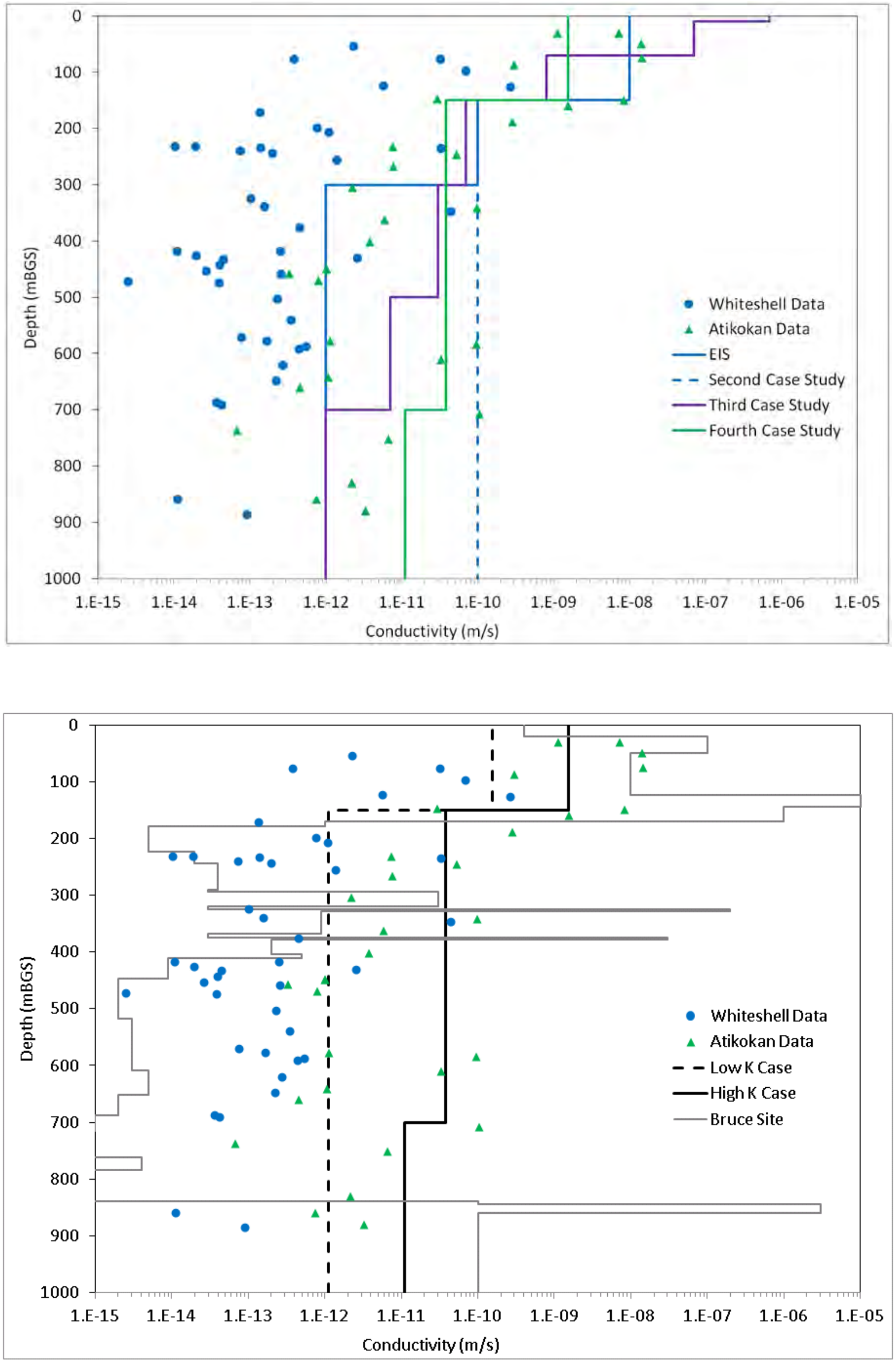
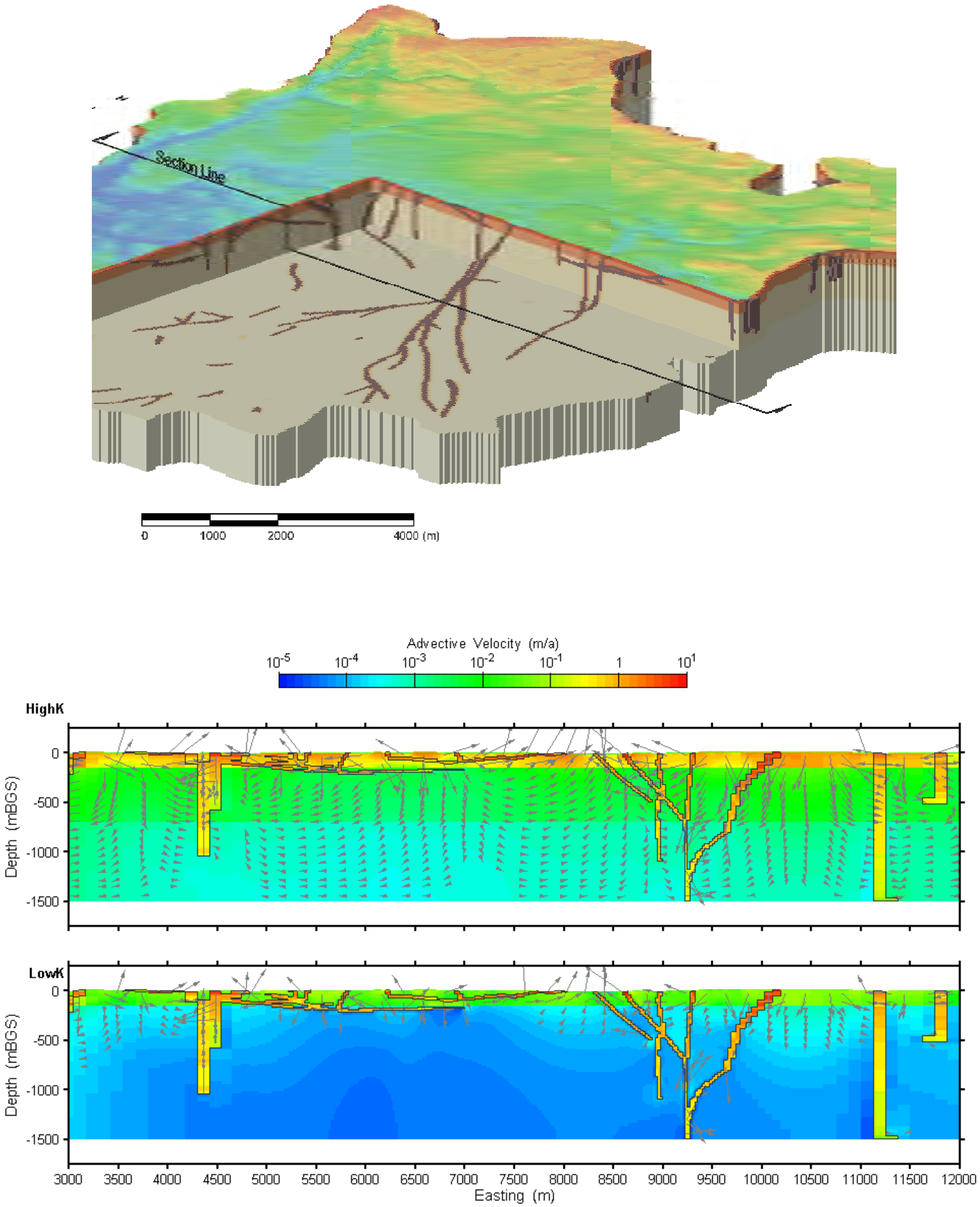


Figure 6.3: (a) Granite rock data at two sites and rock mass hydraulic conductivities assumed in various Canadian used fuel repository case studies. (b) Comparison of granite rock data with hydraulic conductivity at Bruce site. The reference repository depth is 680 m.



Notes: Rock hydraulic conductivities are shown in Figure 6.3(b).
Color shading is absolute velocity, arrows are XY velocity vectors.

Figure 6.4: Groundwater velocities in the rock porosity for range of rock mass hydraulic conductivity profiles, across vertical cross-section shown in top figure.

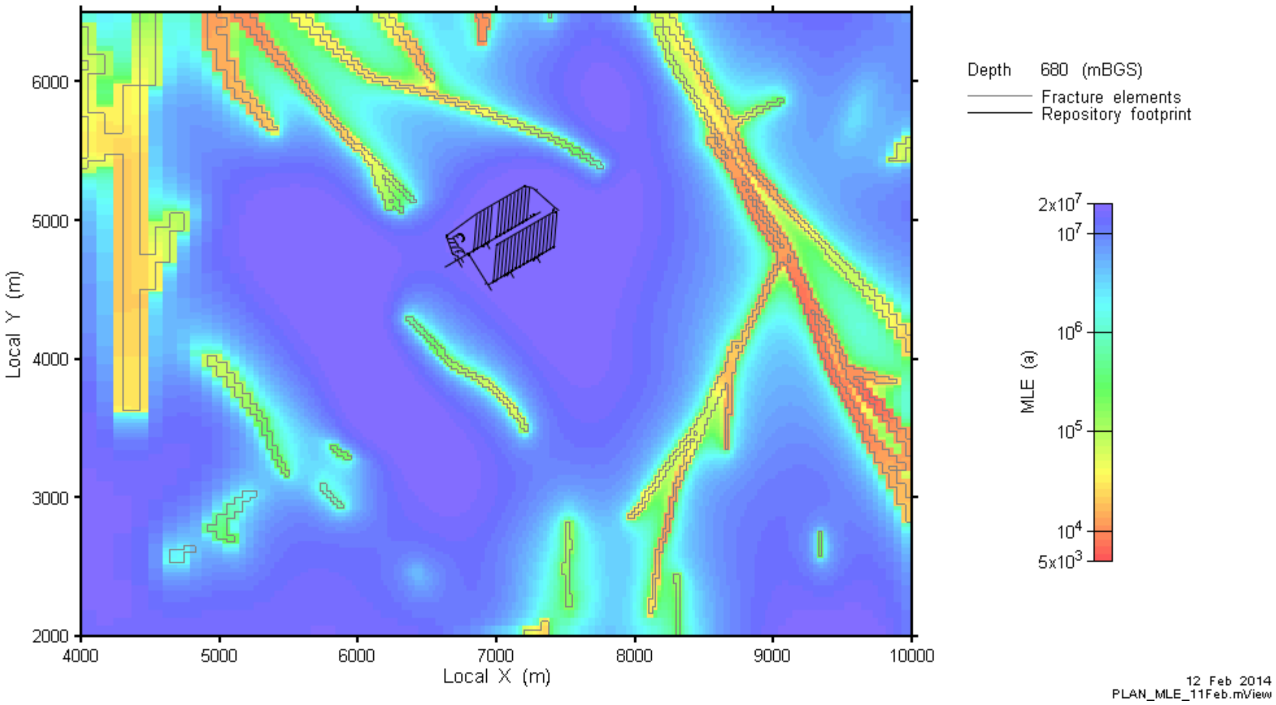
Figure 6.5 below illustrates how an L&ILW DGR repository might be located within the major fractures using this hypothetical site as basis.

Specifically, Figure 6.5(a) shows the major fractures at 680 m depth in the granite site, and the Mean Life Expectancy (MLE) for a low hydraulic conductivity profile (Low K case from Figure 6.3b), similar to the EIS case (AECL 1994) noted in the Information Request and likely optimistic for granite site. The MLE is a calculated measure of the average time for a molecule released at a given point on the plot to reach surface via groundwater, including diffusion, dispersion and advection. For this case, a potential location for an L&ILW DGR is shown that places the repository in an area of higher MLE. At a real site, there may be other constraints that limit the repository locations, but this illustrates the design approach.

Figure 6.5b shows the surface water features and the surface fractures, relative to the repository footprint. As illustrated in Figure 6.2(a) and Figure 6.5(b), there can be a variety of surface water environments around the repository location. For this hypothetical site, using values assumed in NWMO (2012), the central wetland at x,y co-ordinates of (7000, 3600) and the lake system at (8300, 4400) have catchment areas of a few km^2, and annual average water throughputs of around 0.02-0.04 m^3/s. The larger South River along the bottom of the model has a catchment area of around 2000 km^2 and an annual average water flow of 23 m^3/s. The streams associated with the lake and wetland would be first order as they do not have any tributaries. The South River would have a higher stream order, not determined in this hypothetical site model but conceptually around fourth or fifth order.

For comparison, if a large lake system was nearby, then any releases would likely be captured as all this site would be part of its catchment area. Using data from near shore Lake Huron at the Bruce nuclear site as an example, the average water flow through a near-shore volume collecting any releases could be on the order of 250,000 m^3/s (1000 m along shore, 500 m into lake, 5 m average depth, 0.1 m/s average current, Section 6.1.2 Quintessa and Geofirma 2011). (Note that this is flow within the lake, the annual net discharge from Lake Huron is around 5000 m^3/s.)

The direct impact of the repository on these water systems after closure would depend on the extent to which there were any releases, and the amount captured in these water systems. This would vary with the specific site. Assuming that they captured the same amount of any releases, then the main effect would be greater dilution in the larger water systems.



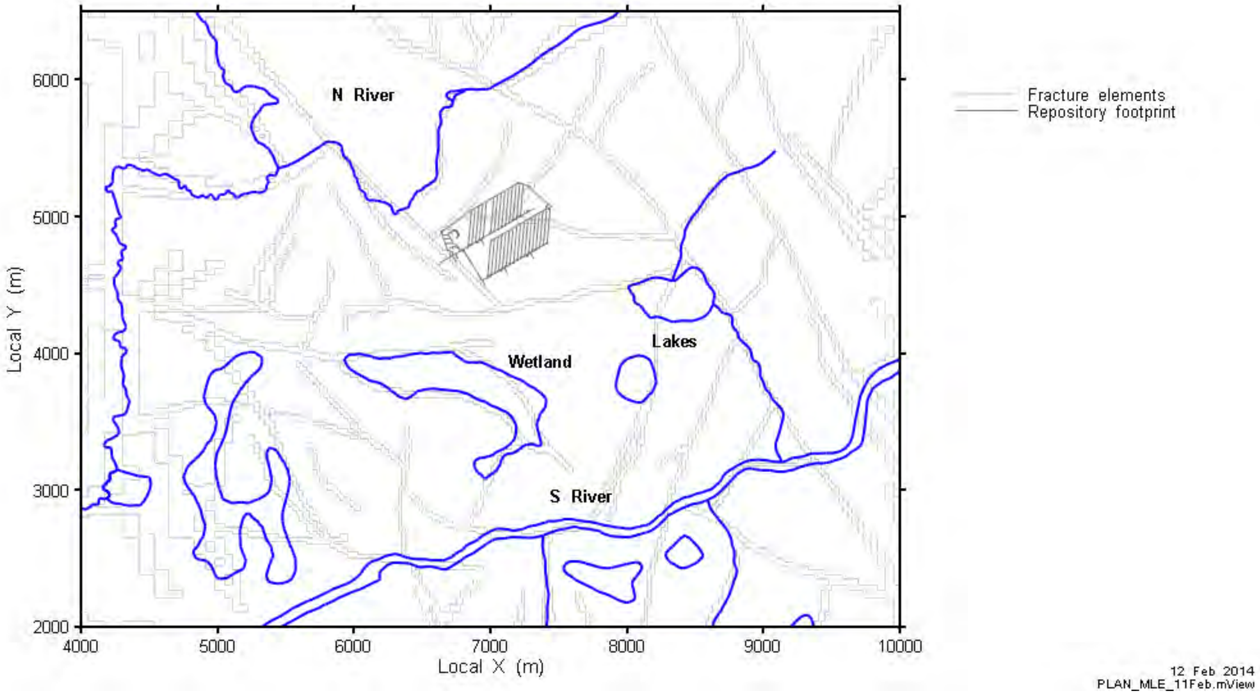


Figure 6.5: Illustrative repository location at 680-m depth at hypothetical site. (a) Major fracture locations at 680-m depth, and Mean Life Expectancy for Low K case of hydraulic conductivity. (b) Surface fracture locations and surface water features.

6.7 Worker Health and Safety:

DGR facility construction and operation are similar to the *Bruce Site DGR.* However, there is much more road transportation of waste packages. And there may also be a need to develop infrastructure, including roads and power lines if the site is remote. The conventional worker health and safety risk would therefore be generally larger than that of the *Bruce Site DGR*.

Nuclear safety will be related to the rate of waste package handling. This will occur during the initial 40 year period while waste packages are transferred from the WWMF to the DGR. After this transfer, there is no further worker exposure. This will be similar to the *Bruce Site DGR*.

Possible differences in a *Granite Site DGR* could include higher levels of natural radon, increased water ingress if fractures are intercepted at repository level, and differences in rock stability due to in-situ stresses. These would need to be assessed for a specific site.

6.8 Public Health and Safety:

During the DGR's operational phase, the main impact on public safety from normal operations would be from the low routine emissions from the facility and from transportation. The effect of the emissions would be very low and similar to that for the *Bruce Site DGR* option, assuming similar distances from repository to nearest public location. The potential effect from transportation would also be very low, but higher for the *Granite Site DGR* option due to the increased waste package transportation from WWMF to the site.

After closure, any releases of radionuclides would have to occur by transport through the surrounding rock or shaft seals as dissolved species or gaseous species. These processes are very slow in low permeability rock, and there would be radioactive decay, dispersion and dilution before any materials would reach surface.

Potential differences in the postclosure evolution in a Canadian Shield granite site relative to the Bruce sedimentary rock site could occur due to differences in rock permeability and fractures, differences in water salinity, and differences in rock mineralogy, stability and strength. In particular, as indicated by Figure 6.3, most granite sites are likely to be more permeable than the very low permeability Bruce sedimentary rock. As a result, there will be faster resaturation by water, faster generation of gas, and faster release of radionuclides via groundwater and gas relative to the very low values at the Bruce site. However the site and design in granitic rock would be selected to ensure that any releases were well below criteria.

There are no detailed analyses available for an L&ILW DGR in Canadian Shield granite. Other studies have indicated that deep geologic repositories on appropriate Canadian Shield sites could provide safe isolation and containment for used fuel (AECL 1994, AECL 1996, OPG 2004, NWMO 2012). Although the designs are different, the used fuel studies provide an indication that Canadian Shield sites can provide long-term isolation and containment.

6.9 Loss of Institutional Control:

At closure of the DGR, it is expected that the shafts would be sealed, surface facilities removed, and institutional controls put in place. These could include local, provincial and national records, land use controls, fencing and markers. The intent would be to preserve the knowledge that the repository was placed at that location. There might also be some ongoing level of monitoring at surface. The details would be developed with the regulator and community at that time, based upon the knowledge and technologies 50 years from now.

At some time in the future, it is possible that there would be loss of stewardship or institutional control of the site. This could be due to some significant event, such as war or epidemic outbreak or severe climate change. Since the repository is also very passive, it could also be due to simple passage of time since nothing significant would be observed to change at surface. However, even in this case, societal memory could preserve knowledge of the site for a long time. In the worst case, it may be assumed that eventually all records, markers and memory of the repository location lost.

As part of the *Bruce Site DGR* safety assessment (Ch. 8, OPG 2011b), it is assumed that this control is not effective 300 years from closure of the repository, including even memory of the nature of the site. It is further assumed that people move onto the site, and are therefore directly exposed to any releases from the facility.

However since the repository is not dependent on active maintenance, it would continue to perform as intended. This is the Normal Evolution Scenario. Any impacts from the repository are expected to be orders of magnitude below current regulatory criteria. The impacts would be even smaller for someone living further distant, such as someone living near shore and obtaining water and fish from Lake Huron.

If it is assumed that inadvertent human intrusion occurs once stewardship is lost, then the worst case would be for excavation direct into the repository. This would be unlikely because of the lack of mineral resources in these rocks, the depth of the repository and its small footprint. Inadvertent intrusion could occur through a borehole drilled directly into the repository, bringing water materials to surface and creating a pathway for gas and groundwater release. The consequences of intrusion were assessed for the *Bruce Site DGR* using simple models, and are summarized in Section 8, Addendum. The consequences for a *Granite Site DGR* are expected to be similar due to similar amounts of material brought to surface by borehole. (The C-14 contribution was smaller than other radionuclides for the *Bruce Site DGR*, but could be different - higher or lower - due to specific site differences affecting the amount in gas). The consequences of loss of institutional control to persons living on the site would remain at similar levels for tens of thousands of years due to the long life of some of the radionuclides in ILW.

6.10 Sustainability:

Sustainability may be assessed through several factors, notably energy usage and materials usage. At a conceptual level, the energy and material usage should be similar to that for the *Bruce Site DGR* for a similar repository design. Potential differences would include those due to the need for transportation to the site of the wastes from WWMF, and possibly of materials and personnel to the site if it is remote. The details of the granite site would lead to other differences in detail (e.g., amount of rock support, use of backfill).

Section 7: References

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OPG. 2011b. OPG’s Deep Geologic Repository Project for Low & Intermediate Level Waste - Preliminary Safety Report. Ontario Power Generation report 00216-SR-01320-00001 R000. Toronto, Canada.

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Quintessa and Geofirma. 2011. Postclosure Safety Assessment: Data. Quintessa Ltd. and Geofirma Engineering Ltd. report for the Nuclear Waste Management Organization NWMO DGR-TR-2011-32. Toronto, Canada.

Section 8.
Addendum: Loss of Stewardship and Institutional Control

At some time in the future, it is possible that there would be loss of stewardship or institutional control or even societal memory of the site. The consequences of such loss of stewardship or institutional control are assessed in this Addendum. It is assumed that the site would no longer be maintained and monitored, and that any surface buildings and containers left to degrade. People are assumed to move onto the site shortly after the loss of control and to carry out normal activities, unaware of the potential presence of radioactive wastes.

Status Quo and Enhanced Surface Storage Options:

For the *Status Quo* and *Enhanced Surface Storage* options, this would pose a significant risk since the wastes are at surface. As these structures degrade, rainwater would eventually percolate through the structures and either runoff onto adjacent land, or infiltrate through the till and into the groundwater aquifer beneath the site. In either case, radioactivity would be released, which would lead to dose consequences.

These have been assessed using simple models adapted from those used to assess failure consequences for the Covered Above Grade Concrete Vault (CAGCV) option considered in the 2003 preliminary safety assessment of concepts for a permanent waste repository at the Bruce nuclear site (Quintessa 2003). In that analysis, the CAGCV was considered as a permanent disposal option for LLW and was backfilled; however the models have been adapted to the present case.

In the *Status Quo* option with loss-of-stewardship, it is assumed that the buildings and containers break down gradually over 100 (LLW) to 200 years (ILW) from the time of the loss of stewardship, allowing rainwater to percolate through the facility and either run off onto adjacent land, or drain through the till and into the groundwater aquifer and there to Lake Huron. We consider two exposure cases - first, a person using the adjacent land for growing crops, and second people living at the adjacent Lake Huron shore and consuming a high fish diet. Simple estimates using the methodology from Quintessa (2003) suggest that if stewardship was lost at 300 years after closure (assumed here to be 2062), and people moved on site immediately, the dose consequences to someone growing crops on land that was contaminated by runoff would be of the order of 1000 mSv/a, while the dose impacts to someone living near shore and obtaining water and fish from Lake Huron would be about 0.1 mSv/a. The dose to persons living further distant would decrease with distance.

In the *Enhanced Surface Storage* option, the structures are more robust. In this case, it is assumed that the buildings and containers break down gradually over 200 (LLW) to 400 years (ILW) from the time of the loss of stewardship. Using the same models as above, simple estimates suggest that the consequences are essentially the same as the *Status Quo* option as the increased robustness does not significantly affect dose impacts.

If it is assumed that intrusion occurs once stewardship is lost, then the worst case would be for excavation direct into the structures. The impacts have been calculated using a simple model similar to that considered in the preliminary safety assessment (Quintessa 2003). For the RWSBs, the peak impact would be about 300,000 mSv/a to the excavator; for the IC18s, the peak impact would be about 400 mSv/a to a site dweller following excavation; and for the LLSBs, the peak impact would be about 1 mSv/a to the excavator.

These models can be applied to other assumed timescales for loss of stewardship. Figure A.1 shows the results for various times for the *Enhanced Surface Storage* option; the results are similar for the *Status Quo* option.

Figure A.1 shows that the LLW requires stewardship for time frames of around 300 years. Also that Operational ILW requires stewardship for timeframes of about 10,000 years. By 10,000 years the remaining hazard in the Operational ILW (e.g. resins) are low enough that even direct intrusion doses are on the order of a few mSv/a. After this time frame, the only path that leads to significant doses is that due to direct intrusion (excavation) into the retube wastes. These wastes require stewardship for time frames beyond 100,000 years, if kept on surface.

Bruce Site DGR and Granite Site DGR Options:

As part of the *Bruce Site DGR* postclosure safety assessment (Ch. 8, OPG 2011b), it is assumed that institutional control is not effective after 300 years from closure of the repository, including even memory of the nature of the site. It is further assumed that people move onto the site, and are therefore directly exposed to any releases from the facility.

However since the repository is not dependent on active maintenance, it would continue to perform as intended. This is the Normal Evolution Scenario. Any impacts from the repository are expected to be orders of magnitude below current regulatory criteria. The impacts would be even smaller for someone living further distant, such as someone living near shore and getting water and fish from Lake Huron.

If it is assumed that inadvertent human intrusion occurs once stewardship is lost, then the worst case would be for excavation direct into the repository. This would be unlikely because of the lack of mineral resources in these rocks, and the depth of the repository. Inadvertent intrusion could occur through a borehole drilled directly into the repository, bringing materials to surface and creating a pathway for gas and groundwater release.

The consequences of inadvertent borehole intrusion were assessed for the *Bruce Site DGR.* For these simple estimates, it was further assume that:

- people lived near the site during the drilling, and on the site afterwards;
- contaminated drilling debris was left at surface on the site;
- the borehole was not sealed afterwards.

The dose consequences would range from about 1 to 30 mSv/a at 300 years depending on whether the drilling is stopped at the repository horizon, or if it is extended down to the pressurized Cambrian formation at about 850 m at the Bruce site (Section 8.7.1.3, OPG 2011b). The higher consequence would occur for the deeper well, due to the flow of water from the pressurized Cambrian formation through the unsealed borehole. The consequences of loss of stewardship to persons living on the site would remain at similar levels for tens of thousands of years due to the long life of some of the radionuclides in ILW.

Figure A.2 shows the results for the borehole intrusion into the *Bruce Site DGR,* for various receptors. In this analysis, the borehole stops at the repository. The dose to the drill crew is about 1 mSv due to exposure to Nb-94 in the drill core debris. The 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 at about 1 mSv/a. Since Nb-94 has a 20,300 year half-life, most intrusion doses do not decrease significantly until after about 100,000 years.

A borehole in a *Granite Site DGR* would also be unlikely as the site would not be located where minerals were known to occur, and also there would be no prospect for oil or gas as may occur in sedimentary formations. Similar amounts of waste material would be brought to surface as for the *Bruce Site DGR* because this is related to borehole size. A deep pressurized rock layer is unlikely at a granite site, and therefore in principle there should be little influence of drilling depth on consequences. Therefore, although not specifically analysed, it is expected that the dose consequences in a *Granite Site DGR* would be similar to that for the *Bruce Site DGR.*

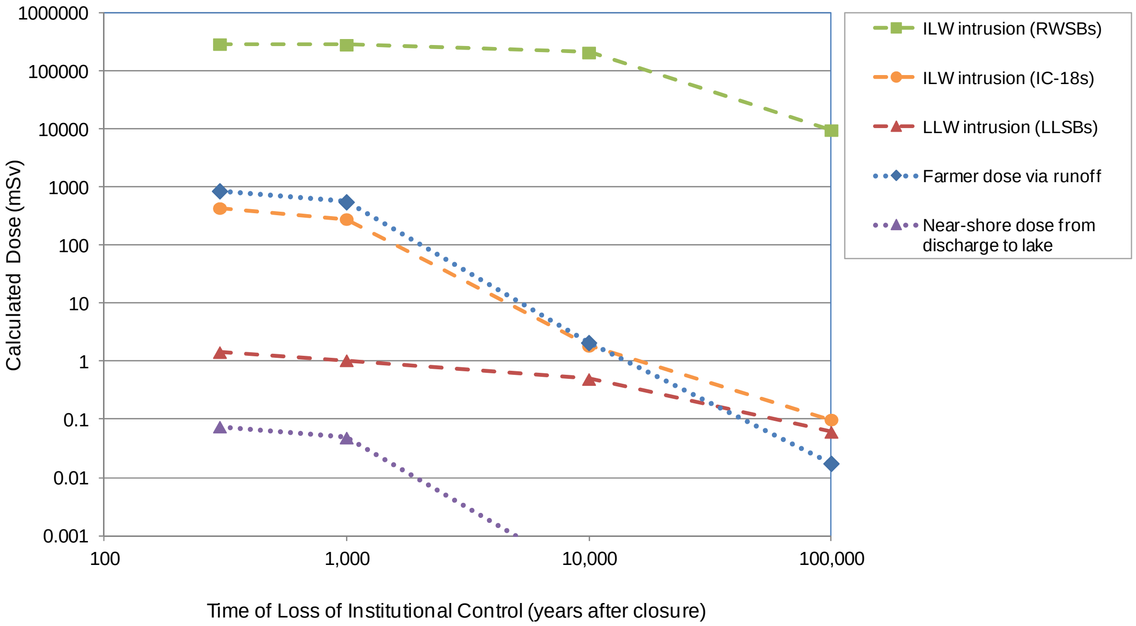

Figure A.1: Calculated Doses for Human Intrusion in the Enhanced Surface Storage Option via Groundwater and Intrusion Pathways, for Loss of Stewardship at Different Times

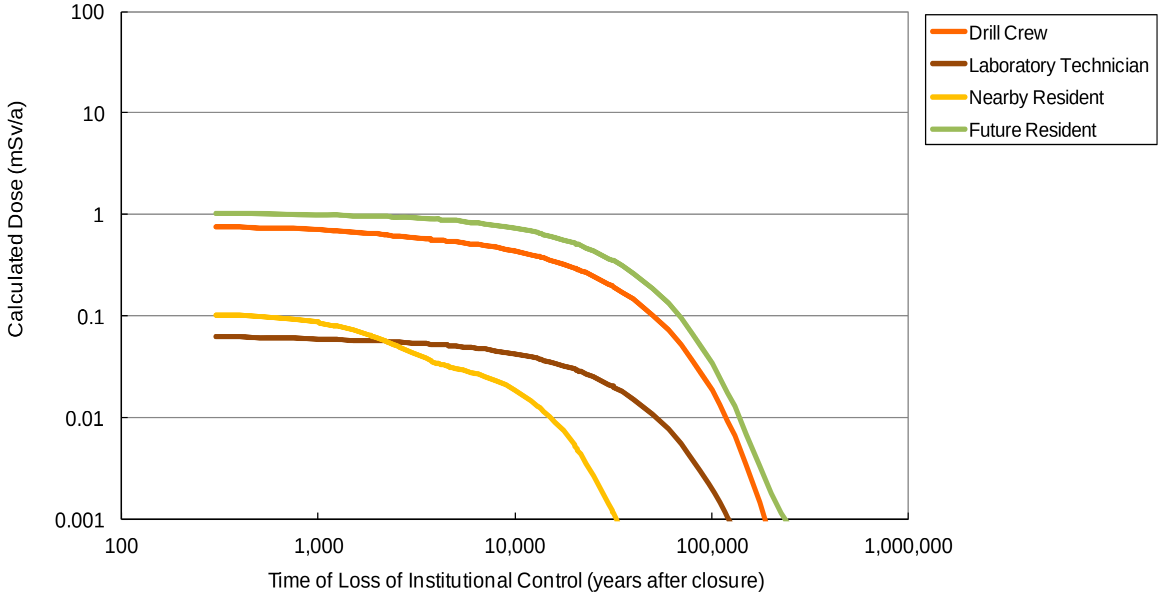

Figure A.2: Calculated Doses for Human Intrusion in the Bruce Site DGR Option for a Borehole Drilled to the Repository Horizon, for Loss of Institutional Control at Different Times (adapted from Figure 8-36, OPG 2011b)

Appendix VI: Biographies of Expert Group Members

Maurice B. Dusseault, PhD (U Alberta, Engineering 1977), PEng (AB and ON), is Professor of Geological Engineering in the Department of Earth and Environmental Sciences Department, University of Waterloo. He carries out research in coupled problems in geomechanics, oil production, and novel deep waste disposal technologies. Geomechanics interest areas include CO_2 sequestration, hydraulic fracturing, oil and gas well integrity, steam injection for heavy oil production, biosolids injection, and thermohydromechanical coupling in fractured rock systems. He holds 10 patents and has co-authored two textbooks as well as over 500 conference and journal articles. Maurice works with governments and industry as an advisor and professional instructor in petroleum geomechanics. He was a Society of Petroleum Engineers Distinguished Lecturer in 2002-2003, visiting 19 countries and 28 separate SPE sections, speaking on New Oil Production Technologies. He teaches a number of professional short courses in subjects such as production approaches, petroleum geomechanics, waste disposal, and sand control, presented in 20 different countries in the last 10 years. Maurice has served on the Council of Canadian Academies Expert Panel Report on Shale Gas Environmental Impacts (expected May 2014); he is a member of the Scientific Advisory Council of the New Brunswick Energy Institute, a member of the Hydraulic Fracture Review Panel of the Government of Nova Scotia, a senior science advisor to the Alberta Department of Energy, and a technical advisor to the Alberta Energy Regulator.

Tom Isaacs works on issues at the intersection of nuclear power, national security, waste management, and public trust and confidence. He is a Visiting Scientist at Lawrence Livermore National Laboratory and a Visiting Scholar at the Stanford University Center for International Security and Cooperation. He was a member of the National Academy of Sciences Board on Nuclear and Radiation Studies, and was the lead advisor to the U.S. Blue Ribbon Commission on America's Nuclear Future formed at the request of President Obama, which made its recommendations in early 2012. Among the organizations Tom has advised recently are the U.S. Department of Energy, the Canadian Nuclear Waste Management Organization, the Japanese Nuclear Waste Management Program, and the Korean Atomic Energy Research Institute. He is an annual lecturer at the World Nuclear University Summer Institute held at Oxford University. Tom began his career with an extended tenure at the Atomic Energy Commission and the U. S. Department of Energy. During his career, Tom has helped design advanced nuclear reactors, developed nuclear safety programs, brought the discipline of decision analysis to nuclear affairs, managed a large government organization responsible for safeguards and security, led a national security analytical organization, help several senior management positions in government, led the U.S. siting effort for waste management facilities, worked directly with Congress to draft and implement new laws, managed a major international program for a decade, sat on advisory committees for university departments, and published and presented papers in a very wide network of domestic and international settings. His degrees are in chemical engineering from the University of Pennsylvania and engineering and applied physics from Harvard University.

William Leiss is a Fellow and Past-President (1999-2001) of the Royal Society of Canada and an Officer in the Order of Canada. From 1999 to 2005 he held the NSERC/SSHRC Research Chair in Risk Communication and Public Policy in the Haskayne School of Business, University of Calgary, and from 1994 to 1999 he held the Eco-Research Chair in Environmental Policy at Queen's University. His earlier academic positions were in political science (Regina, York), sociology (Toronto), environmental studies (York), and communication (Simon Fraser). At Simon Fraser he was also Vice President, Research. He is currently a Scientist with the McLaughlin Centre for Population Health Risk Assessment, University of Ottawa. He was a member of the Senior Advisory Panel for the Walkerton Inquiry (2000-2), Chair of the Task Force on Public Participation for Canadian Blood Services (2002), and an advisor on risk management to the Commission of Inquiry into the Investigation of the Bombing of Air India Flight 182 (2008-2010). He is author, collaborator or editor of fifteen books and numerous articles and reports. Three books are made up of case studies dealing with controversies, in Canada and elsewhere, about health and environmental risks: *In the Chamber of Risks: Understanding Risk Controversies* (2001); *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication* (with Douglas Powell, 1997; second, enlarged edition 2004); and *Risk and Responsibility*, 1994 (with Christina Chociolko). Earlier books are *The Domination of Nature* (1972), *The Limits to Satisfaction* (1976), *Social Communication in Advertising* (1986, 1990, 2005), *C. B. Macpherson* (1988, 2009), and *Under Technology's Thumb* (1990), all of which are currently in print. With the exception of *Social Communication in Advertising,* all of these titles are published by McGill-Queen’s University Press. His newest book, *The Doom Loop in the Financial Sector, and Other Black Holes of Risk,* was published by The University of Ottawa Press in October 2010. Over many years he was responsible for organizing expert panel reports on behalf of The Royal Society of Canada.

Greg Paoli serves as Principal Risk Scientist and COO at Risk Sciences International, a consulting firm specializing in risk assessment, management and communication in the field of public health, safety and risk-based decision-support. He has experience in diverse risk domains including toxicological, microbiological, and nutritional hazards, air and water quality, climate change impacts, and engineering devices, as well as risk assessment for natural and man-made disasters. He specializes in probabilistic risk assessment methods, uncertainty analysis, the development of risk-based decision-support tools and comparative risk assessment. Greg has served on a number of expert committees devoted to the risk sciences. He is currently serving on a U.S. National Research Council Committee on Safer Chemical Substitutions. Recently, he was a member of the U.S. National Research Council committee that issued the 2009 report, Science and Decisions: Advancing Risk Assessment, also known as the Silver Book. He serves on the Canadian Standards Association Technical Committee on Risk Management. He has served on several expert committees convened by the World Health Organization. Greg completed a term as Councilor of the Society for Risk Analysis (SRA) and is a member of the Editorial Board of Risk Analysis. He was awarded the Sigma Xi – SRA Distinguished Lecturer Award. Greg holds a Master’s Degree in Systems Design Engineering from the University of Waterloo.

Appendix VII: Short List of Technical Sources

General:

Australia: Parliament of Australia, "Radioactive waste and spent fuel management in Australia": http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BN/2011-2012/RadioActiveWaste

Institut de Radioprotection et de Sûreté Nucléaire (ISRN), *Radioactive Waste Management.* 2013: www.isrn.fr

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OECD, "Radioactive Waste Management Programmes in OECD/NEA Member Countries": https://www.oecd-nea.org/rwm/profiles/

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France:

Gérald Ouzounian, Michel Dutzer, and Patrice Torres, "Disposal of short-lived waste in France,", "Nuclear Engineering International" (April 2012): http://www.neimagazine.com/features/featuredisposal-of-short-lived-waste-in-france/.

Centre de l'Aube facility, which began operating in 1992: There is an excellent, extended description of this site at: http://www-pub.iaea.org/MTCD/publications/PDF/csp_006c/PDF-Files/paper-27.pdf

In addition, there is a 2009 PPT presentation on the three principal French facilities (Manche, Aube, and Morvilliers), with good photographs and diagrams showing facility structures as well as geological formations, at:
http://www.iaea.org/OurWork/ST/NE/NEFW/CEG/documents/ws022009/3.%20Near%20Surface%20Repositories/3.2%20French%20Near%20Surface%20Repositories,%20Andra%20Engl.pdf

Spain:

El Cabril Facility:
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ENCLOSURES

TO

OPG RESPONSE TO IR-EIS-12-513 CLARIFICATIONS

University of Ottawa
R. Samuel McLaughlin Centre for Population Health Risk Assessment
1 Stewart Street, Ottawa, ON K1N 6N5

8 May 2014

Ms. Laurie Swami
Vice-President, Nuclear Services
Ontario Power Generation
889 Brock Road
Pickering, ON L1W 3J2

Dear Ms. Swami:

On behalf of my colleagues in the Independent Expert Group – Maurice Dusseault, Tom Isaacs, and Greg Paoli – I am pleased to transmit herewith our "Report of the Independent Expert Group on Risk Perceptions of the Four Alternative Means for Managing the Storage and Disposal of Low- and Intermediate Level Radioactive Waste in Ontario."

I would be pleased to respond to any questions that you have; to reach me by phone: 613-297-4300.

Sincerely,

William Leiss, O.C., Ph.D., FRSC
Professor emeritus, School of Policy Studies, Queen's University
Scientist, McLaughlin Centre for Risk Assessment, University of Ottawa
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Report of the Independent Expert Group on Risk Perceptions of the Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario

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SUBMITTED BY:

MAURICE DUSSEAULT, TOM ISAACS, WILLIAM LEISS (CHAIR), GREG PAOLI

SUBMITTED TO:

THE JOINT REVIEW PANEL FOR THE DEEP GEOLOGIC REPOSITORY PROJECT FOR LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE (DGR)

May 8, 2014

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Section I

Introduction

This Report was prepared in response to a communication, dated 6 March 2014, from the Deep Geologic Repository Joint Review Panel (JRP).[1] In the excerpts from this communication quoted below, the JRP asked the Independent Expert Group (IEG) to consider the following issues:

1. "…[T]he Panel expects that there be a comparison of *risk perception* (and thus, *risk acceptability*) among the four options…. [T]he Panel suggests that the Expert Group focus on uncertainty. This is because the technical risk analysis of the four options will have a direct link with the analysis of the effects of the technical uncertainty on risk perception."
2. "Many submissions [to the JRP] presented comparative risk perceptions and risk acceptability among status quo, enhanced surface storage and deep geologic repositories. These submissions, together with information in the published literature and the Expert Group's analysis and professional judgement should be used to produce a relative risk perception/acceptability score for the four options."
3. "…[T]he Panel would encourage the Expert Group to comment on how risk perception among Aboriginal peoples might better be acknowledged and incorporated."
4. "The Panel expects that the analysis then go forward with further consideration of the *perception* of each of the four options, as influenced by the relative degree of technical uncertainty associated with the primary uncertainty issues listed above."
5. "The Panel maintains that use of a combination of evidence provided by submissions as well as published literature is sufficient to discriminate among the options if the Expert Group focusses, as is suggested above, on the effects of relative uncertainty on risk perception and risk acceptability."

In this supplementary Report the Independent Expert Group has sought to respond in detail to the issues and perspectives on risk perception and risk acceptability raised by the JRP. We have done so in the following way: First, we have commissioned a background study of the published literature on all of the general topics raised in the JRP letter (risk perception, acceptable risk, and uncertainty as a factor in risk perception). Since there is a large literature on the recent treatment of these subjects, dating back to the 1970s, the background study is extensive; therefore, we have given a short summary of the study in Section II below, and have placed the complete study in Appendix A.

Second, in Sections III and IV we have provided an overview of our understanding of risk perceptions of the four options, identified by the JRP, for managing low- and intermediate-level nuclear waste in Ontario. These risk perceptions treat separately the views of Aboriginal interveners in this discussion, on the one hand, and all other interveners, on the other. Our selection of material in our two overviews was made using a software-base search routine of all the submissions made to the JRP as well as the transcripts of hearings conducted by the Panel. Finally, in Section V we present our Observations and Conclusions with respect to the issues and perspectives raised by the JRP in its letter of 6 March 2014.

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[1] The complete text of the letter will be found in Appendix B of this Report.

Section II

Risk Perception of Nuclear Waste Disposal: Summary of the Background Study

Risk Perception.

Risk perception has been studied from the point of view of decision-making under conditions of uncertainty, qualitative factors associated with risk sources, demographic and psychological factors, and broader contextual factors relating to individuals' social values and their trust in risk managers. There are also findings relevant to perceptions of risk from radiation, nuclear power, and nuclear waste management and disposal.

Radiation from industrial sources is commonly thought to be a high risk by non-experts, associated with the possibility of accidents with fatal and catastrophic consequences, with little attention to the low probability that such accidents will occur. Risks from nuclear power are perceived to be unfamiliar and not observable, imposed on the public and not easily avoided or reduced. There is also a sense for some persons who are adamantly opposed to nuclear power on the grounds that it interferes with nature.

Also, nuclear power is often identified in terms of its high risk without consideration of its benefits, as individuals – experts and non-experts alike – frame an activity as predominantly a risk or a benefit and downplay the significance of the other side of the balance. The framing of nuclear power as a risk is associated with a more general negative perception of large-scale industries that impose risks on the public, while producing benefits that are diffuse and may not be experienced directly. This framing process is also seen in situations of higher risk that are tolerated because people experience, and value, benefits from the activity or use of a substance.

While commonly observed perceptions of risk from nuclear power and nuclear waste correlate strongly with a range of qualitative factors associated with the risk source, as well as demographic and psychological factors that influence individuals' judgements, the most important factors that influence perceptions of nuclear power are people's broader attitudes and values. These general attitudes and values shape more specific perceptions of risk from an activity, and the response people have to information on the activity as well as the trust they have for risk managers. Perceptions of the risk of an activity are associated with certain 'worldviews,' political values and belief systems, and are stable components of a person's general social orientation and outlook. People who hold 'ecological' values, for example, are more likely to perceive technology to be a risk and to oppose large industrial technologies such as nuclear power.

These value systems also shape the trust that individuals have in information, information sources, and risk managers. Particularly where risk perceptions relate to an issue of high value or political concern, people trust managers whose values are similar to their own, and who can be trusted to act in their best interest. Judgements about risk are complex determinations made in the context of individuals' knowledge and experience, their attitudes and values, and their social relationships. They are thus partly social phenomena, subject to interactive processes and broad social impacts. Judgements about a risk often become 'amplified'; in other words, specific risks may become the focus of heightened interest and concern through processes of information interpretation, whereby information is filtered through personal values and social interactions. One such potential effect is that of stigma, in which negative imagery associated with a risk or activity is attributed to related activities or to an area in which a facility perceived as dangerous or undesirable is located.

Nuclear power, and by association nuclear waste disposal, are highly charged issues that engage people's values and social priorities. These attitudes and value priorities can persist when possible advantages of nuclear power are discussed, so that some people may negotiate a 'conditional' or 'reluctant' acceptance of nuclear power if, for example, it may be advantageous in preventing climate change by offsetting the use of fossil fuels in energy generation. On the other hand, many of those living in communities where these facilities are already operating, or will be operating in the future, are supportive of them on the basis of the economic benefits they provide.

Perception of Risk within Aboriginal Cultures.

The cultural values and priorities that shape risk judgements of Aboriginal peoples, while they vary among different Aboriginal cultures and communities, are distinct from mainstream Western culture. The dominant priority is the cultural value of the land, generically as a spiritual entity and principle, and specifically as traditional territory to which a community is tied through history and material practices such as traditional harvesting. The integrity of the community and its culture depend on the continuation of traditional relationships with, and practices in, its territory, placing a primary focus in risk judgements on potential effects of a nuclear waste repository on the continuing integrity of the land.

Aboriginal communities may also have a different social structure than mainstream society, with a more participatory and inclusive means of decision making that reflects high degree of respect for community elders. They often have a traditional, more experiential approach to knowledge and to understanding the world.

Perceptions of Nuclear Waste.

Nuclear waste is commonly perceived as representing a high risk, sometimes even higher than nuclear power itself. This is partly because nuclear waste remains hazardous for a very long time, requiring monitoring and management processes that are unprecedented in human history. People often frankly reject scientific claims that the risks can be assessed and managed for such a long period into the future, and that a facility can be designed to contain the wastes for that long a period. Because of this long time-frame, nuclear waste facilities appear to place an inequitable burden of risk, and responsibility for management, on future generations, who cannot consent to the facility.

Aboriginal communities in particular may consider the placing of toxic waste in the earth to be an affront to the sacred, and, in the context of the multi-generational perspective that many Aboriginal cultures assume in their actions on the environment, they may be more averse to the long-term threat posed by the wastes.

Efforts to site a nuclear waste repository have frequently been contentious and sometimes fail. More recent efforts in several countries have focused on the selection of a site through a participatory process within volunteer communities, resulting in successful attempts to site a nuclear waste facility. Financial benefits, such as stable employment opportunities and increased commercial property tax revenues, are of course available to communities which agree to host a facility. Such benefits are regarded as appropriate by those who support nuclear facilities, but may be interpreted as exerting inappropriate pressures on smaller or remote communities by those who do not.

Conclusions on the Concepts of Uncertainty and Acceptability.

Experts make an effort to quantify and compare the uncertainties in various facility components and designs, and of different event scenarios, as a core consideration in a decision on the location and management of a repository that must contain nuclear wastes for thousands of years. Many non-experts, however, are not interested in quantifying uncertainties, and are more likely to refer to unknowns, asserting that many factors are simply unknowable over such long time periods. Instead of quantifiable uncertainties, non-experts are more concerned with the consequences that are possible. In addition, they are concerned about the need to delegate responsibility for designing, operating and monitoring such a facility to experts who often do not share their concerns for the risks or who do not appear to share their values with respect to the environment that is vulnerable to the risks.

The determination by a potential host community that a facility is acceptable is often seen as the desired endpoint of a participatory process. The Background Study suggests, however, that acceptability appears to represent an unrealistically simple concept entailing a generalized consent to proceed. The importance of the recognition of benefits and of the ‘conditional’ acceptance that has been observed among those who do not support nuclear power, suggests that agreement to host a facility is a more complex decision. The concept of tolerability has been used in other risk management contexts to express a risk that is actively managed to a level that is deemed appropriate in light of the benefits that are received from the activity. This multi-dimensional concept directs attention to the conditional or reluctant acceptance that may be granted by community members who acknowledge the value of a facility while they still have concerns about it. It reminds decision-makers and participants that ongoing attention to benefits and to risk management is an integral part of the decision-making and future management processes.

Section III

Positions on the Proposed Project Expressed by Non-Aboriginal Interveners to the Joint Review Panel

Submissions to the Joint Review Panel were made by individual members of the public, Environmental Non-Governmental Organizations (ENGOs), community associations, and others; most are based in Canada, and a few are based in the United States. Individuals and representatives of groups also made oral interventions during public hearings before the Panel. Submissions made on behalf of Aboriginal Peoples, as well as oral interventions made at public hearings by representatives of Aboriginal Peoples, are considered separately in Section IV.

The record of submissions and hearings transcripts were searched for statements and expressions of views relevant to the perceptions of risk associated with the management of low- and intermediate level (LILW) nuclear waste in Ontario in general terms. These documents were also searched for statements and expressions of views relevant to perceptions about various methods of storage and disposal of such wastes and, in particular, to the proposal to construct a Deep Geologic Repository (DGR) near the Western Waste Management Facility (WWMF) on the Bruce nuclear site.[2]

In this Section we present what we believe is, in an informal sense, a representative sample of these views. However, since we did not conduct a rigorous analytical examination of the documentation available to us, the generalizations that are made in the following paragraphs should be regarded as being examples rather than systematic patterns; thus individual exceptions could be found which are not encompassed in these generalizations. This snapshot, therefore, should not be taken as a complete account of the views expressed.

In general, the views expressed to the Panel in submissions and oral interventions reflected a wide spectrum of public opinion on the substantive matters under discussion. So far as the main issue – the need to provide for safe storage of nuclear low- and intermediate-level waste – was concerned, views ranged from strong support for the specific DGR proposal now under consideration, on the one hand, to a refusal to entertain storing the waste "anywhere on the planet," on the other. So far as the subsidiary issue – what specific management option for storage and disposal of this waste is the preferred one – was concerned, views ranged across a wide variety of potentially feasible options: "as-is" at the existing WWMF; a concept of "hardened" surface storage; the proposed DGR at Bruce; and placement in a suitable facility "somewhere else" in Ontario.

It must be emphasized that our primary interest in examining these materials was not to discern the spectrum of proposal solutions for the management of nuclear LILW in Canada, as expressed by interveners to the Joint Review Panel. Rather, we have sought to understand the public perception of risks in Canada that is associated with the accumulation and management of nuclear waste, and of the four options discussed in our earlier report, in accordance with the directive in the JRP Letter. The background study we commissioned on this subject (Section II and Appendix A) was designed to provide us with some analytical tools in this regard, which we could utilize in examining the submissions and interventions by members of the public.

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[2] Search software using a variety of words and phrases was used to examine all of the text in the various submissions and hearings transcripts. See further the "Note on Keyword Searches" at the end of this Section.

Many of the published academic studies on public perception of risk are based on exercises using hypothetical settings or questions in order to elicit the underlying structures in people's reasoning about risk situations, structures that otherwise remain tacit and unarticulated. (Sometimes these are called "mental models.") The results, as presented in the Background Study, reveal quite stable patterns of thinking about risk across populations and countries, on the basis of which robust inferences can be made about how any random cross-section of the public might be expected to react to a new situation, presented to their communities, involving a carefully-planned technology that is intended to deal with a complex problem in risk management.

This is exactly the situation in Bruce County, where a network of small communities near the shores of Lake Huron in Ontario has been presented, for the first time in Canada, with a proposal to place hazardous radioactive materials in an engineered facility deep underground in close proximity to their homes and businesses. Few phenomena in nature are as complex as is the electromagnetic spectrum, along which are found both enormous benefits (the combination of visible light and invisible radiation from the sun, and the electromagnetic fields that make wireless technologies possible, including cellphones), as well as potentially lethal threats (damaging health effects from high-energy gamma radiation). Furthermore, the long periods of radioactive decay require carefully-planned technologies to contain those dangerous radioactive products, involving (in the DGR proposal) the combined capacities of both engineered and natural barriers.

Those responsible for designing the facility needed to respond to a particular challenge – in the present case, storing nuclear LILW – are required to use the language of formal risk assessment to make the case that they can do so safely. This language involves concepts such as hazard characterization, exposure pathways, probabilities and consequences or impacts (expressed quantitatively), risk estimations, uncertainty ranges for risk estimations, and risk mitigation options. This is the kind of language used in the technical "discourse on risk" for formal risk assessments.[3]

This is not at all the language used in most of the public discourse on the risks of storing nuclear LILW. The contrast here may be seen if we summarize the general themes found in the submissions and hearings, which are illustrated in the following paragraphs. What is important to note is what is *not* articulated, as well as what is clearly expressed. These general themes are as follows:

A. Risks associated with handling and storing radioactive wastes are considered entirely separately from any benefits derived from nuclear power: In other words, for those opposed to the DGR proposal (for whatever reason), risks and benefits are almost never mentioned together. However, among those who support the creation of a DGR at the Bruce nuclear site, some express the belief that accepting the benefits from nuclear power generation entails a responsibility to manage its wastes.

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[3] The benefits associated with successfully storing radioactive waste safely are assumed in this scenario. These include the direct social and economic benefits for the host community, as well as the indirect benefits, for all Ontarians, derived from continuing to use nuclear energy to generate electricity. In this case the risks of handling radioactive materials are thought to be "outweighed" or exceeded by the associated benefits by a very substantial margin.

B. Risks associated with handling and storing radioactive wastes are considered only as a discrete problem, and are not framed on a comparative basis with the risks of alternatives to nuclear power for electricity generation (for example, coal-fired generation stations).

C. Opponents to the DGR proposal do not, for the most part, place their opposition in the context of a more general set of social values, but rather treat this issue in isolation (in contrast with the Aboriginal perspective, as described in Section IV).

D. When comparing different options for managing nuclear wastes, interveners usually do not express the comparison in terms of their perception of relative risks, preferring instead to make certain general observations (for example, criticizing the DGR as exemplifying the maxim, “out of sight, out of mind”).

E. Probability or likelihood of harm is never quantified.

F. Consequences of adverse effects are never quantified.

G. Uncertainty is never quantified, and is usually treated as equivalent to “unknown.”

As a generalization, and acknowledging explicitly that there are many individual exceptions to it, one is obliged to conclude that the two discourses about risk – the technical and the public – have very little in common. Although they are both referring to the same managerial issues and technologies pertinent to nuclear waste, they have fundamental differences in the way that conclusions about those issues are arrived at and the kinds of reasoning used to support those conclusions.[4] These differences are well-illustrated in the following extracts from the materials in submissions and hearings, which are referenced with the document number citations in the Canadian Environmental Assessment Agency (CEAA) Register for the DGR project. *No quotation marks are used, but the following extracts are all direct citations from the record.*

Risk Perception:

- …[M]embers of our community, after five generations in the Hamlet of Inverhuron, will be forced to leave due to the impact of noise, pollution, a feeling of insecurity due to possible accident or malfunction of the deep repository and the lowering of property values due to stigma. (Marti McFazdean: CEAA Doc#846)

- The risk perception of those who would buy agricultural goods, visit, or purchase a cottage in the area may be shaped by the notion that Kincardine is a nuclear oasis. The research that OPG has done around stigma, because it is limited to the local study area and immediate municipalities, is unable to capture these complexities. (Huron-Grey-Bruce Citizens Committee on Nuclear Waste: CEAA Doc#1363)

- …[T]he DGR does represent a hazard with perceptions of high risk consequences*. All the cards and letters sent to CEARIS from ordinary Canadians and Americans, from Michigan to California, from*

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[4] We wish to emphasize strongly the point that, in making this list, we are in no way suggesting or implying that the modes of reasoning used in the public discourse are incorrect or inappropriate, or are less compelling than those found in the technical discourse.

service organisations like the Provincial Council of Women of Ontario, speak of the dangers of storing these wastes so close to the lake. ... (Eugene Bourgeois: CEAA Doc#944)

Risk Acceptability:

- The radioactive threat to the Great Lakes -- 20% of the world's surface fresh water, and drinking water supply for 40 million people -- is unacceptable on its face and must be cancelled immediately. You cannot risk such an environmental and health disaster. (Kathy Babiak: CEAA Doc#524)
- I am therefore skeptical of the phrase "acceptable risk" when the likelihood of an incident is low, but the consequences if it does occur are shattering. (Voice of Women for Peace: CEAA Doc#1380)
- Lake Huron is not only one of our treasured Great Lakes, but it provides fresh water, recreational opportunities, habitat for a large diversity of eco systems and species, and living space for millions of people on both sides of the US/Canadian border, which are all at risk should containment of the proposed repository fail, due to human error, systems failure, geologic conditions, or other catastrophic events. These unacceptable risks will not be confined to the life of the waste site, but will last for many thousands of years,… (National Council of Women of Canada: CEAA Doc#75)

Adverse Consequences:

- [T]he effects of the event are unbounded: *especially with a time frame extending into the hundreds of thousands of years*. (Eugene Bourgeois: CEAA Doc#944)
- The site fault. Did OPG also mention the fault in the area that the DGR would be built on? A small earthquake could very well widen this fault and thereby weaken or breech the integrity of the DGR. Result? Game over for 40 million people who rely on the fresh water from the Great Lakes. And possibly for the children who will be at risk for nuclear-waste induced illnesses, deformities and cancers. (Joanne Martin: CEAA Doc#1104)
- I am here today because I feel that the proposal of a Deep Geological Repository no further than 1.2 kilometres away from Lake Huron, the second-largest of the Great Lakes, is a mistake. I feel that this is an unsafe and unreliable venture in which the potential for accidents is being grossly downplayed. (Caitlin McAllister: CEAA Doc#1653)

Probabilities:

- Since radioactive waste has to be kept completely contained for such a long time that it might as well be forever, not only does Murphy's Law become inescapable, but many of the scientific tools we habitually use become useless. Probabilities no longer apply, because everything that has more than an infinitesimal probability is going to happen sooner or later. Mathematical models of the containment system no longer apply, because they can't possibly take into account everything that might happen over such a long time period accurately enough to make reliable predictions. Worst of all we cannot do scientific experiments to test and improve these models, or any proposed containment system, because such experiments would require millions of years to produce valid results. (R. Gordon Albright: CEAA Doc#1403)

- No increase in radioactivity exposure during the construction and long term operation of the proposed DGR is acceptable. OPG states in their documents that the DGR "is not likely to result in any significant residual adverse effects to human health or the environment, including Lake Huron and the Great Lakes." "Not likely" is not a reassuring answer and presents too much uncertainty.

How will a DGR for nuclear waste beside our drinking water result in a healthy outcome for ourselves and future generations? Where is the Precautionary Approach? (Jim and Brenda Preston: CEAA Doc#1373)

Uncertainties:

- Because of the long-term and possibly unrecoverable consequences of an accident or leak resulting from faulty or unforeseen research, no ambiguities or uncertainties should be acceptable concerning the burial of nuclear waste. Anything less than that is risk-taking. (Peter Storck: CEAA Doc#1051)

- In summary OPG's proposed DGR increases the likelihood – albeit a very tiny likelihood – that Lake Huron waters could be contaminated by radionuclides at some point over the next 60 to 1,000,000 years. OPG has advanced extensive explanations in its proposals and responses to information requests to argue that the likelihood is very small. Nevertheless, uncertainties remain that cannot be eliminated or even reduced at present. (Peter Venton: CEAA Doc#1374)

- The areas of uncertainty are around the characterization of the geology, the effectiveness of the containers (none proposed, in this case), the estimates of corrosion and gas buildup, the reliability of the computer models, etc. These are all areas of uncertainty in this case, as in others…. The preferred alternative is that which reduces these uncertainties, and retains the option of pursuing a sounder and more secure option in the future. That means continued storage at site, in engineered containers which can be monitored, performance can be measured, and the containers can be replaced or re-encapsulated if needed – as needed – at some point in the future. (Dorothy Goldin Rosenberg: CEAA Doc#1395)

- Therefore, I am deeply concerned for the danger caused by burying this low and mid-level radioactive waste because over such a long-design life, we don't know what will happen. The DGR risks the contamination of Lake Huron and all of Canada's heartland. Water from Lake Huron feeds into Lake Erie and Lake Ontario, so tens of millions of human beings downstream will also be affected. (Peter Ormond: CEAA Doc#675)

- As such, key questions include, how such material would be able to re-enter the human environment? What conduits are available, in terms of permeable rock formations, fault zones, fracture zones (which may have no fault movement along them), and deep groundwater circulation? There is further uncertainty as to how the nuclear waste will interact with the barriers (ie corrosion of the barriers, the releasing of gases), seismic or glacial activity, and how radioactive material will react in a closed environment. Again, we must ask - where is proof of safety? (Dorothy Goldin Rosenberg: CEAA Doc#1395)

Preferred Location "far away":

- Is it necessary to take ANY risk, when a DGR can simply be located somewhere else far away from the Bruce Nuclear Power Plant, and far away from Lake Huron or any of the Great Lakes, where these risks are not present? (Beverly Fernandez: CEAA Doc#713)

- The storage dump should be located in granite, in an area which is not subject to earthquakes, and away from our fresh water, and away from densely populated areas. (Harry Giles: CEAA Doc#985)

- Alternately, choose a site in Canada that is far above the local water table in crack free granite and hence is inherently dry. (Joanne Martin: CEAA Doc#1378)

- So the best possible scenario would be OPG abandoning the present site for a less risky site in the Canadian Shield, in order to guarantee that we keep the Great Lakes and all the interconnected waterways free of the possibility of nuclear waste contamination. This will be of ultimate benefit to the vast majority of Canadians and our American neighbours, whom also have a very great stake in the continuing good health of the Great Lakes. (Joanne Martin: CEAA Doc#1104)

- International experts agree that radioactive waste is best stored far from people, animals and water sources. Ignoring this broadly held and logical conclusion, the plan to construct the DGR in our region, the home of many picturesque small towns, an area reliant on agriculture and a vacation destination for tourists, defies responsible planning principles. (Save our Saugeen Shores: CEAA Doc#1370)

"Out of sight, out of mind":

- Spend money thoughtfully and usefully, and in the next 40 to 100 years figure out a useful way to use this waste. Figure out one solution for all nuclear waste -- low, intermediate, and high level. Never in life can you bury your problems and think that they will not resurface. Nuclear waste is no different. Out of sight is not out of mind. (Paul Kluster: CEAA Doc#639)

- And therefore, we would recommend that in the absence of permanent safe solutions, society can best meet its obligations to protect the biosphere from existing nuclear waste through longer term management based on surface or near surface monitored and retrievable storage. In other words, in sight and in mind with visible institutional controls and monitoring, that in fact, the average public could take an interest and have some ownership in as well to ensure that we have adequate funding, adequate care. (Algonquin Eco Watch: CEAA Doc#1631)
- In summary, the risk of burying low- and intermediate-level nuclear waste "out of sight" and potentially "out of mind" of future generations is simply an unacceptable risk to take. It is prudent to assume, based on other precedents, that breaches of containment will occur…. Continuous surface or near-surface containment with institutional monitoring and retrieval capability is the precautionary route to take. (United Church of Canada: CEAA Doc#1273)

Preferred Option "As Is":

- If it is safely stored now, as you say it is, continue to do it that way. Why rock the boat into the unknown with the concurrent risks of leaks and disaster. Fortify even further the storage currently and in the future above ground at-site. Hopefully, it can be recycled some way, without trying to bury it to eternity with all the unforeseen risks below the surface of the ground, with accompanying negligence in building materials and workmanship of the DGR over time, and old age of the structure deteriorating with time as all structures (natural and man-made) ultimately do, in addition to all the inherent transportation risks. (John Mann: CEAA Doc#1389)

- Status quo storage of low and intermediate nuclear waste – above ground and retrievable – has many advantages. There would be little need for construction as it has been in use since 1977 and has an estimated lifespan of around 100 years. This system of management allows indefinite access, giving the researchers fifty more years to conduct further research and to develop the means to further enhance the above-ground storage systems. (Canadian Voice of Women for Peace: CEAA Doc#1377)

- So there's a few factors. If you're going to do surface or accessible, retrievable waste storage, you have to keep a population aware that this is happening. And as Dr. Harvey said, you have to have monitoring, you have to know it, you have to be able to repair it and so on. That is easier -- "easier" -- than something that is deep underground that you then have difficulties retrieving without causing more damage. (Anna Tilman: CEAA Doc#1593)
- This process is flawed and on OPG's own evidence, the status quo is the preferred option before you today. It will remain the preferred option until science can prove the same certainty as safety as the status quo has proven over the past 40 years. (Siskinds LLP: CEAA Doc#1685)

"Abandonment":

- The concern is institutional control and the lack of possibly institutional control in abandoning a site of this nature. How are you going to alert future generations? How are you going to avoid any intrusion if the site is not being monitored, abandoned forever, which is one of the major problems with this DGR proposal is abandonment. You cannot abandon something of this nature and ensure that if there is a problem where is the control? What if there is impairment in institutional control? What if there's no funding anymore to provide this? What if there is no memory of what this was, retained? How is this going to be looked after considering the long-lived radionuclides? So that is one of the major problems with the concept of the DGR and in this particular case, that abandonment phase. (Anna Tilman: CEAA Doc#1593)

- Nuclear waste must never be abandoned. It must be kept in engineered facilities where it will always be monitored -- forever be monitored and retrievable should containment fail. There must be zero tolerance for the escape of radiation from the storage facility. We have no right to impoverish or imperil the lives of our children and grandchildren and all future generations with any increase in exposure to ionizing radiation. (Teresa McClenaghan, CELA: CEAA Doc#1606)

Deep Geologic Repository:

- Imagine when an earthquake starts breaking your underground cavern apart. Who will go down there to retrieve the nuclear waste and bring it to the surface as the walls break apart, water flows in and the sealed containments crack apart? Will you? I doubt anyone will be able to stop such a calamity. The waste will go into the Great Lakes. It will flow out into the ocean. It will kill the life in the lakes, the people near the lakes, and it will stop people from enjoying the lakes, making a living from the lakes, and transportation on the lakes. (Kathy Barnes: CEAA Doc#1152)
- It only makes sense that placing medium level waste in sealed containers, far underground in structurally sound rock and monitoring them makes more sense than having it near the surface where acts of terrorism or acts of nature i.e. tornadoes, floods etc, could cause the release of the waste to more readily affect the public safety. (Barry Clemens: CEAA Doc#1361)
- In one-on-one conversations, several persons mentioned the need to support a DGR, especially after the events of the Goderich F2 tornado and, therefore, we agree with the assertion of OPG that a

DGR is more secure than the current aboveground storage for the existing waste and the waste to be generated in the future. (Neil Menage: CEAA Doc#1618)

- Nothing is immutable, not even rocks. Containers of this waste will inevitably corrode. Cracks and fissures will develop in the rock formations and widen over time. Water and gas contaminated with radionuclides will flow through the cracks and penetrate the barriers in the repository. Chemical and microbial processes and interactions will occur that could further erode the barriers. Climate change, glaciation, and earthquakes could severely destabilize the repository. And then, there is the possibility of accidental and even intentional intrusion into the repository. (Anna Tilman: CEAA Doc#1387)

- Okay, so why a Deep Geologic Repository? Well three options were studied, enhanced processing and storage, safe -- surface concrete vaults and rock vaults. And we looked at both deep and shallow. And the study trips revealed a deep rock option -- vault option was likely the most appropriate for Kincardine. We -- there was a group -- Golder was used to study the various options and they concluded that the deep rock option had the highest safety margin, also that the Kincardine geology was likely ideal for the deep rock repository. As for us, we were going to support the safest option that was available. We felt it was the only way that we could responsibly go. (Mayor Larry Kraemer: CEAA Doc#1567)

These excerpts illustrate many of the general points about risk perception that are referenced in the Background Study (Appendix A):

1. Public risk perceptions especially where risks are thought to be high, tend to be strongly influenced by the factors listed under the categories of “dread” and “unknown” risks (Appendix A, page 4, Table 1).

2. The public participants also expressed views that are consistent with risk perception respecting a complex technology and a complex hazard (Appendix A, page 6): “Risks from technology are often seen as imposed, often by large-scale industrial activities – primarily complex technologies or processes” (page 6). When faced with such complexity, some public participants express the view that it is inappropriate to situate such a facility in small communities with a rural character.

3. Many studies show that “people’s perception of the risk level of an activity is related to their trust in the authorities who manage it” (Appendix A, page 7), and this influences the judgements of some people about the risks inherent in projects that have a heavy involvement by private industry and government or public-sector organizations.

4. Risk judgements are influenced by “broader social and political attitudes and values” which are relatively stable over time and thus are not likely to change with new information (Appendix A, page 10).

5. The process whereby attention becomes focussed over protracted time-frames on particular risks, through small group interactions and media coverage, can result in an amplification of perceived risks (Appendix A, page 12).

6. Where modern technologies are concerned, risks are uppermost in most people's minds, and quite often people are not strongly influenced by the benefits derived from those technologies. Opinion surveys in many difference countries show that "people view nuclear power and nuclear waste as extremely high in risk and low in benefit to society" (Slovic 2012, cited in Appendix A, page 20).

7. Members of the public, generally speaking, overwhelmingly focus on harmful consequences that may occur, without reference of the likelihood or probability of the occurrence of the underlying event which may give rise to specific consequences (Appendix A, page 29).

8. In the context of public risk perception, "risk acceptability" – that is, a clear statement about what kind and level of risk is thought to be acceptable – is rarely articulated, if ever; nor can a concept of acceptable risk (either absolutely or relatively, in terms of alternatives) be derived from the positions of interveners (see Appendix A, pages 30-31).

Note on Keyword Searches

A specialized software program, dtSearch Desktop version 7.72, was used to perform global searches throughout all items on the CEAA Registry posted up to the end of February 2014, up to and including CEAA Doc# 1831. Items posted on the CEAA Registry with specific comments on the Environmental Impact Statement Guidelines were not included in the searches.

For each of the four options identified in IR EIS-12-513, combinations of specific keywords were used to find any references to the risk perception and/or acceptability of risk associated with the primary uncertainties specified by the Panel (in the letter dated 6 March 2014), for the public and Aboriginal groups in submissions and interventions during the public hearing/meeting sessions. Boolean searches were used to find structured groups of keywords linked by connectors such as *and*, *or*, *w/30*[5]. As an example, one of keyword combinations used to find references to *risk perception* and *acceptability of risk* for the *proposed DGR* with respect to *accidents* was:

> *(DGR or deep geologic* reposit*[6]) <u>w/30</u> (uncert* or probab* or risk* or likelih* or conseq* or impact* or permiss* or communit* or accept*) <u>w/30</u> (accid* or incid* or event* or malfunc* or fire* or Chern* or Three Mile* or Fuku*).*

Results of all searches with respect to risk perception/acceptability were grouped into:

(Public or Aboriginal Input) x (4 Options) x (9 primary uncertainties identified in the 6 March JRP letter)

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[5] "*apple w/30 pear*" means that "*apple*" must occur within 30 words of "*pear*"

[6] "*reposit**" means "*repository*", "*repositories*", etc.

Section IV

Positions on the Proposed Project Expressed by Aboriginal Interveners to the Joint Review Panel

Representatives of several different Aboriginal groups made submissions to the Panel on the proposal to construct a Deep Geologic Repository (DGR) at the Bruce nuclear site. These include the Saugeen Ojibway Nation (SON), whose lands are on the shores of Lake Huron north of Kincardine); the Historic Saugeen Métis (HSM), whose territory is on the Lake Huron shoreline from Tobermory to south of Goderich); the Métis Nation of Ontario (MNO), representing Métis communities throughout Ontario; the Mnidoo Mnising First Nations (representing six First Nations in the Manitoulin Island area); and a 'global representative' for Traditional Indigenous Human Rights. While there is considerable overlap in the type of information provided by each group, they expressed a range of positions on the DGR proposal and on the decision-making process.

The transcripts and submissions to the Joint Review Panel cited here are on the public record of the review, and were collected by the Canadian Environmental Assessment Agency (CEAA), the agency responsible for managing the review. They are referenced by the document number assigned by the CEAA, and since these are often quite long documents, page numbers have been added.

Identity and Assertion of Rights.

Most of the Aboriginal submissions began with a statement of the history of their First Nation or community and an assertion of its legal right to its territory and to the pursuit of traditional hunting and harvesting activities in that territory. The SON describes itself as "an unceded First Nation" (CEAA Doc#894: page 3) that claims certain rights to their traditional territory, while the HSM asserted its rights over the lands and waters of the proposed DGR site. The MNO, HSM and the SON described the historic relationship of their Nations and communities with the Government of Canada, including the general right of Aboriginal communities to harvest foods in their traditional territories as set out in the Constitution Act (CEAA Doc#1675: 101), and more specific treaties and other agreements; there were several mentions of the Crown's 'duty to consult' (CEAA Doc#1270: 3-4). The SON described the recent legal decision that permitted their communities to rebuild their commercial fishery, which had been neglected during earlier legal disputes (CEAA Doc#1461: 2-5, 7-44).

Expectations for Process.

Related to the assertion of rights over traditional territories and claims of responsibilities of the federal government, most Aboriginal interveners stated that the proponent and project reviewers have an obligation to consult with them extensively on this proposal. Many submissions referred to a 'history of exclusion,' previous failures of government to consult with them on the installation of industry on their land, including the initial construction of the Bruce nuclear power stations, and more recently the location of wind farms, which took place without their consent (CEAA Doc# 894: 6). They also recounted the process that was followed by OPG and the Canadian Nuclear Safety Commission, which had been marked in many instances by problems, including lateness, in establishing proper notification and consultation procedures and providing capacity (CEAA Doc#894: 2-3; 1675: 106). However, some positive relationships have been developed, including a strong working relationship between the HSM and OPG and the CNSC, with good efforts by OPG to notify them of the proposal to build a nuclear waste repository, helping them understand the facility and including them in planning discussions and the review process (CEAA Doc#1675: 85, 106). Many individuals from HSM communities have been employed by the generating station and they appreciate the respectful process that OPG follows with them. Submissions by the SON noted that OPG has made a commitment that it will not begin construction on the project without support from the SON communities (CEAA Doc#1427: 98-99). MNO is working with OPG to identify a long-term agreement (CEAA Doc#1675: 114).

Cultural Values.

Most of the submissions made by Aboriginal interveners included a statement of the cultural context that shapes the perspective of the First Nation or community to the land, and to its traditional territory specifically. The HSM stated that no individual owns the land: Rather, the people are the caretakers of the land; the land provides for them, and they in turn are responsible for protecting the land. It was often stressed that the most fundamental principle is the critical relationship of the people with their territory: A SON representative stated that “who we are as a people is inextricably linked to the lands and the waters” (CEAA Doc#1741: 147).

Several submissions mentioned the importance of spiritual beliefs in the decision. One intervener said that “when we allow anyone to poison Mother Earth what we are really saying is that it is OK to poison our Children and Grandchildren and all future generations” (David Eagle, CEAA Doc#1156: 1). MNO stated that “... while the fish or the animals or vegetation may not be directly affected, people's use of that specie or their attitudes of using those things can change. Whether it's perceived safety issues or increased activity or just the way people feel about experiencing their traditional activities on the land“ (CEAA Doc #1675: 134). The Mnidoo Mnising Elders Circle (CEAA Doc#1383: 2) stated that the care and protection of mother earth are part of Anishinaabe sacred teachings and are their ‘foremost priority.’

Another SON intervener (CEAA Doc#1704: 38) argued that it is “offensive” that scientists could assert that there are “no tangible reasons for Aboriginal people to change how they value plants and animals they harvest for traditional purposes.” This statement, it was said, overlooks the incompatibility of waste with the rock, which is the first order of Creation: “If our people come to believe that it is no longer right to consume the plants, fish or animals for food or spiritual reasons, this cannot be mitigated by demonstrating that there are no new radiological effects.” For example, if sweetgrass is perceived as being less ‘pure’ because of concerns that it may have been affected by radiation, it may not be viable for spiritual purposes (CEAA Doc#1704: 55). It was also noted that public hearings do not offer an appropriate context for addressing such matters (SON: CEAA Doc#1741: 153-154).

These statements illustrate Aboriginal values and the type of knowledge that is credible among Aboriginal people, which are distinct from mainstream culture and particularly from scientific knowledge. It was mentioned by several interveners that cultural teachings are passed down from generation to generation (CEAA Doc#1741: 147). The Mnidoo Mnising Elders Circle representative (CEAA Doc#1383: 3) stated that the elders "provide the appropriate teachings that reflect our cultural[ly] sensitive manner," and which is an essential link from the past to the future, completing the "circle of life."

Specific Concerns Related to the Proposed Repository.

Aboriginal interveners stated that the DGR project could damage the land that they live on, which would in turn damage their rights, interests and way of life. Several Aboriginal interveners stated that they are concerned that a repository could change the relationship of the people to their territory, threatening the ability of the land to sustain them and undermining the culture and identity of the people (e.g., CEAA Doc#894: 9). A major concern is for the waters and the fisheries, both the sustenance fishery and the recovering commercial fishery. The SON (CEAA Doc#1461: 5) stated that the disposal facility "within hundreds of meters of spawning grounds" posed "a significant new threat" to the fish they rely on for food and for the commercial operation. These activities could be damaged physically by the industrial activity or by contamination from the waste, as well as by stigma effects that reduce the market value of the fish and the commercial fishery and related tourism industry; it was stated that efforts to rebuild the commercial fishery likely could not 'withstand the blow of stigmatization' (CEAA Doc#1704: 39).

In addition, many outlined concerns about adverse impacts that the proposed repository could have on their lands and waters. The HSM emphasized the "potential for severe impacts on the community's constitutional rights for sustenance harvesting, in the immediate future, and for centuries into the future" (CEAA Doc#1270: 6). There were a number of comments on the need to study the potential impacts of transporting waste to the facility, as well as challenges to the determination that transportation issues were outside of the scope of the EIS. Concerns were also raised about the threat of extreme events, such as severe weather, that have not been factored into the existing facility design. Many comments referred to the events at the Fukushima reactor in Japan caused by the earthquake and tsunami, with concerns expressed that the possibility could not be ruled out that similar events could happen at the repository site over the long waste management timeframe (e.g., CEAA Doc#894: 9; 1462: 33; 1383: 2).

There were a number of criticisms of the Environmental Impact Statement (EIS), relating to the process by which elements to be assessed were determined and to the adequacy of the EIS itself. The MNO pointed out that they had been left out of the process to identify the Valued Ecosystem Components that should be studied as part of the EIS; these were "incorrectly chosen" and so the EIS does not reflect Métis values for the land. The MNO provided a complete traditional land use study, but noted that this has not been incorporated into the EIS; they argued that they should be able to sit down with the proponent and explain their land use study and the way the information in it can be used (CEAA Doc#1675: 152).

Other submissions detailed perceived deficiencies in the EIS, such as the failure to assess an alternative site and a number of other technical aspects of the proposed facility and its design. It was also noted by interveners that central characteristics of the project have been left to be defined in later licensing stages of the approval process, rather than being included in the formal environmental assessment. Further, the contentions were made that the EIS has an incomplete waste inventory, as well as an undefined geoscientific verification plan, insufficient alternative means assessment, and no analysis of different options for managing intermediate waste components. Concern was expressed by other interveners that decommissioning waste from Pickering could be included in the facility, which would appear to be a change in the scope of the project (CEAA Doc#1704: 22).

On the social assessment side, there are statements to the effect that the socio-economic impacts are not known, and that there is an inadequate analysis of the potential impacts of stigma, suggesting that OPG does not understand the possible effects that stigma could have on the social and economic life of the communities. It was argued that some surveys of tourists' opinions are not valid as the sample size was too small and was limited in geographic scope (CEAA Doc# 1427: 44), and that the polls conducted to determine community support of the project are not reliable, since they used a vague question and produced inconclusive results (CEAA Doc#1427: 96-97). Larger nuclear power issues were also mentioned, since low- and intermediate-level nuclear wastes are products of nuclear power generation; interveners wanted to know how the construction of a low- and intermediate- level waste repository fits in with plans to manage spent fuel from power reactors.

Trust and Uncertainty.

Varying levels of trust were expressed in the different organizations involved in the project. The HSM expressed appreciation for the positive relationship it has with OPG (CEAA Doc#1362: 5). But a fundamental lack of confidence in scientific assurances of safety was expressed by a number of interveners. The SON stated that OPG has failed to demonstrate the social or technical safety of the project: The consequences of the project "are not known and in many cases are not even considered" (CEAA Doc#1461: 4), and SON communities "do not have sufficient confidence in the completeness of scientific and technical estimates" of the project (CEAA Doc#1427: 85) The long time period over which the waste must be contained "denies any real certainty for the future reliability of containment" (CEAA Doc#1675: 102).

There was a basic lack of trust that the project will have no impacts on the water or the environment, the people's health or their means of making a living. A Chief asked (CEAA Doc#1704: 33): "Can we trust this project? Can we accept this project and can we agree to have this project as part of our future for all times?" As noted above, Aboriginal people need to know if the DGR will be technically safe, but they also need to know that it will be done in a way that is consistent with "spiritual and cultural teachings and does not cause harm to fundamental elements of who they are as a people" (CEAA Doc#1741: 154). The HSM stated that a conclusion that there are no potential impacts would indicate a failure to understand "the potential nature of the Aboriginal rights or which rights could be engaged" (CEAA Doc#1675: 79).

Ongoing Role of Aboriginal Peoples in the Repository Project.

Both the SON and the HSM acknowledged that the ultimate goal of the assessment process is to find a way to manage nuclear wastes and that they would have a role in that management. The SON observed that the waste management problem in their territory is “not of our own design but certainly we’ve got to be part of shaping the solutions for that waste problem” (CEAA Doc#1704: 88). The HSM expressed conditional support for the project, stating that they “recognize and accept that there is a nuclear waste issue that must be addressed” (CEAA Doc#1362: 7), and acknowledged that “we are all responsible collectively to develop a safe storage option for nuclear waste created here” (CEAA Doc#1675: 104). The HSM explained that they have received economic benefits of employment at the Bruce generating station and benefits from its activities, and looks forward to continuing involvement in working with OPG on the DGR. They noted that they have been living in the area alongside the nuclear power plant and don’t have the same sense of stigma that others might (CEAA Doc#1675: 150).

Despite these statements of support for the goal of managing nuclear wastes, both the SON and the HSM noted a number of conditions that would need to be met for their clear approval of the project.

The HSM expect to be involved in monitoring the DGR ‘as the project goes forward’: given the significance of the threat posed to their constitutionally protected Aboriginal rights, they require a high degree of consultation (CEAA Doc#1270: 5). A clear and formalized understanding of the way that HSM concerns will be considered and integrated into long-term decision-making processes will need to be developed. Agreements directly with Métis communities, or conditions stipulated in regulatory approvals, could be used to ensure that “the proponent continues to be held accountable to the affected Aboriginal community” through all phases of the project, including construction, operation, monitoring and decommissioning (CEAA Doc#1270: 7).

The SON stated that people will need the opportunity to decide their support for the project, which they believe will pose a ‘permanent’ risk to their land, water and people “regardless of how small we may now predict” the impact to be (CEAA Doc#1704: 36); under these circumstances there must be conditions for the acceptance of the project by the people. The people must “be asked for their agreement” and the project should proceed only “when the people most affected fully understand the project and when they are supportive of it moving ahead” (CEAA Doc#1704; 39-40). The SON stated that some concerns regarding the transportation of nuclear waste through its territory must be addressed or the assessment will be ‘fundamentally incomplete’ (CEAA Doc#1463: 56). “[R]egardless of what the Panel decides, our people know that the work is not complete, and SON leadership will work tirelessly to make sure that the work is completed and to the satisfaction of our people” (CEAA Doc#1704: 45). Projects in their territory that are acceptable would be those that do not subject their territory or people to undue risks or harms; that contribute to the long-term sustainability of the territory by improving the environmental, social, cultural and economic well-being of the people; and that ensure that the wastes are managed, monitored and regulated effectively with their appropriate participation (CEAA Doc#894: 10).

MNO have been engaging with OPG with discussions towards an agreement for the period of the construction phase with a desire and interest to reach a long-term agreement for the operations of the project. The specific details of that agreement are not yet completed. MNO's presentation at the JRP hearing provided information to OPG on the level of commitment required in order to proceed in good faith with OPG (CEAA Doc#1675: 90-91).

Summary and Conclusions:
Aboriginal Peoples' Perspectives on a Nuclear Waste Repository

The positions expressed by Aboriginal participants in the review process echo the cultural values and perspectives on risk that are expressed in published literature on Aboriginal attitudes to technological risks, as described in the Background Study. This enlarges an understanding of the importance of culture, social relations and political dynamics as shaping risk judgements within Aboriginal cultures.

In terms of perceptions of risk, the Aboriginal interveners all stressed the primary importance of their spiritual and material ties to their traditional territory, and their concern that adverse impacts of a DGR would undermine the traditional harvesting activities that strengthen those ties to the land and give the community its sense of identity and cohesion. While the Aboriginal interventions make it clear that they are able to address more technical aspects of risk and environmental assessment, it is also clear that their perspective places a stronger emphasis on the value of specific entities that are at risk, rather than on perceptions of the risk source and of the significance of its threat to human health more generally. This suggests that reassurances that any escape of radiation from the facility will be at low levels that have no implications for physical health may miss the point; the greater concern is for the undermining, by any means, of the spiritual and social value of the land and the traditional activities that are intertwined with it.

The respect for spiritual connections with traditional territory and for traditional teachings links to a traditional way of perceiving and knowing about the environment that is very different from modern Western scientific knowledge. The Background Study describes the 'gap' between experts and non-experts, which has been used to explain the different judgements that are reached through scientific reasoning and broader contextual reasoning used by most individuals on social situations that involve risk. The traditional aboriginal perspective is, like most non-experts', largely based in cultural and social assumptions rather than scientific principles and methods; however, it is more strongly connected to a coherent alternative body of knowledge, principles of reasoning, and respect for the traditional teachings of elders. Aboriginal people may explain an attitude to a 'risk' in terms of a cultural value that is unrelated to the conventional scientific explanation. There may therefore be a greater need for scientists and other risk managers to understand traditional Aboriginal values and knowledge in an effort to communicate effectively and with mutual respect.

The social traditions of many Aboriginal communities place an emphasis on the necessity to establish relationships based on respect and recognition of rights and responsibilities. Process considerations are very important for all societies studied by risk perception and technology acceptability researchers, but the expectation for a respectful approach to an Aboriginal community and the development of trusting relationships may be more particular within those cultures. Especially where a First Nation or community has experienced marginalization and threats to the continuation of its traditional activities, respect and support for those communities' efforts to protect their relationships of stewardship with their territories will be critical to the development of trusting relationships.

Section V

Observations and Conclusions

Observations:

As the Background Study shows, earlier perspectives that appeared to find strong underlying differences between expert and "lay" perceptions of risk have been modified, suggesting that those differences were exaggerated. However, this does not affect the reality that, in countries such as Canada today, two very different *discourses* about risk will be heard during formal decision-making processes, such as environmental review public hearings carried out under the terms of legislation and regulation.

One discourse will be a technical, expert-based discussion of risk. Project proponents in these circumstances have an obligation to make a "safety case" using the technical terminology of risk assessment, and regulators expect that they will use a highly technical discourse competently. (One good example is the requirement to demonstrate that existing radiation dose limits, for both workers and the public, will not be exceeded.) Interveners at public hearings who are individual citizens or members of public-interest groups are not obliged to use a technical discourse about risk, although some may do so, and some have done so in the present case. The public discourse on risk focusses largely on the hazardous consequences, without consideration of likelihood, associated more broadly with nuclear undertakings. Thus in any environmental review process using public hearings, two quite different discourses will be heard and, for the most part, will have little in common.

Our earlier Report on comparing four options for managing low- and intermediate level nuclear waste, using the techniques of qualitative risk assessment, necessarily embodies a technical discourse. We were asked to use highly technical parameters such as advective gas and water flow, structural and mechanical impairments, waste container integrity, and radiological dose for workers. We made our expert judgements about these parameters on the basis that there are very extensive and reliable bodies of accumulated knowledge which could justify such judgements. We find no comparable parameters in the public discourses on risk that allow for focused comparison of options. However, with respect to other parameters relevant to risk in this case, such as, for example, the possibility of seismic events or future glaciation in the region, there is an element of commonality between the two discourses; but for the most part the public discourse lacks the degree of elaboration necessary to estimate, even qualitatively, the *magnitude* of the risks that are referred to.

The frequent reference in the public discourse to the proximity of the waste storage and disposal site to Lake Huron provides an excellent example of this point. When confronted with the possible Bruce DGR within visible proximity to the Lake, there is for many people almost an automatic assumption that the chain of events leading to the possibility of a breach of containment and thus uncontrolled emission of radionuclides is a very short chain indeed: After all, the physical distance to the water is on the order of one kilometer (700m deep, 1000m to the lake shore). In the technical discourse, on the other hand, the key determinants of the risk of human and environmental exposure to the stored radionuclides are not a function of proximity to the lake, but rather of the geological characteristics of the various types of rock surrounding the underground cavern at different levels: These characteristics give rise to the expert view that any movement (advective flow) of radionuclides dissolved in water and gas through the rock would occur at an extremely slow rate, passing through hundreds of meters of rock mass over a time-span that would render the radioactivity harmless. *Both perspectives* are reasonable when considered in their own terms – but they are incommensurable with respect to the quite different conceptual framework within which each perspective is operating.

Finally, note that we are trying to be precise on an important point: There are indeed "patterns" in the some of the intervener responses; for example, see the collection of statements in Section III, pages 11-13 above, under the following headings: Preferred Option "As-Is," "Abandonment," and Deep Geologic Repository. However, it is not obvious that these statements, taken as a whole, reflect different patterns in the perception of risk. As this collection of statements illustrates, the public discourse is heavily dependent on the concept of safety, rather than risk. The concept of "safety" is inherently oriented around consequences, and the essential difference between safety and risk has to do with probabilistic reasoning, which is downplayed in safety but is essential to risk.

Conclusions:

We can now apply the results of both our background study on risk perception, and our examination of materials from the submissions and public hearings, to the issues and perspectives posed by the letter from the Joint Review Panel dated 6 March 2014:

- "…[T]he Panel expects that there be a comparison of *risk perception* (and thus, *risk acceptability*) among the four options…. [T]he Panel suggests that the Expert Group focus on uncertainty. This is because the technical risk analysis of the four options will have a direct link with the analysis of the effects of the technical uncertainty on risk perception."

- "Many submissions [to the JRP] presented comparative risk perceptions and risk acceptability among status quo, enhanced surface storage and deep geologic repositories. These submissions, together with information in the published literature and the Expert Group's analysis and professional judgement should be used to produce a relative risk perception/acceptability score for the four options."

- "…[T]he Panel would encourage the Expert Group to comment on how risk perception among Aboriginal peoples might better be acknowledged and incorporated."

- "The Panel expects that the analysis then go forward with further consideration of the *perception* of each of the four options, as influenced by the relative degree of technical uncertainty associated with the primary uncertainty issues listed above."

- "The Panel maintains that use of a combination of evidence provided by submissions as well as published literature is sufficient to discriminate among the options if the Expert Group focusses, as is suggested above, on the effects of relative uncertainty on risk perception and risk acceptability."

Responses from the Independent Expert Group:

1. After examining the relevant published literature, and a substantial body of material from the submissions and hearings transcripts, we do not find that risk perceptions, risk acceptability, or perceptions of uncertainties are systematically and coherently structured according to the different management options that have been considered by interveners. In other words, across the range of public views as a whole, we find no discernible *pattern* within those views in which preferences among the four management options are directly or even indirectly related to the perception of risks associated with the storage and disposal of nuclear waste.

2. Since in the public discourse uncertainty is almost never provided in terms of magnitude (i.e., how much uncertainty, expressed qualitatively), there is no way to estimate relative uncertainty, and thus no possibility to discriminate among the options in this respect.

3. With regard to the concept of risk acceptability, we find in the record of the public discourse few statements about what constitutes acceptable risk in the storage of nuclear waste (as opposed to statements about what risks are unacceptable), and thus no basis to discriminate among the four options using this concept.

4. The Independent Expert Group finds that it cannot provide the Panel with a score reflecting public perception or acceptance of the risk of the four options.

5. Both the literature and the evidence provided at the hearing suggest that, in part, the public perception of the risk of the proposed facility is related to the degree of trust in the organizations that have responsibility for the safe management of the nuclear waste (i.e., the proponent, the regulatory authorities, etc.). As noted in the Background Study, public trust requires that the public have “evidence that facility proponents, designers and managers share their concerns about the hazards and their valuation of the environment that may be at risk and plan and manage the facility with those values in mind. Continued tolerance of a nuclear waste facility will require that management facilitate public scrutiny of the facility and its management through being open, with stakeholder participation, provision of relevant information, and reliable notification of any problems that occur.”

6. Aboriginal perceptions of the risks associated with the storage of nuclear waste have been articulated within a comprehensive worldview. In terms of perceptions of risk, the Aboriginal interveners all stressed the primary importance of their spiritual and material ties to their traditional territory. While the Aboriginal interventions make it clear that they are able to address more technical aspects of risk and environmental assessment, it is also clear that their perspective places a stronger emphasis on the value of specific entities that are at risk, rather than on perceptions of the risk source and of the significance of its threat to human health more generally.

7. Interveners on behalf of Aboriginal peoples indicated that conditional support for the project in these communities depends on their ability to participate in decisions and monitor the progress of the plans and the operation of the facility if it is built. Respect and support for those communities' efforts to protect their relationships of stewardship with their territories will be critical to the development of trusting relationships.

APPENDIX A

Risk Perception Background Study

RISK SCIENCES INTERNATIONAL

REPORT

Risk Perception of Nuclear Waste Disposal

A background study

Submitted by:

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Submitted to:

The Independent Expert Group

April 23 2014

Contents

Introduction

This report presents an overview of research on the perception of risk from nuclear waste, with the aim of also providing insight into the conditions that may lead to community support for hosting a nuclear waste disposal facility. It has been prepared in response to a request made to the Independent Expert Group by the Joint Review Panel (JRP) for the Deep Geologic Repository Project for Low and Intermediate Radioactive Waste for a review of research on risk perception and community acceptance of a nuclear waste repository. This background study is in support of the JRP's review of a proposal by Ontario Power Generation (OPG) for a repository at the Bruce Nuclear Generating Station in Ontario.

The report describes research on the psychological and social contextual factors that shape individuals' judgements on the significance of a risk, and its acceptability in light of other considerations about the risk source. As the proposed facility will affect several Aboriginal communities whose traditional territories are in the region of the Bruce Nuclear Generating Station, the report discusses research on risk perception among Aboriginals in Canada as influenced by their cultural frameworks. It reviews research on perception of risk from nuclear power, and nuclear waste in particular, as a specific instance of risk perception and context for judgements on risk. It draws some conclusions from these research fields on two key concerns related to perception of risk from nuclear waste disposal, uncertainty and acceptability.

Risk Perception: Summary of key findings and themes from literature

Risk

Risk is a complex concept that is defined in different ways, according to the way in which the concept is to be used. However there are several essential aspects incorporated in most uses of the concept, both casual and technical. The essential characteristic is uncertainty, referring to the chance or likelihood that an outcome of concern will occur. When used casually, risk has the sense of an unspecified chance of loss or harm from exposure to a danger; in the financial world the focus is on uncertainty, with the outcome being either positive or negative. Risks can be avoided, managed, actively taken, or carefully optimized.

When applied to the professional management of adverse risks, risk is a calculated quantity that incorporates several key factors:

- Hazard: a source of harm, inherent in a substance or activity
- Exposure: measured by type, duration and dose
- Consequence: a specific outcome that results from exposure to a hazard
- Probability: the likelihood that the specified consequence will occur, perhaps expressed as the likelihood with which it may occur (in time) or the incidence with which it occurs (in a population).

In many technical applications, risk is defined as probability times consequence, or simply PxC. It is the (generally) quantitative expression of the probability of occurrence, within a given timeframe, of a specified outcome of concern.

Risk Perception Research

Research on the perceptions of risk by non-experts is conducted within several academic disciplines, each with a particular interest in an aspect of perception, and a related scale of focus and research methodology. These factors are in turn aligned with particular perspectives on risk as a concept and as an individual understanding, social concern and political debate. Each approach assumes a particular concept of risk and model of its function within society; and though risk research is increasingly multidisciplinary and appears more as a spectrum than as separate and discrete types, there are many debates about the appropriate scale, context and methods of research. To some extent the different scales used by the disciplines involved may be seen as complementary, partial perspectives that can be 'nested' to produce a comprehensive picture. However they are also expressions of differences of opinion on the scale on which risk actually 'exists', the contextual factors that are relevant to an understanding of the concept, and the way it is apprehended by members of society.

In almost all risk perception research a primary distinction is made between 'expert' and 'non-expert', 'lay', or 'public' approaches to risk, though the analysis of the differences and the relationships between them varies. The disciplines are generally within the social sciences, and range from cognitive psychology, with an interest in the ways in which individuals use information to estimate probabilities; through social psychology, with an interest in personality and relational factors that contribute to individuals' judgements of the risks of hazards and social activities; to sociology, with an analytical and critical interest in the collective definition and negotiation of phenomena and relationships that are constructed as risks.

The understanding of risk perception in this paper that has been developed through dedicated research from the early 1970s is presented in three sections. The first outlines findings on individuals' cognitive judgements of risks and the factors that influence them; the second discusses research on judgements by individuals within a particular social and cultural context; and the third looks at the social impacts and broader implications of attitudes to risks and risk sources within the population.

Perception of risk

Cognitive processes and knowledge of risks

Research carried out on risk perception by cognitive psychologists was founded on a concern with the processes people use in making judgements under conditions of uncertainty. Risk was interpreted as a probabilistic phenomenon, with uncertainty the most relevant consideration; assessing the probability of an event is a formal means of reducing uncertainty, in order to provide a basis for decision-making and risk management. The most appropriate means of making judgements under such conditions is through the correct interpretation of the information and application of the rules of probability.

An early finding was that non-experts deal with uncertainty not by systematically considering statistics, but by applying a set of mental shortcuts called heuristics. Heuristics are rules of thumb that enable people to use known information to evaluate a situation that appears to be similar. These heuristics lead to systematic biases in estimating probabilities and values (Tversky and Kahneman, 1974). The most common of these heuristics are representativeness, availability, and anchoring. The representativeness heuristic is the evaluation of a probability according to the degree to which it is considered to resemble, or be representative of, another risk that is better understood. The availability heuristic is the ease with which a type of event is brought to mind. This may be due to media coverage, for example, or to familiarity due to a recent similar event or combination of events, which may be a useful guide to a risk judgement, but can also bias the evaluation of a risk. In anchoring, people base an initial judgement on a value, which they then apply to other situations (Taylor-Gooby, 2004).

An important outcome of research on non-experts' perceptions of risks to health and safety is the psychometric paradigm. Using questionnaires to elicit individuals' ratings of a wide range of hazards of different types, researchers found that non-experts' perceptions were generally higher than experts', and were related to qualitative characteristics associated by respondents with those hazards. Non-experts' risk judgements are more contextual, and are more concerned with the consequences of a risk than with the probabilities of their occurrence. Furthermore, the notion of 'risk' is broader, and the consequences of concern are not limited to death or injury, but extend to harm to something that is valued, or a value or principle in itself. A key finding (Slovic, 1992: 120) was that:

> When experts judged risk, their responses correlated highly with technical estimates of annual fatalities. Laypeople could assess annual fatalities if they were asked to (and they produced estimates somewhat like the technical estimates). However, their judgments of 'risk' were sensitive to other factors as well (eg, catastrophic potential, controllability, threat to future generations) and, as a result, differed considerably from their own (and experts') estimates of annual fatalities.

A major finding from this research was that hazards showed 'personality profiles' that are related to their perceived risk. These characteristics were correlated with each other 'across a wide range of hazards' (Slovic 1992: 121), and were found to cluster into two factors that were termed 'dread' risk and 'unknown risk'. Laypersons' perceptions of the risk of a hazard – but not those of 'experts' – have been found to be related to the position of the hazard within the factor space. The characteristics that make up the dread risk and unknown risk factors are shown below; hazards that are high on the 'dread risk' factor are perceived as particularly high risk.

Dread Risk	Unknown Risk
uncontrollable dread global catastrophic potential consequences fatal not equitable, high risk to future generations catastrophic not easily reduced risk increasing involuntary	not observable unknown to those exposed effects delayed new risk risk unknown to science

Table 1 Qualitative factors in risk perception. Adapted from Slovic, 1987.

Demographic factors have also been found to influence perception of risk, although findings on these factors vary. Many risks, particularly environmental and technological risks (Siegrist et al., 2005) are rated as higher by women and by minority ethnic groups (Finucane et al. 2000). There are also differences among age groups and levels of education, with those with higher levels of education typically perceiving lower levels of risk. Other factors, notably social marginalization and poverty, were found to be predictive of higher risk perceptions (Boholm, 1998).

Psychometric studies have been conducted in many countries, and have found more similarities than differences among nationalities in the 'cognitive map' described by the two-factor space (Siegrist et al., 2005); "On an aggregated level, the patterns produced by the psychometric paradigm are very stable." The psychometric paradigm does not describe individual variability as well, however; several factors have been put forward to explain individual variations in risk perceptions, including confidence and trust (Siegrist et al., 2005) and a range of personality factors such as levels of anxiety, desire for control, and experience with risks (Barnett and Breakwell, 2001; see Chauvin et al. 2008 for a list of references for studies on a wide range of variables).

Perceptions of different risk sources

Certain types of risk are consistently judged to be higher, or lower, than actual rates of harm from those sources. Figure 1, below, shows the risk rankings in a recent survey of Canadians' perceptions of a range of risks to health.

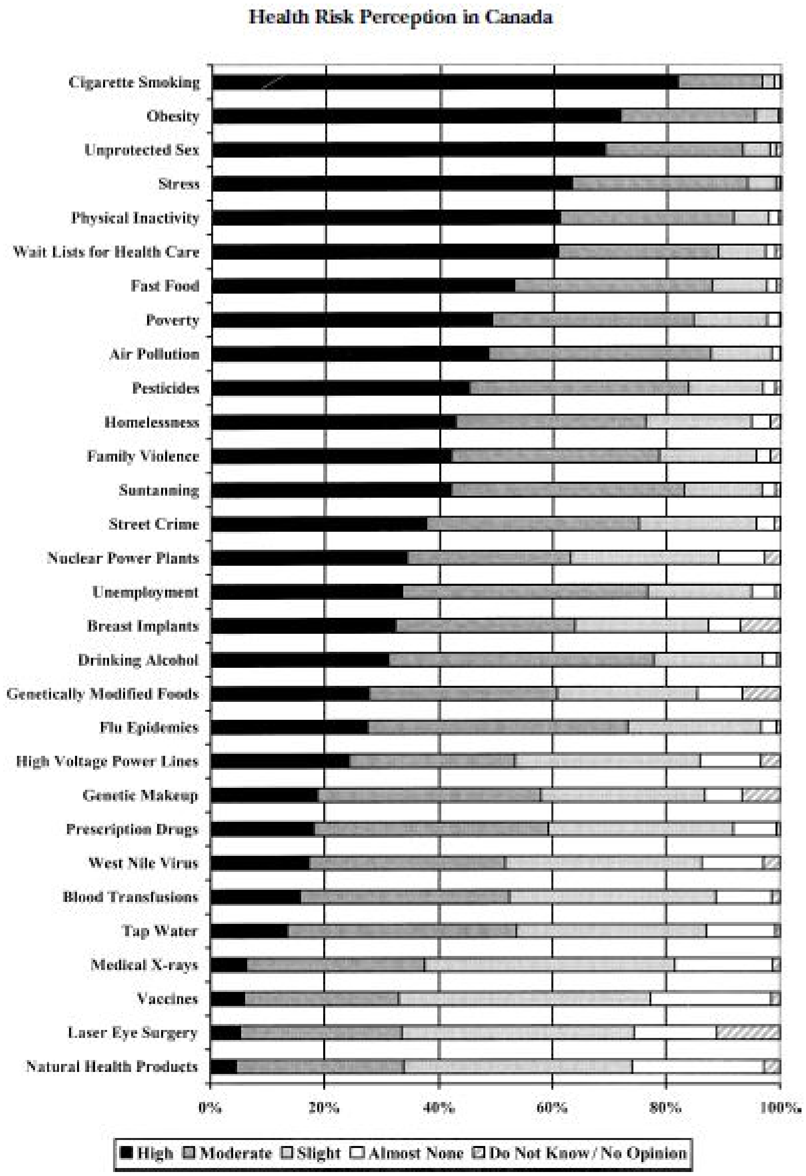

Figure 1 Perceived health risk of thirty hazards to the Canadian public. Krewski et al., 2006.

Some of the risk sources that are associated with raised or lower perceptions of risk have characteristics known to influence risk judgements, such as voluntariness or lack of control.

A major factor that has been observed is that people perceive risks from natural sources as being lower than risks from technological sources, such as industrial chemicals or processes. This bias may lead people generally to be unconcerned about the risks of some natural substances, such as natural radon (Golding et al., 1992; Slovic et al., 1995). Sjöberg (2000) has described an influential factor that he calls "unnatural risk" or "tampering with nature," which expresses the sense that an activity interferes with nature, and incorporates a moral judgement about the activity.

People consistently perceive risks from technology as being greater than those from nature and have elevated perceptions of the risks of chemicals and industrial technologies and processes. In many cases perceptions of a technology differ with the application: for example, medical applications of biotechnology are perceived as lower risk than uses in food crops (Gaskell et al., 1999).

People rate a risk they undertake themselves, or are exposed to voluntarily, as being lower than one that is imposed on them. People ‘discount’ their vulnerability to lifestyle risks, over which they feel a sense of personal control (Sjöberg, 2000), but do not do so with so-called “societal” risks, the risks that are imposed and cannot be avoided by any personal competence.

Framing – benefit-risk dynamic

Many of these qualitative perceptual factors that are inconsistent with actual rates of harm are explained through an understanding of the relationship of the individual with the risks and with the benefits of the risk source. Instead of perceiving and balancing separate judgements of the risk and the benefits of an activity or hazard, people integrate the two factors into a single coherent attitude to the risk.

Research within the psychometric paradigm found “an inverse correlation between perceived risk and perceived benefit across diverse hazards” (Alhakami and Slovic, 1994): perceived risk declines as perceived benefit increases. People construct comprehensive judgements or ‘framings’ of activities in to which ‘risk perception’ factors are integrated, to arrive at an overall ‘risk-dominated’ or ‘benefit-dominated’ perspective on an activity or other risk agent (Alhakami and Slovic, 1994). When people focus on the benefits of an activity they tend to downplay the risks. On the other hand, when people do not have personal experience with the benefits of an activity and perceive themselves to be susceptible to imposed risks, they are likely to frame that activity as a risk (Leiss, 1989; Leiss and Chociolko, 1994). Researchers related this framing dynamic to “intuitive and experiential thinking, guided by emotional and affective processes” (Alhakami and Slovic, 1994; Finucane et al., 2000); this was termed the ‘affect heuristic’ (discussed in more detail below), in which the dominant perspective is ‘liked’ and results in the downplaying of the other (Alhakami et al., 1994; Finucane et al, 2000).

Risk-benefit framing helps us understand some degree of the high perceptions of risk from many technologies. Risks from technology are often seen as imposed, often by large-scale industrial activities - primarily complex technologies or processes. These may produce diffuse benefits that may not be experienced directly by individuals, but carry risks to which individuals feel vulnerable, such as air pollution or chemical spills. People cannot control their exposure to these hazards and are dependent on remote social systems of control for protection from them. The downplaying of the benefits of these technologies is related to the ‘feeling of powerlessness’ in relation to them (Alhakami et al., 1994). In addition, many of these technologies are complex and not well understood by non-experts, adding an additional concern factor.

On the other hand, most people tolerate high risks from substances or activities that they benefit from, such as medications and driving, as they focus on the benefits that they experience from these activities and downplay the risks. Many people actively pursue risky activities, again focussing on the experience of benefits from the activity, and in many cases also valuing the personal control that they can exercise in the activity.

Trust

Many studies have found that people's perception of the risk level of an activity is related to their trust in the authorities who manage it (Siegrist et al. 2000). This suggests that the public's disapproval of major technologies is associated with a lack of faith in government and industry (Slovic, 1993): "Public fears and opposition to nuclear-waste disposal plans can be seen as a 'crisis in confidence', a profound breakdown of trust in the scientific, governmental and industrial managers of nuclear technologies." This has been explained in part by the greater visibility of 'trust-destroying' events and the fact that they carry more weight than positive events; and to the American style of democracy that gives individuals and groups the right to intervene in proceedings, challenge government agencies, and pursue policy changes through litigation (Slovic, 1993: 680). Trust has emerged recently as a dominant consideration in the public acceptance of or aversion to a technology.

General social surveys have shown declining levels of trust in government and industry, as well as for the set of social and political values they represent and advocate.

Uncertainty

Relatively little research has focussed on the public understanding of uncertainty (Frewer et al., 2003). Research focussed on eliciting the effect of uncertainty on the perception of a risk concluded that "uncertainty information had very little effect on perceptions of concern"; instead the qualitative factors described in the psychometric paradigm, such as natural or man-made, seemed to determine the risk perceived.

However, as noted above, research conducted within the psychometric paradigm has found that an unfamiliar risk, that is, one that is unobservable, or not understood, is associated with higher perceived risk. Similarly, people will often seek to reduce the uncertainty in an unfamiliar situation by likening it to one or another characteristic of a familiar one.

Risk perception research has often linked uncertainty with trust in risk managers, regulators and government. Based on a theoretical perspective that social or 'system' trust reduces complexity by delegating certain tasks to others (Bradbury et al., 1999), risk perception research has often observed that trust in managers of complex tasks or decisions helps reduce uncertainty to a more manageable level: "the less we know about an activity, the more we need to rely on others to make decisions and the more our judgements become a matter of trust" (Savadori et al., 2004; 1290).

The relationship of risk perception, uncertainty and trust is complex, and is discussed in more detail below.

Experts and non-experts

As noted, a fundamental focus of attention from the beginning of risk perception research has been the 'gap' between experts' and non-experts' risk judgements; experts' judgements (of the same risk ranking tasks as non-expert study participants) are closer to 'actual' rates of harm, and are consistently lower than those of non-experts. The inference from this observation was that experts were applying a systematic and rational analysis to the risk estimation task, whereas non-experts applied heuristic strategies, or considered qualitative or emotional associations with the hazard, leading to systematic errors. Only when experts make judgements outside of their field of expertise are they thought to rely on perceptual factors commonly employed by non-experts (Beyer et al., 2012). It should be noted that the basis on which these conclusions about the relative accuracy of the experts were based would now be considered weak: the experts included in these early studies were a group of 15 individuals described as professional risk assessors, including a geographer, and environmental policy analyst, and economist, a lawyer and a government hazardous materials regulator (Wright et al., 2002). The hazards that were to be ranked spanned a wide range of technologies and activities that applied to no single field of expertise.

More recent studies using experts qualified in the field of the study have generally concluded that expert risk assessors also use a set of heuristics in formal risk assessment; heuristics are not simply "error-prone rules of thumb" used by non-experts, but function as a "series of rules for bounding problems, collecting data and making sense out of it" (MacGillivray, 2014: 785).

Research on risk perception finds that the difference between experts' and non-experts' risk perceptions is a function of the level of risk – that is, across many different risks, experts' judgements are lower than non-experts.' Experts make systematic errors in estimates of risk frequencies that are similar to those made by non-experts, and also use similar decision-making strategies and qualitative associations, within the context of the same psychological factors, as non-experts. For example professional underwriters were "a little better in their risk judgements [of annual frequencies of deaths from a range of causes] than the lay persons . . . but the differences in performance between experts and lay persons were small in magnitude, and the nature of the biases . . . were common to both groups." (Wright et al., 2002).

A study that asked a group of professional medical assessors to evaluate a portfolio of prescription drugs (Beyer et al. 2012) found that, while all assessors applied relevant technical risk assessment considerations, their assessments varied according to their degrees of worry for safety, consideration of product benefit, and emphasis on ethical issues. There were also differences attributed to differences among assessors: senior assessors were more risk averse than more junior assessors, and female assessors appeared to be less risk averse as a consequence of greater sensitivity to benefit considerations (Beyer et al. 2012). However an earlier study found that young female professional toxicologists had higher perceptions of risks than their older, male colleagues (Mertz et al., 1998).

Experts' attitudes to technologies are similar to those observed in non-experts' (Sjöberg, 2003); experts' opinions were often biased towards their own fields, with some 'acting as promoters of a technology', considering that the risks within their field had been exaggerated but that others had been neglected (Sjöberg, 2003). Experts in the same field may differ in their risk judgements. Some of this is related to professional orientation and affiliation; for example, toxicologists working for industry see chemicals as less dangerous than do toxicologists working in government and universities (Kraus et al. 1992; Barke and Jenkins-Smith, 1993). Members of disciplinary groups differed among themselves on key issues of scientific assessment and decision-making such as the value of animal studies for predicting health effects in humans, and the existence of a safe level of exposure to a carcinogen (Rizak and Hrudey, 2005).

One researcher (Sjöberg, 2002: 455) states that "there is no ground . . . for stating that experts' risk perception has a radically different basis than that of non-experts. On the contrary, the psychological dynamics appear to be similar when it comes to structural properties of risk judgements."

Broader attitudes, political values, social relations

The findings of experimental psychology on individual cognitions and perceptions of risks continue to have relevance to understanding public judgements of certain types of activities; however the analysis of these factors needs to take a broader perspective in order to capture the dynamic that is operating with risk issues. In 1992 a leader in this research field (Slovic, 1992: 120) claimed that the psychometric paradigm had come to "encompass a theoretical framework that assumes that risk is subjectively defined by individuals who may be influenced by a wide array of psychological, social, institutional, and cultural factors." However, he noted that "although the psychometric paradigm has been oriented toward cognitive psychology and behavioral decision theory, I believe that societal response to hazards is multidetermined and thus needs to be studied in a multidisciplinary way" (ibid: 149).

Research that takes a broader analytical perspective on the findings produced by psychometric research on the cognitive strategies that non-experts use in judging risks gives more useful insight into the formation and function of risk judgements in society. The integration of cognitive strategies used by non-experts to judge risks into broader attitudes and values reveals the logic that relates the risk associations and cognitive strategies into a coherent and rational approach to individuals' decision-making in complex society. Risk perceptions are stable attitudes that are shaped by prior and more fundamental social values.

Instead of piecemeal judgements on risks, and on benefits, based on cognitive shortcuts to reduce the complexity of probabilities and technical assessments, non-experts form judgements on risks based on their prior knowledge of, and experience with, the risk sources, such that the risk judgements are consistent with their attitudes. This view of risk judgements suggests not only that perceptions of risk involve broader considerations such as benefits of the activity, but also that the overall judgement is shaped by underlying and more general attitudes (Poortinga and Pidgeon, 2005). Risk attitudes are 'embedded in a system of general attitudes and values' that guide the derivation of more specific attitudes in a way that preserves the evaluative tendency of the higher-order attitudes" (Grunert et al., 2003: 439).

It has been found numerous times that people's risk judgements are influenced by, and are consistent with, their broader social and political attitudes and values, and that these are stable and do not shift with new information. For example, people's beliefs about and values for nature influence the risks they will perceive in technology. Those who hold "ecological" values are more likely to consider technology to be a risk (Axelrod, et al., 1999). Research on the perceptions of health risk among Canadians has found a correlation between respondent's judgements of risks and their broader attitudes; perceived risk from environmental and social factors correlated with "belief statements reflecting environmental and social concern" (Krewski et al. 2008: 175). Broader social and ideological orientations are influential, as are specific attitudes to a hazard or technology (Sjöberg, 2000).

This principle applies to experts' risk judgements as well as non-experts'. Professional ecologists, and university scientists in several plant biology disciplines, opposed genetic engineering of crops, stressing the unpredictable environmental effects of the crops but having little opinion on the benefits that are claimed for the crops. Scientists who supported the use of GM crops, on the other hand, tended to be employed in the biotechnology industry and to be confident in industry research; they believed that GM crops are not fundamentally different from their conventional counterparts and that there are benefits to be gained from their use (Kvakkestad et al., 2007).

When psychometric research variables are expanded to include broader attitudes and values, many judgements about risks are seen to be driven by social attitudes and assumptions. The "white male effect" describes the finding that a cluster of well-educated white men in a survey sample rated risks as lower than other participants of both sexes and other races. The researchers suggest that "white males see less risk in the world because they create, manage, control, and benefit from so much of it" (Flynn et al. 1994). It has also been found that lower than average perceptions of environmental risk are held by white males with conservative political views (McCright and Dunlap, 2011).

Researchers have expanded on this observation to explain the prevalence of 'climate change denial' among white males holding traditional conservative values in the United States (McCright and Dunlap, 2011). They suggest that this position is held as part of an effort to protect an elite identity against "charges of societal danger . . . levelled at activities integral to social roles constructed by their cultural commitments" and to defend the predominant social and economic system."

The incorporation of stable attitudes and values into judgements about risk has been explored through the lens of the affect heuristic. 'Affect' is described as a general positive or negative feeling that is linked, through experience and learning, with an activity (Finucane et al., 2000; Poortinga and Pidgeon, 2005). The affect heuristic is the decision-making process by which "images, marked by positive or negative affective feelings, guide judgement and decision making" (Finucane et al., 2000). The affect heuristic suggests that general affective images of an activity are prior to, and direct, judgements of risk and benefit. This reverses the model that cognitions or beliefs build evaluations or general preferences, asserting that instead broader attitudes guide the formation of more specific beliefs. Psychologists now are considering that risk perceptions combine analysis and feelings in a 'risk-as-value' approach that "motivates individuals and groups to achieve a particular way of life" (Finucane and Holup, 2006: 144).

Summarizing the importance of understanding the role of affect and of values in risk perception, Finucane and Holup (2006: 145) observe: "research suggests that analytic and affective processes work in partnership to identify and prioritize experiences that are valued positively (and thus pursued) and experiences that are valued negatively (and thus avoided). Together, dual processes comprehensively govern the valuation of risk information in order to maintain a particular way of life."

A similar elaboration of the influence of trust on risk judgements gives insights into the political nature of trust relationships on risk management issues. Analysis of early findings that trust in risk managers is related to lower perceptions of risk suggested that increasing trust might reduce perceived risk (Slovic, 1991). Some researchers suggested that trust consists of characteristics, or 'dimensions of trust' including expertise, reliability, competence and care, and honesty and fairness, which are assumed to be universal, apparent to all observers, and thus generally considered 'trustworthy' (Cvetkovich and Nakayachi, 2007). This approach has led to risk communicators and risk managers to aim to increase trust in institutional sources of information and thus to reduce perceived risk, by conveying these qualities in risk communication and building trust through participation (Kasperson et al. 1999).

Other researchers argue that trust in risk information and managers and risk perceptions are reflections of more general attitudes towards a technology or risk management situation. Instead of a constellation of psychological attributes of a trusted risk manager, trust is characterized as a complex judgement of a risk context and the relationships among the stakeholders involved. The type of trust involved is 'social trust' (rather than personal trust), or a willingness to cooperate based on two "context-specific judgements" (Cvetkovich and Nakayachi, 2007). The first judgement assesses the saliency of values that apply to the problem at hand; the second assesses the "perceived agreement or similarity between self and the other person about what is important, that is, salient value similarity." This trust is context-specific; in situations of high concern people tend to trust risk managers with values similar to their own, and whom they perceive to be acting in their best interest.

In the light of this value-based understanding of risk, risk perception appears as a broad, contextual consideration of the important aspects of a technology or activity, such as the benefits of the activity and their distribution; risk and technology issues are seen as intrinsically political and social relational. Members of the public are "less concerned with making choices about which risks they are willing to tolerate than they are with grasping which political interests lie behind the promotion of particular choices" (Priest et al., 2013).

Social impacts and implications of risk judgements

Judgements about risks are complex determinations made by individuals in the context of their knowledge and understanding, their attitudes and values, and their social relationships. As such, risk judgements often become collective judgements and social phenomena, subject to many interactive processes of information dissemination and interpretation that themselves occur within broader social and institutional contexts. It is through some of these processes that a risk can become a 'risk issue'; that is, a matter related to a risk that is highly salient within the public, or within a particular group of stakeholders (Leiss, 2001). This may develop from factors inherent in the risk itself (such as a risk source of particular concern or the involvement of a vulnerable group), or it may relate to broader factors such as concerns about risk management practices, or wider debates about a technology.

The Social Amplification of Risk

Kasperson et al. (1988) noted that apparently minor risk or risk events, as assessed by technical experts, sometimes produce massive public reactions, accompanied by substantial social and economic impacts.

The social amplification of risk framework (Kasperson et al, 1988; Pidgeon et al., 2003) draws on communications theory to map out factors that contribute to people's interpretation of a risk and the movement through society of beliefs about risks and risk events. The basic principle is that "hazards interact with psychological, social, institutional and cultural processes in ways that may amplify or attenuate public responses to the risk or risk event" (Kasperson et al, 1988:178). Social amplification itself is "the phenomenon by which information processes, institutional structures, social-group behavior, and individual responses shape the social experience of risk, thereby contributing to risk consequences" (Kasperson et al, 1988: 181). Amplification occurs when these processes combine to heighten awareness and response to a risk, as is often seen with technological activities or chemical risk events; attenuation is seen with such well-documented health risks as indoor radon or aflatoxin (a carcinogen) in peanut butter, about which people are generally unconcerned. The steps of amplification include filtering of signals for attention; processing of risk information and attaching social values to it; interacting with cultural and peer groups to interpret and validate signals; formulating behavioural intentions to tolerate or take action against the risk or risk manager; and engaging in group behaviour to accept, ignore, tolerate, or change the risk.

Individuals may attend to certain sources of information on a risk that they trust, which may have the effect of reducing uncertainty for the individual and of polarizing opinion in society into separate and often conflicting camps (Eiser, 2004). In the case of amplification, one possible outcome of increased concern and salience about an issue is stigmatization.

Stigma

One characteristic that emerged was that of stigma, defined as "a mark placed upon a person, place, technology or product, associated with a particular attribute that identifies it as different and deviant, flawed, or undesirable (Kasperson et al. quoted in Peters et al. 2004). Stigma is intensely negative imagery that is strongly associated with something that is socially disapproved; it can generate fear and anger, and is associated with both affective and cognitive responses (Peters et al. 2004). Stigma can be associated with substances or products. Negative imagery is associated with chemicals; the word 'chemical' is interpreted as a synthetic substance, rather than as a fundamental component of nature, and associations with it are mostly negative, eliciting responses like 'dangerous, poison, or toxic'. Stigma is often associated with technologies, or with places or communities in which technologies perceived as dangerous or unacceptable are located (Gregory and Satterfield, 2002; Miller and Sinclair, 2012).

Stigmatization often occurs as a result of media coverage, and associated risk amplification (Slovic, 2000), in many cases following an accident or critical event that serves as a 'signal' that the technology involved holds "abnormal risk" (Gregory and Satterfield, 2002).

Aboriginal perception of risk

Aboriginals make risk judgements according to the same basic principles as any other social group or community; that is, they rely largely on qualitative factors about a risk, and interpret these through the lens of their knowledge of and relationship with the risk source and their social and cultural values. As has been observed in many risk perception studies in many countries, overall attitudes about an activity are driven by judgements of its value and benefits.

However, Aboriginals' perceptions of risk, and judgements of risk sources, often differ from mainstream risk judgements, because many Aboriginal cultural assumptions and values, as well as material conditions and interactions with the environment, are different from those of the mainstream Canadian society. In order to understand the perceptions of risk by Aboriginal individuals and communities, it is necessary to be familiar with the cultural context that shapes those perceptions.

It is important to note that there are many Aboriginal groups in Canada, including the Inuit, Métis and many First Nations, which include communities both on and off-reserve from British Columbia to the Maritimes, as well as the Territories and Nunavut. These societies, nations and communities have long histories grounded in the way the communities lived in their traditional lands within these very diverse geographical regions; there is therefore no single 'Aboriginal' perspective.

Despite the diversity of Aboriginal culture in Canada, many North American Aboriginal cultures share a set of general assumptions and values that differ from key characteristics of Western culture. There are a number of cultural and social factors that form the context within which risks and risk sources are perceived and judged.

Relation to the land

Land – nature as a spirit, the environment as providing foods and other material that communities use to survive, and territories that are traditional for individual communities – is central to Aboriginal activities, culture and identity. Nature, and the earth, is sacred; people and communities are part of Creation generally, and nations and communities are tied to specific traditional territories in which they carry out traditional hunting and other cultural practices.

Nature, physically and literally, embodies the sacred; the whole of creation, the land itself, is alive. 'Mother Earth' is meant literally as humans' mother; water is Earth's blood, rocks and minerals her bones, and plants her hair (Paper, 1990). Sharing a creator, humans are related to all other forms of life and can communicate with them; humans can take animal form, and animals can change into human form. Other species were regarded as 'people' with their own qualities and purpose within creation, and with whom humans relate as kin (Deloria, 1992). For Aboriginal cultures, humans are part of creation and are not superior to the rest of life, but were placed on earth "to be caretakers of all that is here' (Clarkson et al. 1992). This is closely tied to the traditional use of the land, which imparts a sense of the sacred into community relations with the land: "Every location within [a tribe's] original homeland has a multitude of stories that recount the migrations, revelations, and particular historical incidents that cumulatively produced the tribe" (Deloria, 1992: 122). While there is "great unanimity" among Aboriginal nations about the natural world and humans' behaviour in it, they are also distinct because they live in different local ecosystems; knowledge and values are not seen as universal (Henderson, 2000: 259 - 264).

Beyond the spiritual meaning of Nature, the land matters to Aboriginals in very material ways. Traditional uses of land maintain culture and strengthen communities, as many Aboriginal communities still hunt, fish, and harvest local plants which have been used by the people for many years. Carrying out traditional practices on ancestral lands and sacred places is fundamental to their identity and their survival as a people. Traditional foods "are those culturally accepted foods available from local natural resources that constitute the food systems of Aboriginal peoples. The concept of food system includes sociocultural meanings, acquisition and processing techniques, use, composition and nutritional consequences for the people using the food. Of importance to understanding the role that culture plays in determining food choice in Aboriginal communities is that the activities required to procure traditional food are not merely a way of obtaining food but, rather, a mode of production that sustains social relationships and distinctive cultural characteristicsThese practices are vital for the maintenance of traditions and cultural cohesion" (Willows, 2005).

As Simpson (2003) notes,

> From a social perspective, being out on the land strengthens our relationship to our extended families and deepens our spiritual understanding of life and our place in it. Consuming traditional foods revitalizes our cultures, our languages and our ceremonies and it reinforces our sovereignty within our families, communities and Nations. Gathering rice, berries, and plants requires our people to remember or seek out Traditional Knowledge in order to understand how to harvest these items in a respectful and traditional way.

Social order

Many traditional Aboriginal cultures have a different social organization and decision-making tradition than Western Culture. Decision-making is often community-based, inclusive and more collaborative than Western expert and specialist-driven processes. Elders are highly respected, in part for their deep knowledge of the environment and of the traditional territories (Friendship and Furgal, 2012).

Knowledge

Knowledge within traditional Aboriginal cultures is more observational and experiential than analytical and technological, as Western knowledge is. Members of Aboriginal communities are likely to rely on sensory methods to judge the state or quality of elements in the environment. Much traditional knowledge is historical and transmitted orally, passed on by Elders (Friendship and Furgal, 2012).

Marginalization

For a complex set of reasons related to social and political factors, including the colonial histories of Aboriginal people in Canada, the health status of Aboriginal communities in general is lower than the general population (Drieder et al., 2013). Housing on many reserves is below the standard expected in the rest of the country; many Aboriginal communities do not have reliable safe drinking water supplies (Patrick, 2011); and "access to and legitimacy of health services has been, and continues to be, a real issue" (Driedger et al. 2013). Many Aboriginals feel their health is a lower priority than is that of the mainstream population, and that their lives 'are less valued' than are those of other Canadians.

Differences in worldviews and values, knowledge and decision-making traditions, combine with social and political factors to create a lack of trust in Canadian authorities, experts and expertise. The combination of social marginalization and the use of traditional knowledge results in a lack of understanding of, and trust in scientific knowledge and dominant Western governance and decision-making. This lack of understanding is mutual, as scientists and authorities often do not understand Aboriginal values and perspectives, and consequently do not recognize that their own styles of knowledge and communication are not in accordance with those they are attempting to reach.

Perception of risk in Aboriginal culture and communities

These cultural assumptions, values and priorities shape the perception of risks by Aboriginal individuals and communities. Several dimensions of risk perception can be recognized as particular to Aboriginal cultures; risks appear as events or circumstances that threaten key values or the viability of important cultural activities. Because of the centrality of nature, and of the use of traditional lands, to the maintenance of culture and community, an event that reduces the ability of the people to carry out their traditional activities on the land is a serious risk. Such threats could be changes in the environment, the wildlife or plants that live in it, access to traditional areas, or contamination that makes the use of traditional foods unsafe. The ability to continue to use the local natural environment is so central to Aboriginal cultural survival that risk to the environment is often simply perceived directly as a threat to culture and to the maintenance of the traditional way of life.

The deep connection between the land and the people leads to a belief that risks to the environment cannot be kept separate from the people: with humans and the rest of nature are united in a single system; "whatever happens to the animal life . . . will also happen to the Anishnawbe" (Morrisseau, 1991: 40). "Elders all over North America know that when the earth is sick, the people will also be sick and this rings true in Indigenous Territories throughout Canada" (Simpson, 2003).

There is a strong interaction between cultural perceptions of the benefits and risks of using or consuming foods and water, as well as with impacts on health and on the community of exposure to risks in the environment.

First, the contamination of traditional foods or water sources leads to complex situations of competing risks and benefits. As there are health and cultural benefits to eating 'country foods' - wild foods hunted or gathered in the traditional way - contamination of these foods causes health risks if they are consumed, and cultural risks if they must be avoided. Reducing consumption has a greater impact than it might in mainstream society; substitutions are less viable, because the hunting itself is integral to the process, and because healthy and affordable alternatives may not be available in remote communities. When people fear that traditional foods are contaminated, they lose confidence in the environment and in the traditional activities involved in gathering them (Indian Affairs and Northern Development, 2003: 74).

This situation has been observed with the discovery of high levels of mercury in some fish species in the North (El-Hayek, 2007), where the risks of mercury in fish must be balanced against the nutritional value of the fish, particularly in a population that relies heavily on fishing and hunting for food, as well as against the cultural values of fishing and eating traditional foods.

In some instances the cultural benefits of using certain traditional foods or water may override risks, particularly if the risks are not readily apparent. The 'values and benefits of the connections with elements of the natural world outside of nutritive contributions' (Friendship and Furgal, 2012) can lead to the consumption of food or water that is not safe. Many individuals, particularly elders "who have spent a large part of their lives outdoors" (Martin et al., 2007) prefer to drink water from creeks, lakes or rivers rather than bottled water or treated tap water: despite the presence of bacterial contaminants, 'raw' water was considered to be "clearer and less contaminated' than water from household tanks, and tastes better, because it does not taste of chlorine (Martin et al. 2007).

Second, the means of identifying and perceiving a risk is different within Aboriginal culture than by scientific methods. Aboriginals may rely on historical knowledge, personal experience and observation, and sensory methods to detect contaminants in food or water, for example. Chemical or bacterial contaminants may be detectable only with technological sampling and testing, and not be apparent to the senses. There is concern about health risks from environmental contaminants, and anxiety is increased by the lack of familiarity with many contaminants and by the uncertainty of receiving information from scientists that does not accord with sensory perceptions or with traditional means of assessing the environment. Many residents of reserves are concerned about the safety of drinking water in their communities. Women on reserves were found in one study to be more concerned about the safety of drinking water than men. The researchers "suspect that this is partly a reflection of the culture, given First Nations women are viewed as guardians of water, possessing greater traditional learning and knowledge of the natural resource"; women with children under 15 were also more concerned (Spence and Walters, 2012).

Uncertainty about the safety of traditional foods and water – "not being aware of whether water has ever been contaminated during the year" (Spence and Walters, 2012) - increased concern about the safety of the water. Many contaminants are not only invisible but are the products of a technological society with which remote Aboriginal communities are not familiar, leading to misunderstandings, uncertainty and anxiety (Indian Affairs and Northern Development, 2003). There may be a 'resistance' to information about invisible contaminants that cannot be tasted or smelled, which increases uncertainty in interpreting the safety of food and the possible presence of contaminants, and creates conflicts between different sources of information and modes of understanding. People may not 'go against the knowledge of Elders when choosing between science and traditional knowledge' (Friendship and Furgal, 2012). Incidents of contamination may require consultation with technical experts who refer to a different system of knowledge: "They must rely on individuals using different modes of understanding, communication and inquiry, and there are often competing messages about the nature and extent of the risks by different experts" (Indian Affairs and Northern Development, 2003).

These complex factors make communicating about risks difficult with Aboriginal communities. Trust is further eroded with the awareness that much of the contamination of the environment, and traditional foods and water, is the result of Western industrial activities. As Simpson (2003) notes, "Colonization, genocide and colonial policies aimed at destroying Indigenous Nations and disrupting our physical and intellectual connections to the land brought tremendous tragedy, sickness and dependency to our peoples. Industrial activities such as mining, deforestation, road building, hydro -electric development, and the contamination of the environment with toxic chemicals continue to threaten the ability of Indigenous communities to rely on our traditional foods systems for our health and well-being and the health and well-being of our families."

Perceptions of Risk from Nuclear technology and Nuclear Waste

General levels of support: survey research

Many surveys provide information on general attitudes to nuclear technologies and applications; some of these are general risk perception studies (Krewski et al., 2006); others include questions on nuclear technologies in general public opinion surveys (for example the Eurobarometer surveys discussed by Greenberg, 2012); while others are dedicated studies of levels of opinion on nuclear technologies (Kim et al., 2014). These offer a broad, high-level picture of public opinion on nuclear technologies over time, and relative to other issues, social concerns, and risk sources. However, the general surveys provide little depth on any issue and do not offer interpretation and explanation of findings. It is also difficult to compare information from several surveys as the questions asked and the analyses performed on the data are specific to each study.

In the United States, there is fairly stable support for the use of nuclear energy, with benefits perceived as greater than risks (Jenkins-Smith, 2011). Support for the increased use of nuclear power in the U.S. fluctuated between 44% and 52% from 2005 to 2010 (Greenberg, 2012). The Eurobarometer survey of 2005 found an average of 37% of the populations of the EU countries favoured nuclear power and 55% were opposed; however there was a wide range in approval among countries. Several surveys reported a steady increase in positive opinion in Europe and the United States up to 2010, with the populations evenly split between support and opposition. An international opinion survey found that an average of 38% favoured the use of nuclear energy, with a majority of respondents supporting the technology in India and the US. While only 34% of respondents to this survey approved of the construction of new nuclear power plants, approval was higher in the US (44%) and the UK (43%). It has been found in a number of studies that nuclear waste is perceived as a higher risk than nuclear power (Sjöberg, 2004; Whitfield et al., 2009).

The events at the Fukushima plant in Japan caused levels of support to drop in many countries (Greenberg, 2012). The international survey found that those who opposed nuclear power were most influenced, with 26% of those opposed to nuclear power strongly influenced by the Fukushima events in the US and 20% in the UK. As is discussed in more detail below, the effect of these events on individuals' perceptions of the risks of the technology depended on their pre-existing broader attitudes (Yeo et al., 2104).

Many studies ask respondents about the level of their support or opposition to nuclear technologies; one study of data collected in 2005 by the International Atomic Energy Agency (IAEA) distinguished between strong and reluctant acceptance of nuclear power, and opposition to the technology. 'Reluctant acceptance' was defined as "acceptance of the use of nuclear energy without a friendly attitude towards it because of a high level of dependence on nuclear energy, and a lack of alternative energy sources within that country" (Kim et al., 2014). Researchers were able to classify the 19 countries involved in the survey into four groups according to the levels of support and opposition. Group 1 countries had a high level of acceptance and a high level of strong acceptance; Canada is in this group, along with Australia, China, India, South Korea, Mexico and the US (Kim et al., 2014).

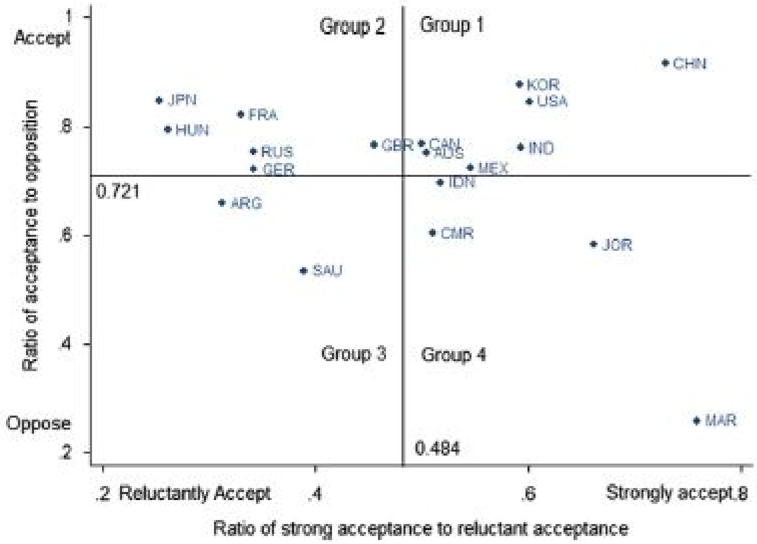

Figure 2. Classification of public acceptance of nuclear power over 19 countries. Kim et al., 2014.

There have been a number of findings on attitudes towards different aspects and applications of nuclear technologies: even when there is general support for the use of nuclear energy, there is commonly opposition to the local siting of a plant (Whitfield et al., 2009). Advocates of nuclear energy have anticipated that since nuclear power is a sustainable means of generating electricity that does not emit carbon dioxide, concern about climate change might change attitudes and revive the technology; however that appears not to be occurring (Whitfield et al.,2009; Bickerstaff et al., 2008).

Finally, Krewski et al. (2006) included nuclear power plants in a list of hazards that were ranked by respondents to the survey. One-third of the participants in this survey considered that nuclear power poses a high health risk, compared to 6 % who considered medical x-rays as being a high risk (Slovic, 2012).

Factors in attitudes to nuclear technologies

Qualitative factors related to radiation

As noted above, studies within the psychometric paradigm have described a number of qualitative factors that are associated with risk perceptions. Many of these factors apply to public perceptions of radiation and nuclear power, which differ from experts in fields related to radiation and nuclear technologies (Hardeman et al., 2004).

It is useful to understand the 'risk profile' that is presented by radiation and nuclear technologies; however it should also be noted this perspective leaves out contextual factors such as social dynamics and personal and political values, which are the most influential factors shaping attitudes to risk and acceptability.

Perceptions of the risks of radiation follow the pattern of qualitative associations (Ramana, 2011). The following are the key factors that are associated with non-experts' perceptions of the risks of radiation from various sources.

Risk of different sources of radiation: industrial, medical and natural

Radiation from nuclear power, and particularly nuclear waste, is perceived as high risk; nuclear technologies ranked very high on the 'dread' and 'unknown' scales created by Slovic (1987). Nuclear waste and nuclear weapons were considered to be the most serious of five nuclear and environmental hazards presented (Whitfield et al., 2009). MacGregor et al. (2002) consider that the perceptions of risk from radiation from all sources are disproportionate to the exposures that actually occur; these perceptions are related rather to concerns about the consequences of exposure to radiation and about risk management.

Other man-made sources of radiation, including medical x-rays, are seen as low risk. It is also a common finding that people are not concerned about radiation from natural sources, even when it may pose a relatively high health risk, such as radon gas in people's homes (Slovic, 2012; Hardeman, et al., 2004).

Risk-benefit relationship

Slovic (2012) attributes some of the reason for the high perceived risk of nuclear power and nuclear waste to the perception that they do not offer social benefits; this same balance explains the lower overall risks perceived from other technologies that use radiation.

> Representative surveys of the general public in the United States, Sweden, Canada, Norway, Belgium, and Hungary have consistently shown that people view nuclear power and nuclear waste as extremely high in risk and low in benefit to society, whereas medical x-rays are seen as very beneficial and low in risk.

Radiation is 'unknown'; invisible and complex to detect

Most members of the public "have a modest understanding of facts related to nuclear energy" (Jenkins-Smith, 2011); conclusions differ on the impact of that level of knowledge on risk perceptions. Jenkins-Smith (2011) found that the more inaccuracies a respondent provided the greater was the perceived risk and opposition to nuclear power. On the other hand, efforts to provide information on nuclear power did not change attitudes to the technology (Ramana, 2011) or changed them slightly (Slovic, 2012).

In terms of the characteristics of radiation and nuclear power as hazards, radiation is invisible and undetectable by the senses; special instruments are required to detect the type and amount of radiation that may be present. This means that it is not possible to be certain that there is no radiation present, or that one is not exposed, and that individuals must rely on experts to measure the radiation and interpret the significance of the risk.

Involuntary exposure

As with many large scale industrial facilities, nuclear power plants may expose those in the vicinity to emissions from routine operations, as well as from spills, leaks and other accidents; there is little possibility for people to reduce or avoid this exposure.

Effects delayed and long-term; may affect future generations

The health effects of exposure to radiation, except at very high levels, are expected to be in cancer that appears years, or decades, after the exposure; cancer is itself a highly feared health impact. Genetic damage from some exposures may also result in adverse impacts on offspring, thus resulting in effects on children and on future generations.

Catastrophic potential

As seen in several severe accidents and disasters, the impact of an incident at a nuclear power reactor is catastrophic; the concern for potential consequences outweighs the consideration that such events are infrequent and have a very low probability of occurring.

These effects include both severe impacts on human health and devastation of the environment for large areas around an accident site. The Chernobyl disaster resulted in a number of immediate deaths and the more or less permanent evacuation of an entire region, displacing many residents and resulting in concerns for heightened frequencies of thyroid cancer in children. The events at the Fukushima plant in Japan following the tsunami in 2011 also illustrated the potential for impacts that are severe, wide-spread, and long-term.

Uncontrollable

When accidents occur with nuclear technologies, the impacts are not easily managed or mitigated, even by experts. The damaged reactor at Chernobyl must be encased in concrete to contain the radiation that it continues to emit, decades after the accident; and international experts were not able to bring the situation at the Fukushima reactor under control after it was damaged by the Tsunami.

Tampering with nature

A later elaboration of the psychometric paradigm has been found to improve the explanation of risk perceptions. Tampering with nature includes 'interference with nature' and 'human arrogance and immorality' (Sjöberg, 2000). When included in a study of perceptions of risk from nuclear power this factor was also associated with a fear of long-term consequences and 'a warning of worse things to come' (Sjöberg, 2000).

Trust in Management

As has been found in general risk perception research, trust in those managing nuclear technologies is a strong factor in support for the technology (Whitfield et al., . . .) MacGregor et al; (2002) found that a majority in the US do not think the risks of radiation are regulated adequately. They do not believe that the government has done all it could to protect them, and do not think that decisions about health risks should be left to experts.

In addition to these qualitative factors that have been associated with the perception of various hazards, it can be seen that the broader effects of stigma and social amplification apply to nuclear issues.

Imagery

Nuclear power originated in military applications and was strongly associated with nuclear weapons through the 1980s. This negative imagery has persisted, and is more recently combined with images of the effects of the accidents and Chernobyl and Fukshima, evoking associations of 'disaster' and 'bad' (Slovic, 2012).

Associated with the factors of invisibility and tampering with nature, nuclear accidents and the emission of radiation appear more as 'contamination' than damage; they 'penetrate human tissue indirectly rather than wound the surface . . . invisible contaminants remain a part of the surroundings – absorbed into the grain of the landscape and the tissues of the body" (Slovic, 2012 quoting Erikson, 1990). These images are associated with industrial applications of radiation, but not with natural sources or medical applications.

Signal value and amplification

Nuclear power and related technologies are highly salient, and incidents and other events receive a great deal of media coverage and commentary. Yeo et al., (2014) suggest that perceptions are strongly influenced by media coverage of risk issues.

As evidenced by the increased concern reported following the Chernobyl and Fukushima events, nuclear plant accidents are subject to social amplification, and generate broader social impacts. The Fukushima events resulted in large public demonstrations calling for the closure of another nuclear power plant located close to a fault line (Ramana, 2011).

Stigma

A large amount of research has been conducted on the potential for nuclear technologies, particularly nuclear waste facilities, to stigmatize a region (Ramana, 2011). Much of this was related to impacts that a proposed nuclear waste facility located at Yucca Mountain in Nevada could have on broader social and economic conditions in the state (Slovic, et al. 1991). This phenomenon has been observed in the Fukushima prefecture in Japan; produce from the affected region is avoided, tourism to the region has dropped, and school children from the area have been bullied by classmates (Slovic, 2012; Ramana, 2011).

Demographic characteristics

The effect of demographic factors on risk perceptions has been considered in many studies of perceptions of nuclear technology, and results are variable. They are generally found to have little explanatory power on perceptions of risk directly, though they do on a number of factors that influence the perception of risk (Whitfield et al. 2009). Others have found however that women are less supportive than men of the use of nuclear power (Stoutenborough et al;, 2013), and to be more likely to perceive very high risks (Sjöberg, 2004).

General levels of education have been associated with higher perceptions of risk (Sjöberg, 2004) and with lower levels of perceived risk (Whitfield et al., 2009). However, while it is generally acknowledged that members of the public are not well informed on radiation or nuclear power (Ramana, 2011; Stoutenborough et al., 2013), it is not clear that this factor affects the perception of risk from nuclear technologies or support for their use.

Worldviews, values and political attitudes

Most researchers of attitudes to nuclear power and nuclear waste disposal advise that the focus of attention should not be on the psychological aspects of perceptions or cognitions about risk, or about emotions, but on the broader attitudes that members of society hold in the context of political systems and processes and of their worldviews and values (2004; Yim and Vaganov, 2003; Kim et al., 2014; Sjöberg, 2003). Broader attitudes shape beliefs (Sjöberg 2000) and influence the interpretation of information (Yeo et al., 2014; Yim et al., 2013) rather than the other way around. Whitfield et al. (2009), in their study on the values-beliefs-norms model of attitude structure, conclude that:

> [T]he individual decisionmaker is neither an isolated, cold, calculating maximizer of the rational actor paradigm, nor is the "cognitive cripple" ruled by incoherent thinking once believed in the psychology of risk. Instead, the decisionmaker exhibits a rich combination of cognitive insight, social and emotional intelligence and cultural awareness, all anchored by fundamental values showing concern for others and the environment.

Within various theoretical frameworks and disciplinary methodologies, researchers are describing the values and beliefs that underlie, and shape, individuals' attitudes to nuclear power (Whitfield et al., 2009 . . . .). Certain values and attitudes are associated with approval of nuclear power, and lower perceptions of risk from nuclear power, while others are associated with opposition to nuclear power and a higher perception of risk.

Whitfield et al. (2009) argue that "attitudes towards nuclear power are driven directly by the perceived risk of the technology and the levels of trust in the institutions responsible for managing it." As has been noted in research focussing on social trust, people show greater trust in those organizations with which they identify, and that share core values.

However, there are other direct and indirect links that explain this association. The perception of risk is affected by both education and by trust in organizations that manage the risk; and this trust is "a function of generalized beliefs or worldview about human impacts on the environment." The following are the important influences on attitudes to nuclear power:

- Individuals with more traditional beliefs have greater support for nuclear power:
    - Traditional beliefs include importance of family, patriotism, and stability, and are associated with less concern for the environment
- Those with more altruistic values are more opposed:
    - Altruism is ”a concern for the welfare of other humans and other species” and is associated with higher levels of environmental concern and perceptions of ecological risk
    - Belief that nuclear technology ‘interferes with natural processes’ is predictive of opposition to nuclear power. ‘Tampering with nature’ associates a moral judgement of human arrogance with the technology (Sjöberg, 2000).
- Trust in those responsible for managing nuclear power is a major driver of support for nuclear power:
    - Those showing greater trust in nuclear organizations are those with “less concern for the biosphere”
    - Those who are more altruistic and have greater concern for the environment (with higher New Environmental Paradigm scores have less trust in nuclear organizations.
    - Trust in ‘inspection authorities’ (in this case the IAEA inspections) is important for those who are ‘reluctant supporters’ of nuclear power (Kim et al. 2014), but this trust does not inspire strong support.
    - Trust in science – a belief that science has solved the problem of nuclear waste disposal - was found to correlate with perceived risk (Sjöberg 2004).

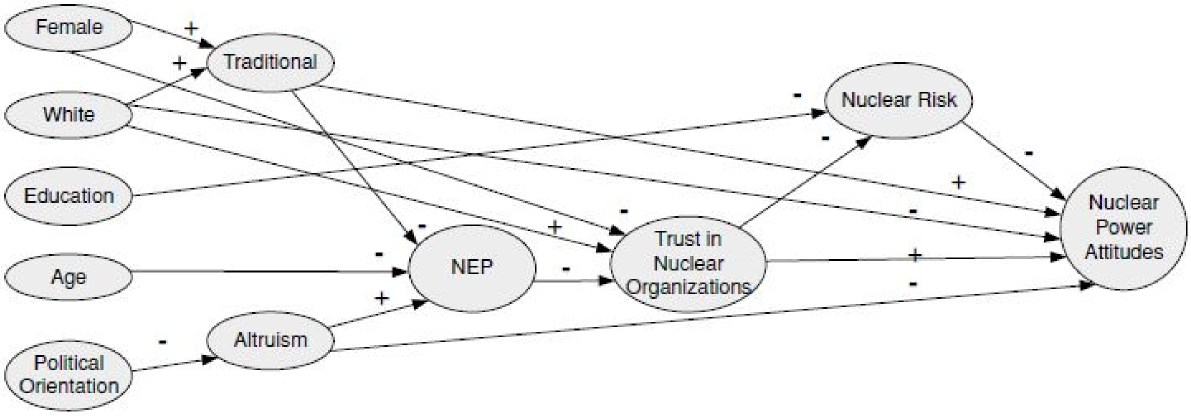

Figure 3. Whitfield et al., 2009. Stern-Dietz (S-D) values-beliefs-norms model of environmental decision making applied to nuclear attitudes. The direction of the association is shown as positive (+) or negative (-).

These attitudes and values have often been represented as basic political orientations, and associated with attitudes towards nuclear power. Yeo et al. (2014), for example, observe that conservatives are more supportive of nuclear power than liberals.

Decision making on nuclear issues

While studies interested in attitude formation focus on psychological and cognitive processes, it is clear that people use a number of conscious and deliberate strategies in pulling together information and personal values and priorities in making decisions. This is closer to a policy analysis approach to understanding differences of opinion and in political priorities; Whitfield et al. (2009) describe the decision process employed by the public as 'social and deliberative'. People's attitudes to a technology are related to their valuing of the benefits they perceive from a particular application of the technology, in relation to its risks, in the context of their confidence in the motivations and competence of those who are responsible for managing it.

Sjöberg (2003) argues that people weigh a range of contextual factors when deciding on an issue of the use of technology. 'Substitutability' of technology was the predominant factor he found in a study of support or opposition to the continuation of nuclear power. Sjöberg argues that in Sweden, where nuclear power generates half of the country's electricity, people will become more accepting of the technology as they realize that there are currently no viable substitutes for the technology. Similarly, people in Japan are 'anxious about nuclear power' but also recognize that it is necessary (Tanaka, 2004; note that this study was conducted before the Fukushima events).

Pidgeon et al (2008) found that there was some support in the UK for increasing the use of nuclear power if it would help address the adverse impacts of climate change – but they emphasize that this response was highly conditional on the provision that the technology "would help"; and that the majority of the population remains opposed to the technology. Bickerstaff et al. (2008) similarly positioned nuclear power as a response to the impacts of climate change and found that the proposition was interpreted as a risk-risk scenario, in which people felt they could 'reluctantly' accept nuclear power if it would help offset the effects of climate change. Pidgeon et al. (2008) and Bickerstaff et al. (2008) caution that attempts to reframe nuclear power as an environmentally advantageous technology relative to fossil-fuel energy sources appears opportunistic and manipulative and will likely fail.

Nuclear Waste

The risks of nuclear wastes are commonly perceived to be even greater than those of nuclear power generation (Bickerstaff et al., 2008). In fact the problem of nuclear waste is often cited as a source of the concern about nuclear power, and members of the public state that they would give greater support to nuclear energy if the high-level waste storage and disposal issues were resolved (Jenkins-Smith, 2011). Because of this it is more difficult to find a location and construct a nuclear waste repository than a nuclear power plant (Tanaka, 2004). There is long history of opposition to attempts to site a nuclear waste facility in many countries, in most cases related to political contexts with the approval and use of nuclear power, with a number of failed efforts to site repositories and to change public opinion on them (Solomon, 2010).

Less research has been conducted on public judgements of nuclear waste than of nuclear power (Jenkins-Smith, 2011), although the studies on stigma carried out in the 1980s and ‘90s focussed on the potential impacts of a nuclear waste repository on the society and economy of the state of Nevada. Nuclear waste is perceived to be highly stigmatizing, in terms of psychological effects, moral objections to nuclear power and water, and economic consequences (Marshall, 2005).

An early study of attitudes to a high-level nuclear waste repository in the US (Flynn et al., 1993) shows large differences between the public and members of the American Nuclear Society. A majority of the public believed there would likely be risks associated with the facility (such as earthquakes, accidents during operations, or sabotage or terrorist attacks); the strongest beliefs were that the buried based would not be contained to prevent underground water supplies, and that regulators “can [not] be trusted to provide prompt and full disclosure of any accidents or serious problems.” Imagery about nuclear waste was very negative, evoking thoughts of death and destruction.

Opinions of members of the America Nuclear Society were almost the inverse of the public opinions; however both groups agreed that there would be accidents associated with the transport of wastes to the disposal site (Flynn et al., 1993).

Research on initiatives to manage nuclear waste in many countries has described a fairly consistent range of social and ethical concerns that have made siting a nuclear waste facility a very contentious and usually unsuccessful undertaking. People are concerned that there will be an accident, or that spills or leaks will contaminate surrounding land; accidents associated with the transportation of wastes to the facility are also a major concern (Marshall, 2005). Although the siting process in many countries involves inviting communities to volunteer to host a facility, through local political processes and plebiscites, many have questioned the objectivity of the information provided to the community and, particularly when financial compensation is offered, whether the consent is genuine or is a result of political or financial pressure. This concern is underscored by the fact that communities that are considered as potential waste facility sites are often remote and economically disadvantaged, so that residents may feel unable to reject a facility that they would otherwise oppose because of the promise of compensation and employment (Marshall, 2005).

In addition to these concerns about regional or social inequities in siting a nuclear waste facility, the very long time that the wastes remain hazardous and will require monitoring or management raises issues of intergenerational justice (Marshall, 2005). The consent for a facility that is expected in a democratic society can only be obtained from the present generation, yet many future generations who cannot give, or refuse, consent will also be affected by, and perhaps at risk from, the facility.

There is frequently some skepticism about the public participation in siting processes, partly as a result of the legacy of secrecy associated with historical nuclear technology decision-making, and partly due to challenges in mutual lack of comprehension between public and technical perspectives. There is often “public unease” about experts’ claims of knowledge about long-term safety (Marshall, 2005), and a lack of trust in the nuclear industry and other risk management authorities.

A contrasting perspective is offered by the example of the successful process to agree to the development of a low-level nuclear waste facility in Port Hope, Ontario, which was driven by collaborative processes between the community, governments and the owners of the uranium refinery that had produced the wastes in activities from the 1930s to the 1970s (porthope.ca). Other factors that contributed to the success of the process were the familiarity with local people with refinery operations, the conviction that existing wastes should be dealt with, and the attention paid to the development of a 'comprehensive solution' that protected property values (NEA, 2003).

Attitudes of the general public to a proposed facility may not be easy to determine through a participatory siting process. This is because those who are more active in such processes – described in one study (Sjöberg, 2003a) as stakeholders – have stronger views and more extreme positions than members of the general public who are less active in such processes. Although stakeholders in a siting process in Sweden were not generally more risk-averse than others, they did have stronger concerns and more extreme views about the issue of nuclear waste disposal (Sjöberg, 2003a). Active stakeholders, both supporters and opponents of the project, had stronger opinions on risks and on benefits than the general public. Opponents perceived greater personal risk, expressed as a perception of damage to nature and new and unknown risk, and expected lower benefits from new business and government economic support associated with a facility. Supporters agreed that there would be benefits from the project and did not agree with the negative, risk statements. Stakeholders who were opposed perceived more risk, and less economic benefit, than non-stakeholders; stakeholders who supported a facility perceived less risk and more economic benefit than non-stakeholders (Sjöberg, 2003a).

More recent research has found that people generally prefer the centralized storage of nuclear wastes and are not comfortable with indefinite storage on the reactor site. The public expects very high levels of monitoring and environmental surveillance of interim storage, and is concerned about transportation of the wastes (Greenberg, 2012). Concerns about uncertainty, and skepticism about the adequacy with which it can be addressed through technical calculations and design, pertain to the uncertainty about future social and political conditions that will affect the way that the facility continues to be monitored or operated. Significant changes in social and political structures and conditions are inevitable but their nature is impossible to predict, and it is impossible even to be assured that facility warning information and symbols will be understood by people living in the area in hundreds or thousands of years (Marshall, 2005).

Opinions are also shaped by perceptions of benefits, and by policy and facility design factors. For example, a design that permits retrieval of the waste is generally preferred; and many people who had been opposed or neutral to the siting of a facility would support it if it were co-located with a research laboratory, which would both study improved ways to manage nuclear wastes and also reduce the stigma of the repository (Jenkins-Smith, 2011). Compensation to a community may increase support for hosting a facility – but only among those who were not previously opposed; such an offer actually decreased support among those who already opposed the project, to whom it appeared to be a bribe.

Some siting processes and related studies have found that communities that are close to a site appreciate the benefits of improved roads that the construction and operation of a facility would bring, and that communities that are closer to a site have higher approval (Jenkins-Smith, 2011). A positive siting process can reduce opposition and build support, as shown with the process to establish a repository in New Mexico (Jenkins-Smith et al., 2011). Greater success has been had in Scandinavia, with successful participatory processes and waste management (Solomon, 2010); Solomon recommends a greater role for social scientists and considerations of ethics and public policy processes in future research and siting processes.

Aboriginal perceptions of nuclear waste disposal

Farrugia-Uhalde noted in 2003 that there was very little research on Aboriginal attitudes to nuclear waste disposal (despite the fact that territory claimed and used by Aboriginal communities has been a major focus for the location of nuclear waste repositories that have been evaluated in Canada). In one of the few studies of Aboriginal perspectives on nuclear waste disposal, Hine et al. (1997) found that Aboriginal survey respondents were significantly more strongly opposed to a repository than the non-Aboriginal respondents. Aboriginals expressed lower levels of trust in the regulators of the technology, and in science and technology than non-Aboriginals, and associated greater costs with the repository than others. Hine et al. (1997) suggest that the Aboriginals' "commitment to future generations" and to their responsibilities of stewardship of the earth explain much of the opposition to a nuclear waste repository, and is a major factor distinguishing Aboriginals' perspectives on the facility from non-Aboriginals'. This study also found that financial benefits that may be offered as a tradeoff against the risk of a repository did not offset the opposition to the project among Aboriginals; this may be due to the very high level of risk perceived from the repository (Hine et al., 1997).

Farrugia-Uhalde (2003) reviews Aboriginal opinion on nuclear waste disposal by North American Aboriginals through an analysis of submissions made to the Seaborn Panel reviewing the concept for the disposal of high-level nuclear wastes. She found that the major issues that Aboriginal participants noted concerned respect for treaty and Aboriginal rights, spiritual and cultural values, the Aboriginal role in decision-making, and the lack of involvement of, and communication with, Aboriginals on the disposal concept.

Aboriginals recognize the risk posed by a possible nuclear waste repository as both a grave violation of the sacred earth and a threatened degradation of a culture. The notion of building a waste repository with potential effects for 100,000 years on the usual five-year planning horizon may be unimaginable to a people accustomed to making decisions with the seventh generation in mind. Other expressions of risk allude more specifically to the violation, by some more complex technologies, of a principle of nature as a threat in itself. A Lakota Sioux elder (quoted in Gowda, 1999: 138) warned that "the atomic force that binds the nucleus together is a sacred force; splitting the atom and transmuting matter is viewed as an intrusion in the realm of God and invites retribution." Placing toxic substances in nature is considered an affront to the sacred.

In addition to these cultural concerns Aboriginal interveners noted their concerns with deep geological disposal as a waste management option, and preferred the option of storing the waste above ground to facilitate monitoring and risk management.

Haalboom (2014) has noted in a recent analysis of Aboriginal participation in governance arrangements of uranium mining in northern Saskatchewan that perceptions of risk are described in terms of a lack of understanding of technical matters, often addressed through the provision of technical information. Haalboom (2014: 12) argues that this risk frame is "not benign" but rather renders "the development process as controllable, calculable and predictable, and those pursuing it as environmentally and socially responsible." Aboriginal participants counter by noting failures of technology and asserting their knowledge of local conditions, often making the dispute over 'techno-scientific' information central to the debate and controversy. While the governance process and provision of information are intended to engender trust with these Aboriginal communities, this dynamic does not achieve that trust.

Summary: Uncertainty and Acceptability

In the light of the observations that have been made through several decades of research on risk perception, particularly on the social and political dynamics that shape complex attitudes of the public and experts to technologies, perceptions of the risks they pose and benefits they offer, and trust in managers, several concluding observations may be made. These observations relate to the role of uncertainty in the controversy over the debate on nuclear waste disposal, and to the issue of the ultimate support of local communities and the public for a nuclear waste repository.

Uncertainty

The public is concerned with uncertainty in the performance and safety of proposed facility, but their interest in it is not the same as experts'. The reason for this can be found in some of the factors that influence risk perception, as well as in more social and political attitudes and priorities.

First, non-experts tend to be less concerned with the likelihood that an adverse consequence will occur than they are with the significance of the consequence itself. This is clearly true of nuclear power, with the very rare but undeniably catastrophic accidents that have occurred, notably Chernobyl and Fukushima. With respect to nuclear waste, people recognize that there are a number of very serious impacts that could occur with a technology that must keep long-lived hazardous wastes contained and 'safe' for hundreds or thousands of years. A large part of the concern with the attention to consequences is the value of the people or ecosystem elements that could be affected.

Second, when non-experts think of uncertainty they are likely to think of the possibility that something may occur, even of various degrees of possibility; they are less likely to be interested in calculating and comparing detailed quantitative probabilities. There will inevitably be significant uncertainty with the long-term responsibility of containing nuclear waste; this recognition, combined with the serious consequences that could affect a highly valued environment, renders redundant the quantification and comparison of uncertainties related to certain functions of the facility.

Third, uncertainty may relate to people's lack of familiarity with a very complex technology, and to concern with the prospect of deep burial, out of sight, of materials whose hazardous properties are invisible. This requires that people delegate the management and oversight of the technology to experts and professional risk managers, as non-experts have very little means of evaluating the performance of the facility themselves. However experiences with processes to assess proposed facilities often make it clear that the experts involved do not share the values of many in the public with respect to the use of nuclear power and the siting and operation of the waste disposal facility; these experts therefore do not have the trust of those groups. Furthermore, there is skepticism that science, and risk managers, are capable of predicting and preventing the adverse consequences that may occur.

Two crucial things are known about a proposed nuclear waste facility: it holds the potential for serious harm to the environment due to the toxicity of the waste material and the long time period over which it must be managed; and the combinations of events – including social and political changes – that might occur in tens or hundreds of years to cause such harm are unknowable. The uncertainties pertain to 'unknown unknowns' that may occur over such long time frames that they are essentially irreducible; efforts to quantify them suggest a focus on the wrong issue, and an investment of greater confidence in the process and results of quantification than is deserved. The presence of such 'large unknowns' and disputes over the meaning of uncertainties is characteristic of amplified risk controversies: Leiss (2003) notes that in risk controversies "incomplete hazard characterization," uncertainty over the range of adverse effects the public should be worried about" can be "compounded by the propensity of spokespersons for industry, often seconded by their governments counterparts, either to downplay or deny the scope of the hazards." Addressing risk controversies requires attention to the social and political dimensions of the controversy, or 'risk issue', as a separate managerial competence.

Acceptability and Tolerance

The concept of 'acceptability' used in relation to the public attitude to the proposed facility refers to a judgement made collectively, or by a majority of the public, that the waste disposal technology can be accepted by the community at that site. It is clear that in most efforts to site a nuclear waste facility such acceptance is not achieved, and where community support has been achieved it is the result of long and carefully conducted processes of consultation with the community in which priorities for addressing risks and benefits are established.

There are a number of critical factors in the development of community support for a facility that are not reflected in the relatively simple term of 'acceptability'. Risk management principles developed by the Health and Safety in the UK make a distinction between acceptability and tolerability that is relevant to the context of nuclear waste disposal (HSE, 1992; HSE, 2001).

In this usage, an acceptable risk is one that is deemed to be low enough that no management is required to reduce it. This is not the kind of support that has been achieved in nuclear waste facility siting processes, or indeed in most applications of complex technology.

The type of support that has been achieved is better reflected in the concept of tolerance: a tolerable risk that is one that is *managed*, and is tolerated at the managed level *in light of the benefits received*. This concept may be more appropriate to the evaluation of public support for a nuclear waste disposal facility, as it retains the notion of negotiated trade-offs and ongoing relationships and responsibility. As the desired outcome of a community siting process, it directs decision-makers' attention to the important relationship between risks and benefits, and to the responsibility of risk managers to attend to that dynamic, ensuring that benefits are received and valued, by those bearing the risks, and that risks are managed to an appropriate level.

The toleration of a risk is conditional – as is the 'reluctant acceptance' of nuclear power as a response to climate change – on both the reception of benefits and on the appropriate control of the risks. The risk is not simply accepted as low enough that it is not a concern, a handing of the issue over to risk managers for them to manage as they see fit.

This conditionality means that the performance of risk managers will be scrutinized; they will not be trusted blindly to manage a nuclear waste facility. The trust that the public will place in risk managers will be "critical trust" (Walls et al., 2004), an "active trust' in which "self-confident and active citizens assess the claims of experts and institutions" (Walls et al, 2004; Taylor-Gooby, 2006). Active, or critical, social trust incorporates critical attention to, or monitoring of, activities and institutions as an essential complement to the delegation of responsibility for risk management; it functions both to manage the social complexity and to monitor the competence of those entrusted to manage the risk and ensure that they remain aligned with social values and expectations.

With this in mind, it is to be expected that achieving tolerance of the risks of a nuclear waste disposal facility will require that the public receive, and acknowledge that they receive and value, benefits from the facility; it will also require that they have evidence that facility proponents, designers and managers share their concerns about the hazards and their valuation of the environment that may be at risk and plan and manage the facility with those values in mind. Continued tolerance of a nuclear waste facility will require that management facilitate public scrutiny of the facility and its management through being open, with stakeholder participation, provision of relevant information and reliable notification of any problems that occur.

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APPENDIX B

Letter from the Joint Review Panel

Deep Geologic Repository Joint Review Panel

March 6, 2014

Laurie Swami
Vice President, Nuclear Services
Ontario Power Generation
<contact information removed>

Subject: Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Independent Risk Assessment Expert Group Comments on Relative Risk Analysis of Community Acceptance in IR EIS-12-513

Dear Ms. Swami:

The Joint Review Panel thanks the Expert Group for its letter regarding the challenges of assessing community acceptance for the four prescribed options in the local and regional study area and outside of the regional study area, as required in IR EIS 12-513. The Panel has determined that the phrase "community acceptance" requires revision and further explanation. Accordingly, the Panel provides the following clarifications to the Expert Group.

Rather than "community acceptance", the Panel expects that there be a comparison of *risk perception* (and thus, *risk acceptability*) among the four options. Risk perception, in turn, is affected by the relative degree of uncertainty associated with each option. The Panel notes that risk perception and risk acceptability are also affected by trade-offs among social and ethical values; however, it does not expect that the Expert Group include social and ethical trade-offs in its analysis since that would go well beyond the intended scope of the IR. Rather, the Panel suggests that the Expert Group focus on uncertainty. This is because the technical risk analysis of the four options will have a direct link with the analysis of the effects of the technical uncertainty on risk perception.

The primary uncertainties associated with the management of low and intermediate-level nuclear waste were described in numerous written and oral submissions to the Panel. Many submissions presented comparative risk perceptions and risk acceptability among status quo, enhanced surface storage and deep geologic repositories. These submissions, together with information in the published literature and the Expert Group's analysis and professional judgement should be used to produce a relative risk perception/acceptability score for the four options.

The Panel expects that the relative risk perception scores will be related, but not necessarily confined, to the following primary uncertainties identified in submissions and reflected in the published literature:

- Accidents and terrorist threats
- Natural events (particularly seismic events and severe weather)
- Transportation risks
- Efficiency and trustworthiness of the options
- Level of confidence needed before proceeding with a given option
- Ease of monitoring
- Retrievability
- Equitable distribution of risks and benefits (theory that those who generate the waste bear more of the risk)
- Risks to future generations

The Panel also heard from Aboriginal groups with respect to the effect of spiritual and cultural factors on risk perception. The distinctive world view of the Aboriginal groups who presented at the Panel Hearing included the concept of "asking permission" of the earth before proceeding with an underground repository. This is just one example of the additional risk perception dimensions that are added when a proposed project might adversely affect potential or established Aboriginal rights, title or Treaty rights asserted in the area. The Panel refers the Expert Group to the Hearing transcripts for days with formal presentations by Aboriginal groups. Scheduled presentations were made on September 16 and 25, 2013 and October 11 and 30, 2013 by the Saugeen Ojibway Nation. Presentations were made by the Historic Saugeen Métis and the Métis Nation of Ontario on October 7, 2013. This information is in addition to the written submissions prepared by each of these Aboriginal Groups. It may not be possible to use Aboriginal risk perception values to discriminate among the four options. However, the Panel would encourage the Expert Group to comment on how risk perception among Aboriginal peoples might better be acknowledged and incorporated.

The Panel understands that many of the above uncertainties will be assessed as part of other portions of the analysis of the four options (e.g. with respect to risks to the Safety Case). However, the Panel expects that the analysis then go forward with further consideration of the *perception* of each of the four options, as influenced by the relative degree of technical uncertainty associated with the primary uncertainty issues listed above.

The Panel did not intend that the requirement for the risk analysis to be "defensible and repeatable" would be interpreted as a requirement for "evidence based" analysis. The Panel's intent was that the analysis be transparent. Transparency produces defensibility. If other investigators understand precisely how the risk analysis results were determined, then repeatability is also possible (although the Panel acknowledges that a different set of experts may produce different outcomes).

The Panel has also determined that the stipulation regarding study area has led to misunderstanding. The Expert Group states in its letter that "there is insufficient information directly relevant to the issue of local and regional community acceptance, based on research having to do with *discriminating* among the four specific options listed in the charge to the Expert Group." The Panel is aware that there is no formal quantitative or qualitative evidence comparing risk perception and risk acceptability of all four options within the local and regional study areas. In fact, such data would be impossible since there are no granitic bedrock locations in the regional study area. The Panel maintains that use of a combination of evidence provided by submissions as well as published literature is sufficient to discriminate among the options if the Expert Group focusses, as is suggested above, on the effects of relative uncertainty on risk perception and risk acceptability.

The Panel acknowledges paragraph #4 in the Expert Group's letter of February 18, 2014. While the Group members were not present throughout the public hearing process, there are extensive and varied records available. To assist the Expert Group in this regard, a description of the information sources follows. The Panel recommends accessing the Canadian Environmental Assessment Registry Internet site at www.ceaa-acee.gc.ca. In the folder called "Hearing Documents", the Expert Group will find both Daily Agenda files (example, document #1563) and daily Hearing Transcript files (example, document # 1567). These are in addition to document #1521 that provides a comprehensive preliminary agenda for the first four weeks of the hearing and document #1722 that outlines the hearing agenda for October 28-30, 2013.

The daily agendas provide a complete list of registered participants for each day and the Hearing Transcripts are a verbatim record of what was said each day. The Expert Group members then have the additional option of watching the daily webcast to obtain information. Webcasts for each day of the public hearing can be accessed at www.nuclearsafety.gc.ca. If you have any questions regarding the search functions of the CEAA on- line project registry, please contact Debra Myles at (613)957-0626.

The Panel hopes that the clarifications regarding its expectations for analysis of risk perception and risk acceptability will assist the Expert Group.

Any questions that you have may be directed to the Panel Co-Managers, Kelly McGee at (613) 947-3710 or Debra Myles at (613) 957-0626.

Sincerely,

<original signed by>

Stella Swanson
Chair
Deep Geologic Repository Joint Review Panel

c.c.: James F. Archibald, Joint Review Panel Member
Gunter Muecke, Joint Review Panel Member

ENCLOSURES

TO

OPG RESPONSE TO IR-EIS-12b-513

University of Ottawa
R. Samuel McLaughlin Centre for Population Health Risk Assessment
1 Stewart Street, Ottawa, ON K1N 6N5

29 May 2014

Ms. Laurie Swami
Vice-President, Nuclear Services
Ontario Power Generation
889 Brock Road
Pickering, ON L1W 3J2

Dear Ms. Swami:

On behalf of my colleagues in the Independent Expert Group – Maurice Dusseault, Tom Isaacs, and Greg Paoli – I am pleased to transmit herewith our "Report of the Independent Expert Group on Additional Figures and Interpretation in Support of Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low- and Intermediate Level Radioactive Waste in Ontario."

I would be pleased to respond to any questions that you have; to reach me by phone: 613-297-4300.

Sincerely,

William Leiss, O.C., Ph.D., FRSC
Professor emeritus, School of Policy Studies, Queen's University
Scientist, McLaughlin Centre for Risk Assessment, University of Ottawa
wleiss@uottawa.ca

Report of the Independent Expert Group on Additional Figures and Interpretation in Support of Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario

SUBMITTED BY:

MAURICE DUSSEAULT, TOM ISAACS, WILLIAM LEISS (CHAIR), GREG PAOLI

SUBMITTED TO:

THE JOINT REVIEW PANEL FOR THE DEEP GEOLOGIC REPOSITORY PROJECT
FOR LOW AND INTERMEDIATE LEVEL
RADIOACTIVE WASTE (DGR)

May 29, 2014

Table of Contents

Introduction

This report contains three sections and two appendices, as follows:

Section 1: Approach to the Task

Section 2: Additional Figures Related to Qualitative Risk Comparison

Section 3: References

Appendix:
I. Request to the Expert Group from the Joint Review Panel
II. Re-Labeled Relative and Absolute Risk Assessment Plots

1 Approach to the Task

This report responds to the following information request received from the Joint Review Panel (JRP) (see Appendix I of this report).

> *"a) Provide an indication of the log-log scale on the risk assessment plots, both Relative Risk and Absolute Risk, for the 12 key features (or pathways of harm) for comparison among the 4 alternatives for the near term (<100 years) and long term (>100 years) in order that the reader may distinguish negligible, low, moderate, high or very high risk assessments on these scales.*
>
> *b) Provide a table and/or figure with accompanying explanatory narrative that summarizes the overall relative risks of the four identified options for the long- term management of low and intermediate level waste, over both timeframes (<100 years and >100 years). Include this summary in OPG's separate submission to address the Panel's follow-up comments on the comparison of risk perception among the four options."*

In response to part (a) of the request, we have provided the same relative risk and absolute risk plots with labelling to explicitly clarify that both the likelihood and consequence dimensions of the risk assessment plots have a logarithmic scale. These re-labeled plots are included as Appendix II of this report.

We have not provided categorical labels (such as negligible, low, moderate, high, etc.) on either the likelihood or consequence scales, and have not provided a categorical indication of the level of risk (which requires simultaneous consideration of both consequence and likelihood). The rationale for not providing categorical indications of likelihood, consequence, or risk is as follows:

- Consistent with the nature of the original request, our original evaluation of risk (Reference 1) was qualitative and not quantitative in nature. The provision of graphical interpretations of this evaluation was intended to facilitate understanding of our qualitative reasoning.
- Categorical labels for probability estimates are known to be an unreliable means of communication of probability due to the high level of variability in public interpretation of words such as "unlikely", "likely", "remote", "rare", "common", "uncommon", "negligible", "improbable", "inevitable", etc.

- Categorical labels for consequences suffer from similar variability in interpretation and necessarily impose a societal valuation on the seriousness of various consequences through the assignment of labels such as “negligible”, “low”, “moderate”, and “high”. The assignment of such labels is normally considered to be the domain of risk management, as opposed to risk assessment, in the usual conceptual separation of these activities in the development of public policy. In addition, we believe that the stakeholders involved would have, and have expressed, highly variable evaluations of the seriousness of various consequences described in our earlier report.
- Given the above lack of definition and consensus on the significance of various consequences, the Independent Expert Group (IEG) is not in a position to apply categorical labels on consequences.
- Due to the inability to provide categorical assessments of likelihood and consequence, we are similarly unable to assign categorical labels to the concept of risk as the combination of likelihood and consequences.

In response to part (b) of the request, we have provided additional figures which provide an overall perspective on the relative risks of the four disposal options, for both timeframes previously assessed. The following section includes an explanation of these figures. This document assumes that the reader is familiar with the previous IEG report (Reference 1). Since the time of this request, we have provided a separate report that addresses the risk perception component of part (b) of the request (Reference 2).

2 Additional Figures Related to Qualitative Risk Comparison

To provide an overall perspective on the array of risks posed by the four disposal options, we have provided two figures (Figures 2 and 3), one for each of the two timeframes. In viewing and interpreting these figures, the following concepts should be carefully considered:

1. The likelihood of the various accidents and events associated with the waste disposal options varies over many orders of magnitude. The horizontal axis of the figures should be understood in logarithmic terms.

2. The consequences associated with the various pathways of harm are highly variable in their nature, the receptors involved (e.g. public, worker, environment) and the magnitude of the consequences. Although the consequences have not been given quantitative meaning in this exercise, they should also be understood to vary over

several orders of magnitude. As such, the vertical axis of the figures should also be understood in logarithmic terms.

3. Due to the use of a logarithmic scale, it is not strictly possible to represent zero on the likelihood or consequence scales. However, in some cases, the likelihood or consequences are considered to be essentially zero. In these cases, the associated icons have been placed directly on top of the axis.

4. Risk, from a technical perspective, is generally understood to integrate the concepts of likelihood and consequence. As such, an increase in either likelihood or consequence is understood to increase the level of risk. With this concept, the risk associated with the various combinations of exposure pathways and disposal options should be understood to increase as the icons are vertically higher in the diagram or as they are further to the right of the diagram. The lowest risks are found in the bottom left corner of the diagram, and the highest risks are found in the top right of the diagram (Figure 1). In addition, by virtue of the logarithmic scales of both consequence and likelihood, the risk continuum represented by the figure should also be understood to span many orders of magnitude.

5. The figures in this report are the result of attempting to combine a series of individual pathway-specific relative risk estimates and absolute risk estimates from the previous IEG report (Reference 1). The IEG did not systematically consider the relative likelihood or consequences of different pathways during the original assessment process. Due to the qualitative nature of the assessment exercise, there is significant uncertainty about the correct icon location in both the likelihood and consequence dimensions such that small variations in the relative locations of icons should not be interpreted as representing a significant difference between their likelihood and/or consequence. Icons appearing close together in a region of the figure can be interpreted as carrying similar levels of risk, including the possibility that the apparent difference in likelihood or consequence could be non-existent or even reversed. As a result, the overall relative risk assessment is most reliable for comparing options that are significantly different in terms of likelihood and/or consequence.

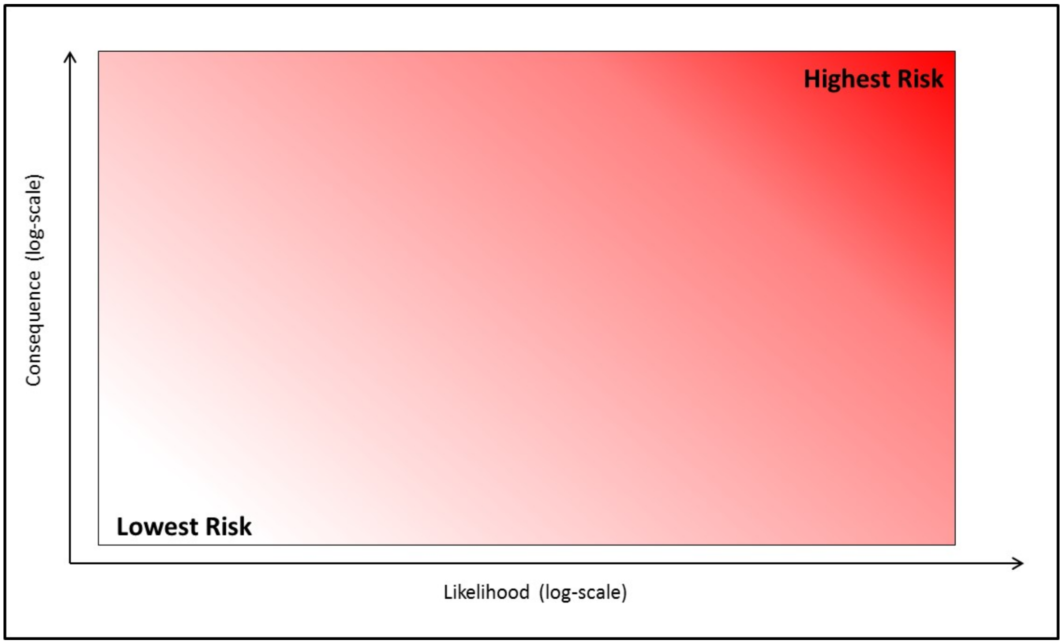
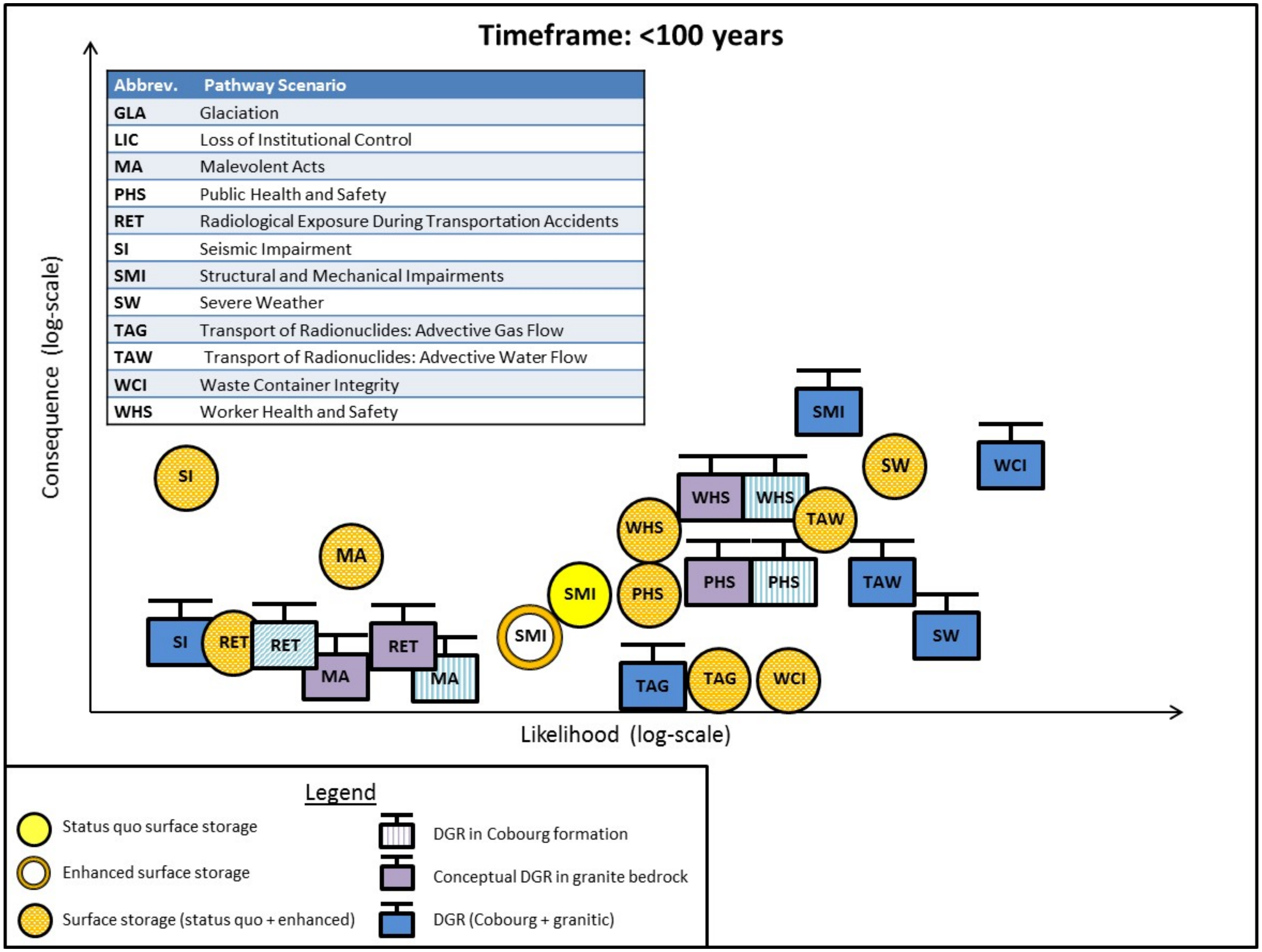
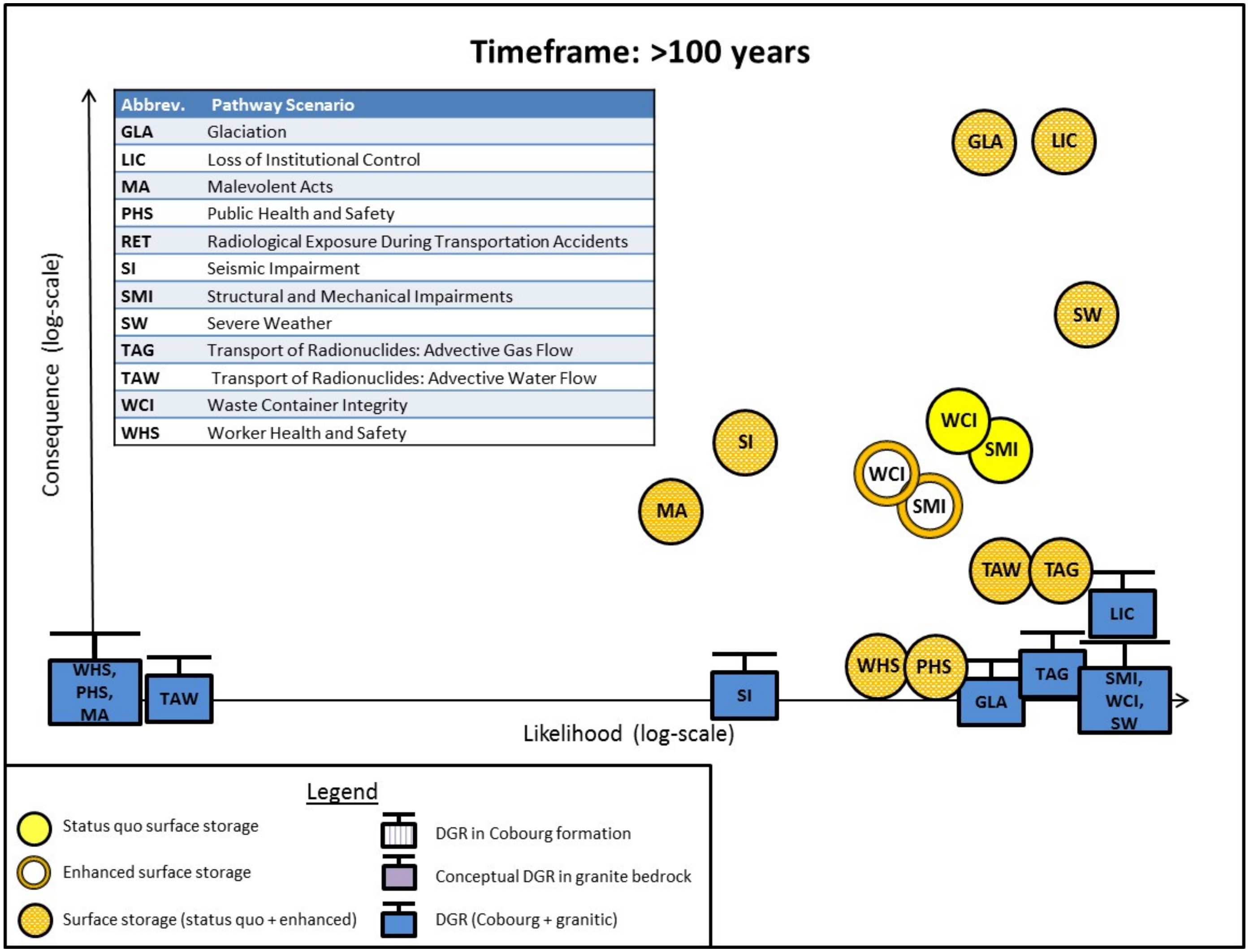


Figure 1. Visualization of the risk continuum based on likelihood and consequence.



Abbrev.	Pathway Scenario
GLA	Glaciation
LIC	Loss of Institutional Control
MA	Malevolent Acts
PHS	Public Health and Safety
RET	Radiological Exposure During Transportation Accidents
SI	Seismic Impairment
SMI	Structural and Mechanical Impairments
SW	Severe Weather
TAG	Transport of Radionuclides: Advective Gas Flow
TAW	Transport of Radionuclides: Advective Water Flow
WCI	Waste Container Integrity
WHS	Worker Health and Safety

Figure 2. Relative risk assessment for four disposal options according to pathways of harm for first 100 year period.



Abbrev.	Pathway Scenario
GLA	Glaciation
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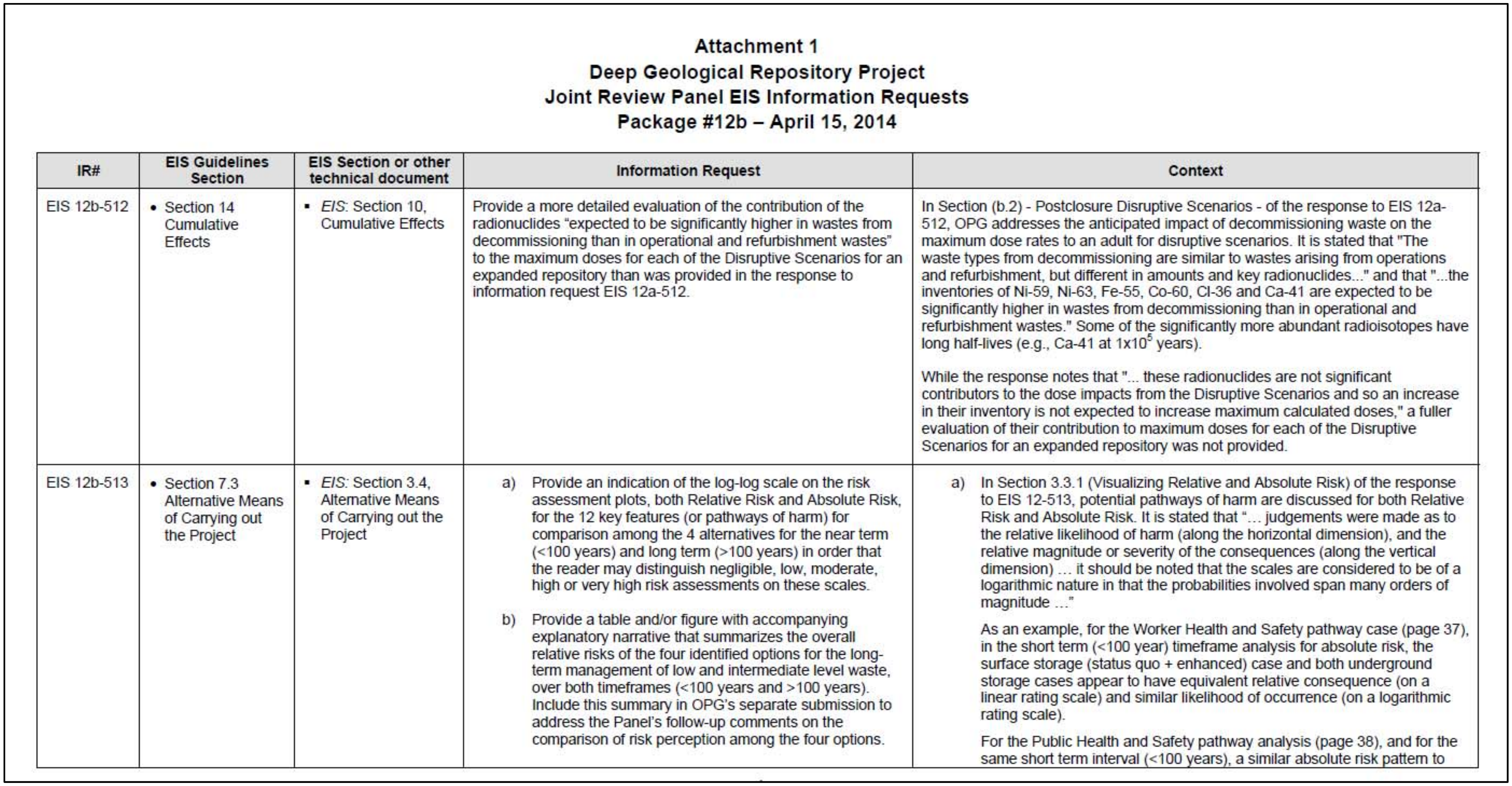
Figure 3. Relative risk assessment for four disposal options according to pathways of harm for period following 100 years.

3 References

1 Report of the Independent Expert Group on Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario. Submitted by M. Dusseault, T. Isaacs, W. Leiss (Chair), G. Paoli to the Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR), March 25, 2014.

2 Report of the Independent Expert Group on Risk Perceptions of the Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario. Submitted by M. Dusseault, T. Isaacs, W. Leiss (Chair), G. Paoli to the Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR), May 8, 2014.

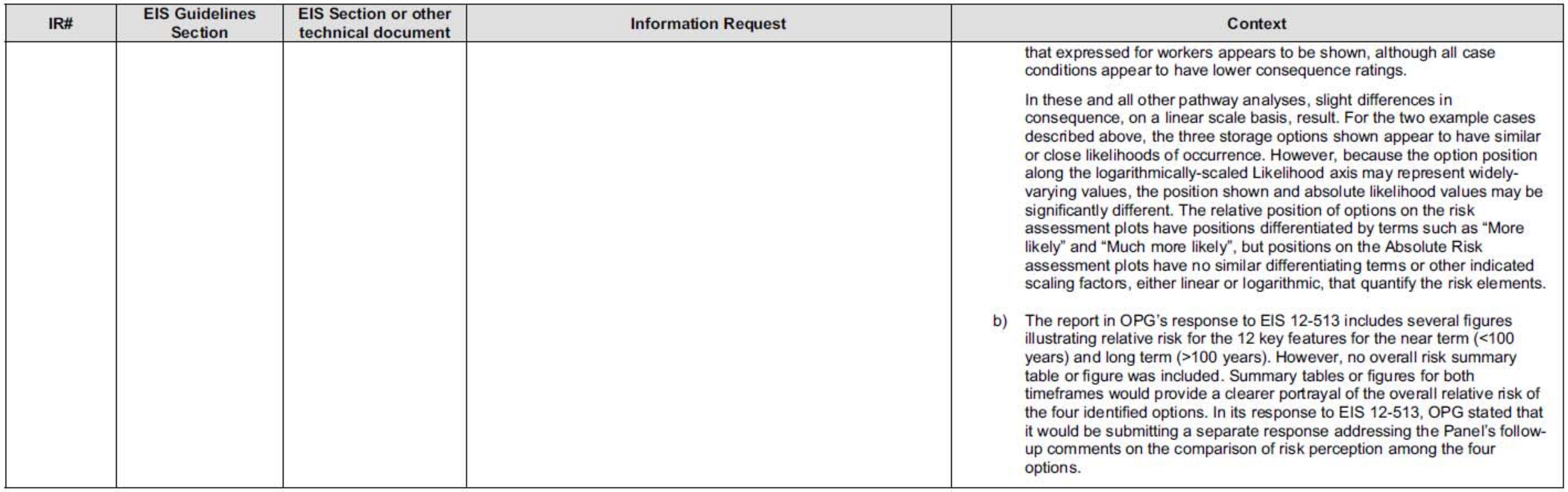
Appendix I. Request to the Expert Group from the Joint Review Panel



Attachment 1
Deep Geological Repository Project
Joint Review Panel EIS Information Requests
Package #12b – April 15, 2014

IR#	EIS Guidelines Section	EIS Section or other technical document	Information Request	Context
EIS 12b-512	• Section 14 Cumulative Effects	▪ *EIS*: Section 10, Cumulative Effects	Provide a more detailed evaluation of the contribution of the radionuclides “expected to be significantly higher in wastes from decommissioning than in operational and refurbishment wastes” to the maximum doses for each of the Disruptive Scenarios for an expanded repository than was provided in the response to information request EIS 12a-512.	In Section (b.2) - Postclosure Disruptive Scenarios - of the response to EIS 12a-512, OPG addresses the anticipated impact of decommissioning waste on the maximum dose rates to an adult for disruptive scenarios. It is stated that "The waste types from decommissioning are similar to wastes arising from operations and refurbishment, but different in amounts and key radionuclides..." and that "...the inventories of Ni-59, Ni-63, Fe-55, Co-60, Cl-36 and Ca-41 are expected to be significantly higher in wastes from decommissioning than in operational and refurbishment wastes." Some of the significantly more abundant radioisotopes have long half-lives (e.g., Ca-41 at 1x10^{5} years). While the response notes that "... these radionuclides are not significant contributors to the dose impacts from the Disruptive Scenarios and so an increase in their inventory is not expected to increase maximum calculated doses," a fuller evaluation of their contribution to maximum doses for each of the Disruptive Scenarios for an expanded repository was not provided.
EIS 12b-513	• Section 7.3 Alternative Means of Carrying out the Project	▪ *EIS:* Section 3.4, Alternative Means of Carrying out the Project	a) Provide an indication of the log-log scale on the risk assessment plots, both Relative Risk and Absolute Risk, for the 12 key features (or pathways of harm) for comparison among the 4 alternatives for the near term (<100 years) and long term (>100 years) in order that the reader may distinguish negligible, low, moderate, high or very high risk assessments on these scales. b) Provide a table and/or figure with accompanying explanatory narrative that summarizes the overall relative risks of the four identified options for the long-term management of low and intermediate level waste, over both timeframes (<100 years and >100 years). Include this summary in OPG's separate submission to address the Panel's follow-up comments on the comparison of risk perception among the four options.	a) In Section 3.3.1 (Visualizing Relative and Absolute Risk) of the response to EIS 12-513, potential pathways of harm are discussed for both Relative Risk and Absolute Risk. It is stated that “… judgements were made as to the relative likelihood of harm (along the horizontal dimension), and the relative magnitude or severity of the consequences (along the vertical dimension) … it should be noted that the scales are considered to be of a logarithmic nature in that the probabilities involved span many orders of magnitude …” As an example, for the Worker Health and Safety pathway case (page 37), in the short term (<100 year) timeframe analysis for absolute risk, the surface storage (status quo + enhanced) case and both underground storage cases appear to have equivalent relative consequence (on a linear rating scale) and similar likelihood of occurrence (on a logarithmic rating scale). For the Public Health and Safety pathway analysis (page 38), and for the same short term interval (<100 years), a similar absolute risk pattern to

Figure 4. Screen shot of request from Joint Review Panel.



IR#	EIS Guidelines Section	EIS Section or other technical document	Information Request	Context
				that expressed for workers appears to be shown, although all case conditions appear to have lower consequence ratings. In these and all other pathway analyses, slight differences in consequence, on a linear scale basis, result. For the two example cases described above, the three storage options shown appear to have similar or close likelihoods of occurrence. However, because the option position along the logarithmically-scaled Likelihood axis may represent widely-varying values, the position shown and absolute likelihood values may be significantly different. The relative position of options on the risk assessment plots have positions differentiated by terms such as “More likely” and “Much more likely”, but positions on the Absolute Risk assessment plots have no similar differentiating terms or other indicated scaling factors, either linear or logarithmic, that quantify the risk elements. b) The report in OPG’s response to EIS 12-513 includes several figures illustrating relative risk for the 12 key features for the near term (<100 years) and long term (>100 years). However, no overall risk summary table or figure was included. Summary tables or figures for both timeframes would provide a clearer portrayal of the overall relative risk of the four identified options. In its response to EIS 12-513, OPG stated that it would be submitting a separate response addressing the Panel’s follow-up comments on the comparison of risk perception among the four options.

Figure 4 (cont.). Screen shot of request from Joint Review Panel.

Appendix II. Re-Labeled Relative and Absolute Risk Assessment Plots

The following plots (Figures 5 through 25) are replicated from the original IEG Qualitative Risk Comparisons report (Reference 1). These plots have been modified to clarify that the likelihood and consequence dimensions are of a logarithmic nature such that the likelihood and consequences, if quantified, would span many orders of magnitude.

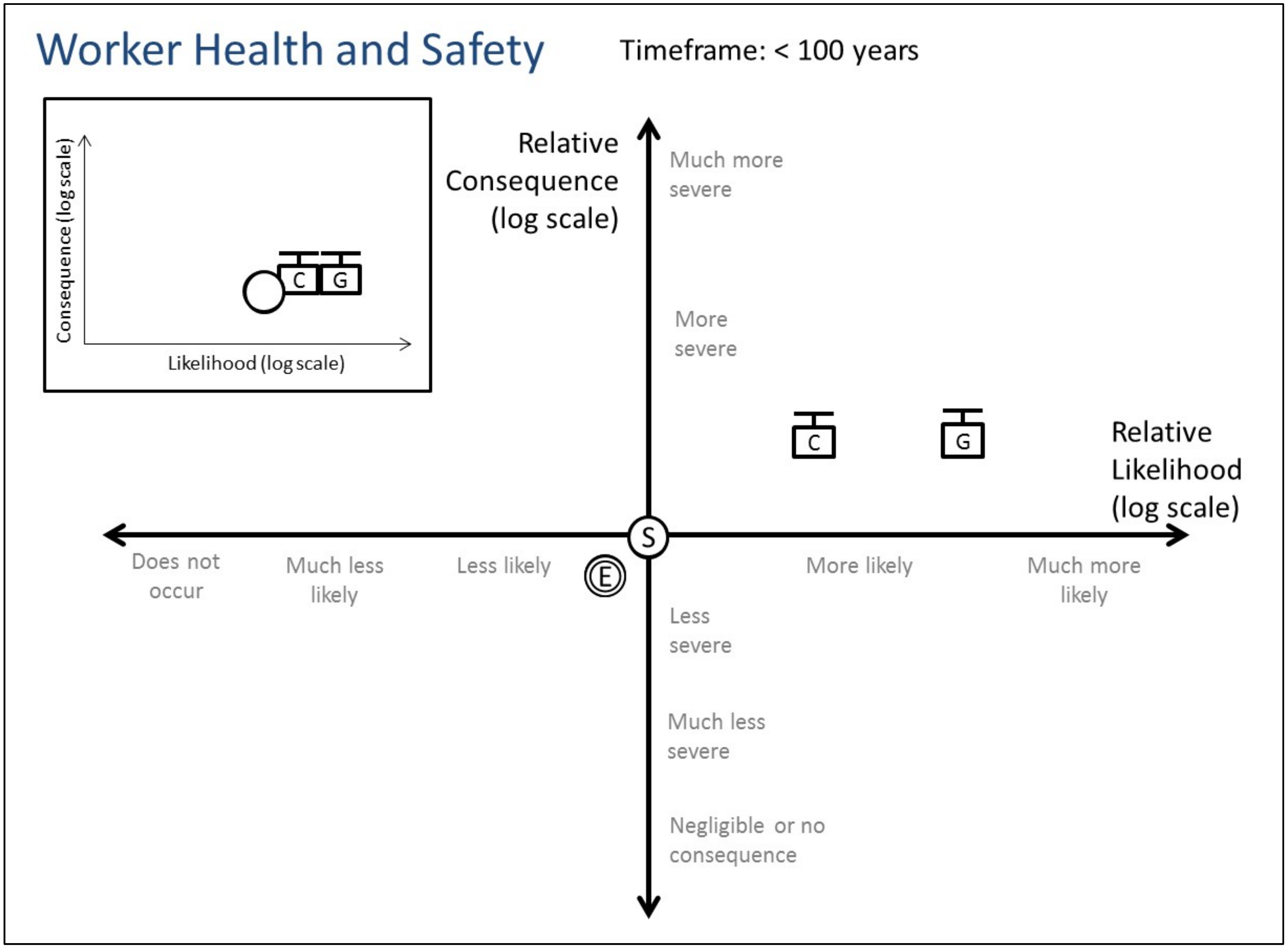


Figure 5. Relative and absolute risk diagrams for worker health and safety (first 100 years).

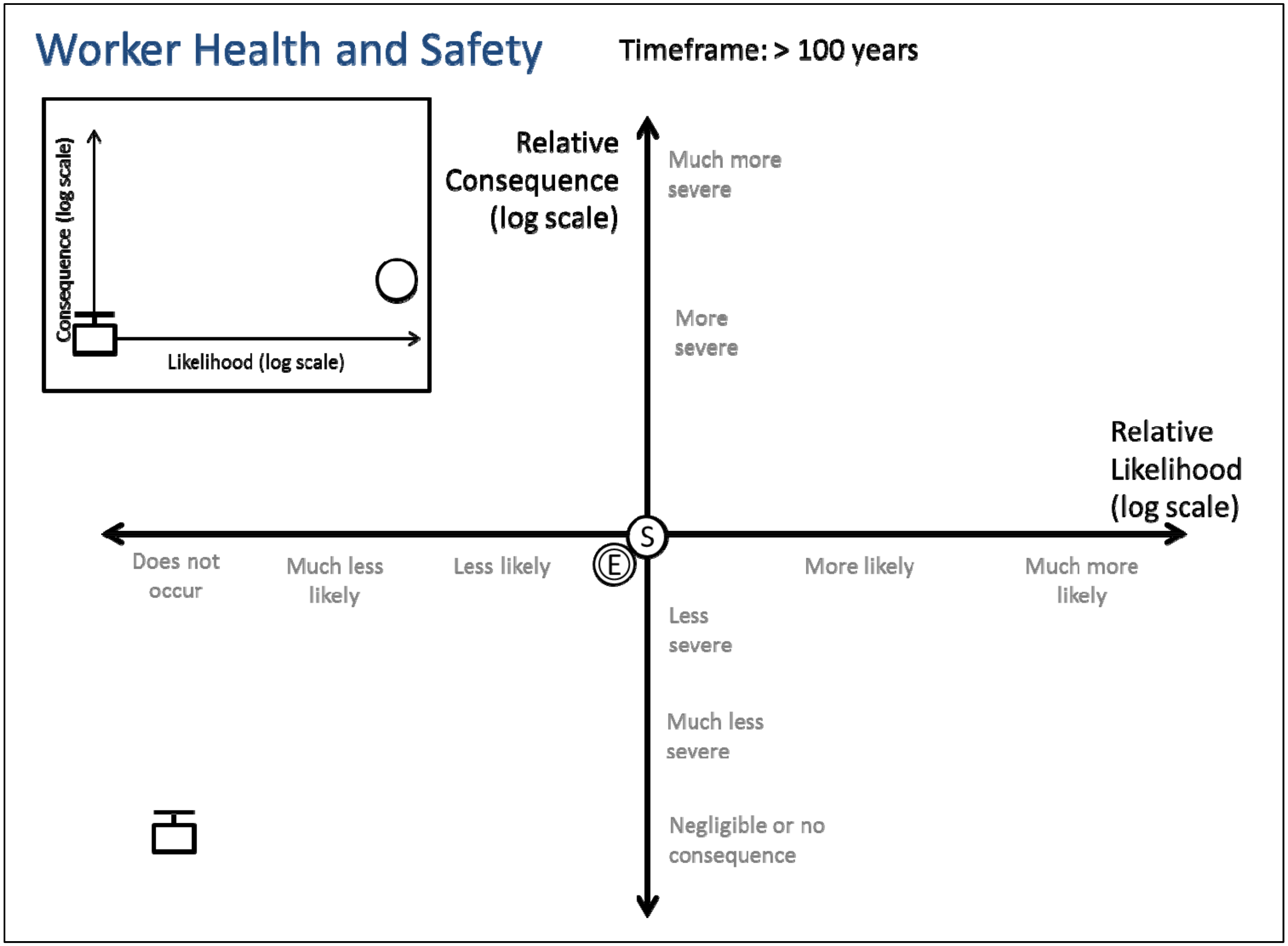


Figure 6. Relative and absolute risk diagrams for worker health and safety (>100 years).

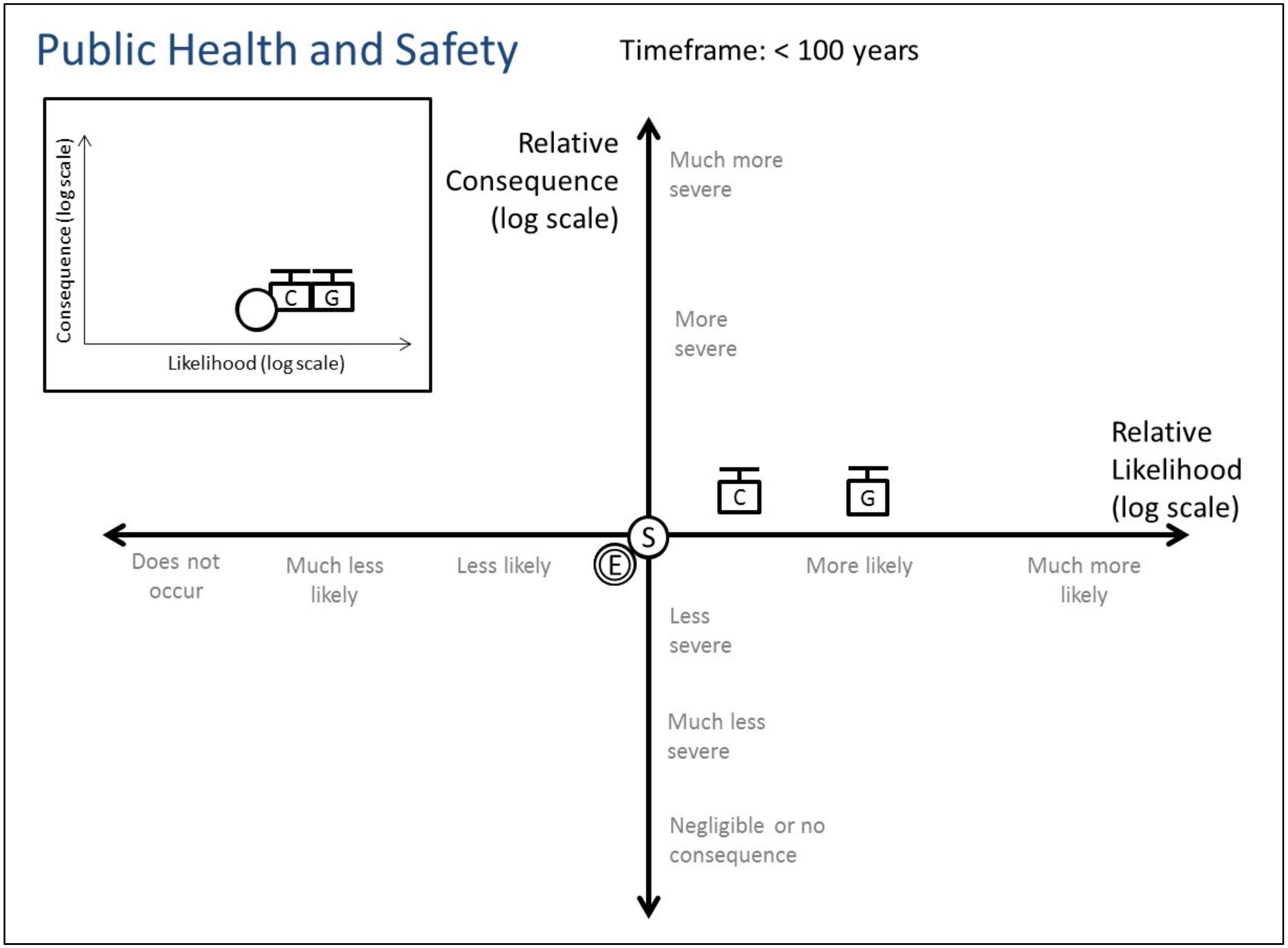


Figure 7. Relative and absolute risk diagrams for public health and safety (first 100 years).

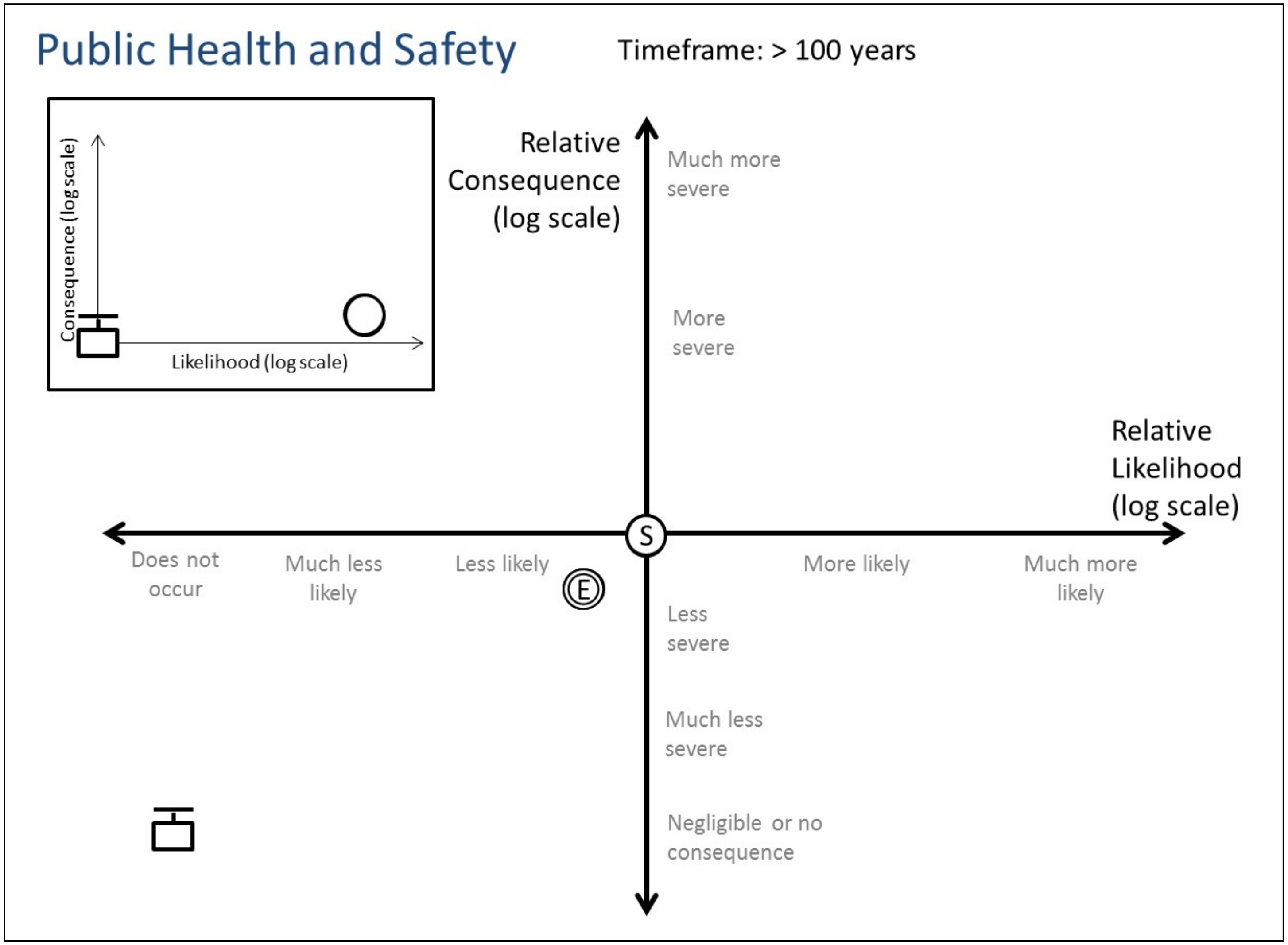


Figure 8. Relative and absolute risk diagrams for public health and safety (>100 years).

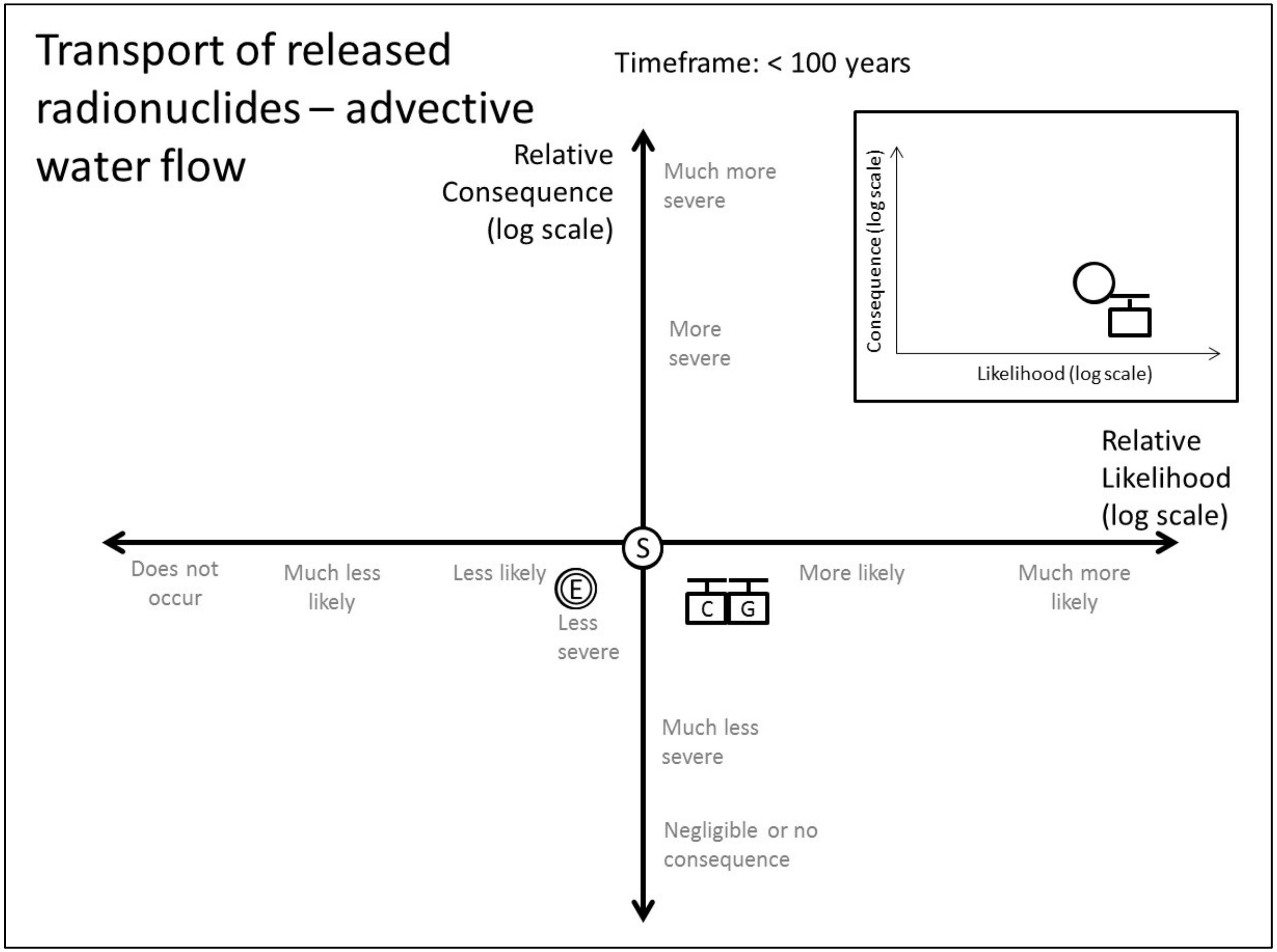


Figure 9. Relative and absolute risk diagrams for transport of released nucleotides – advective water flow (first 100 years).

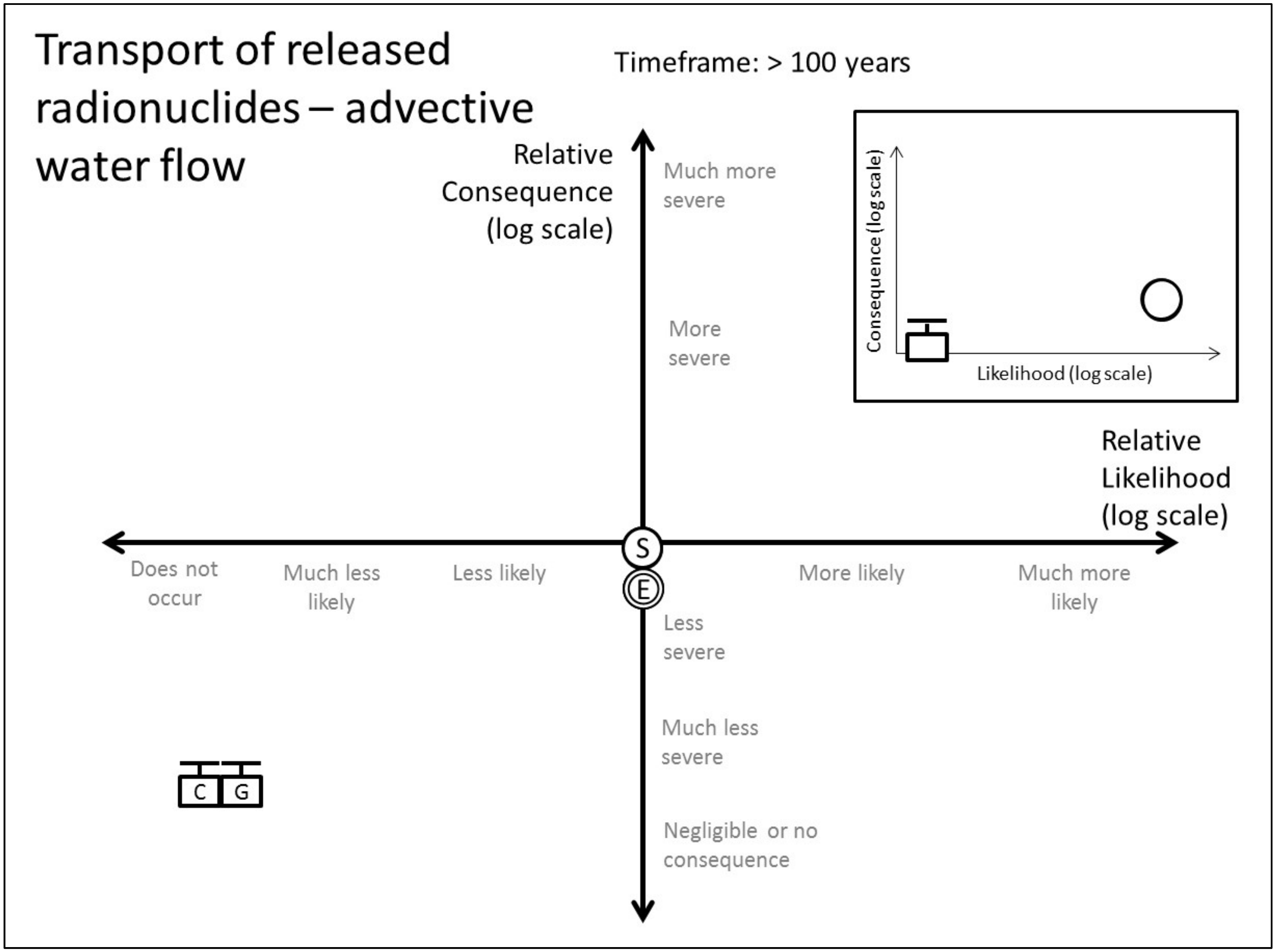


Figure 10. Relative and absolute risk diagrams for transport of released nucleotides – advective water flow (>100 years).

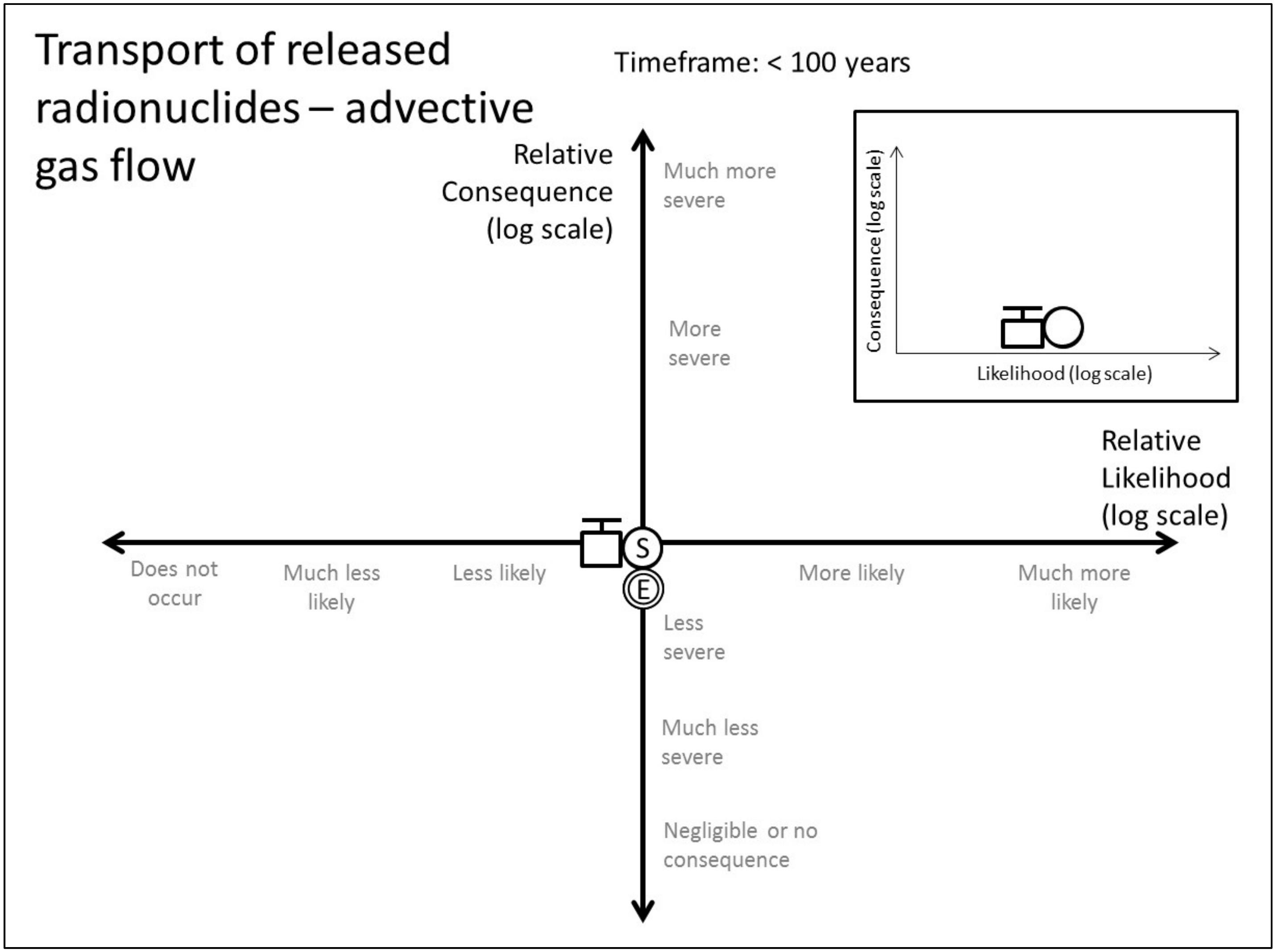


Figure 11. Relative and absolute risk diagrams for transport of released nucleotides – advective gas flow (first 100 years).

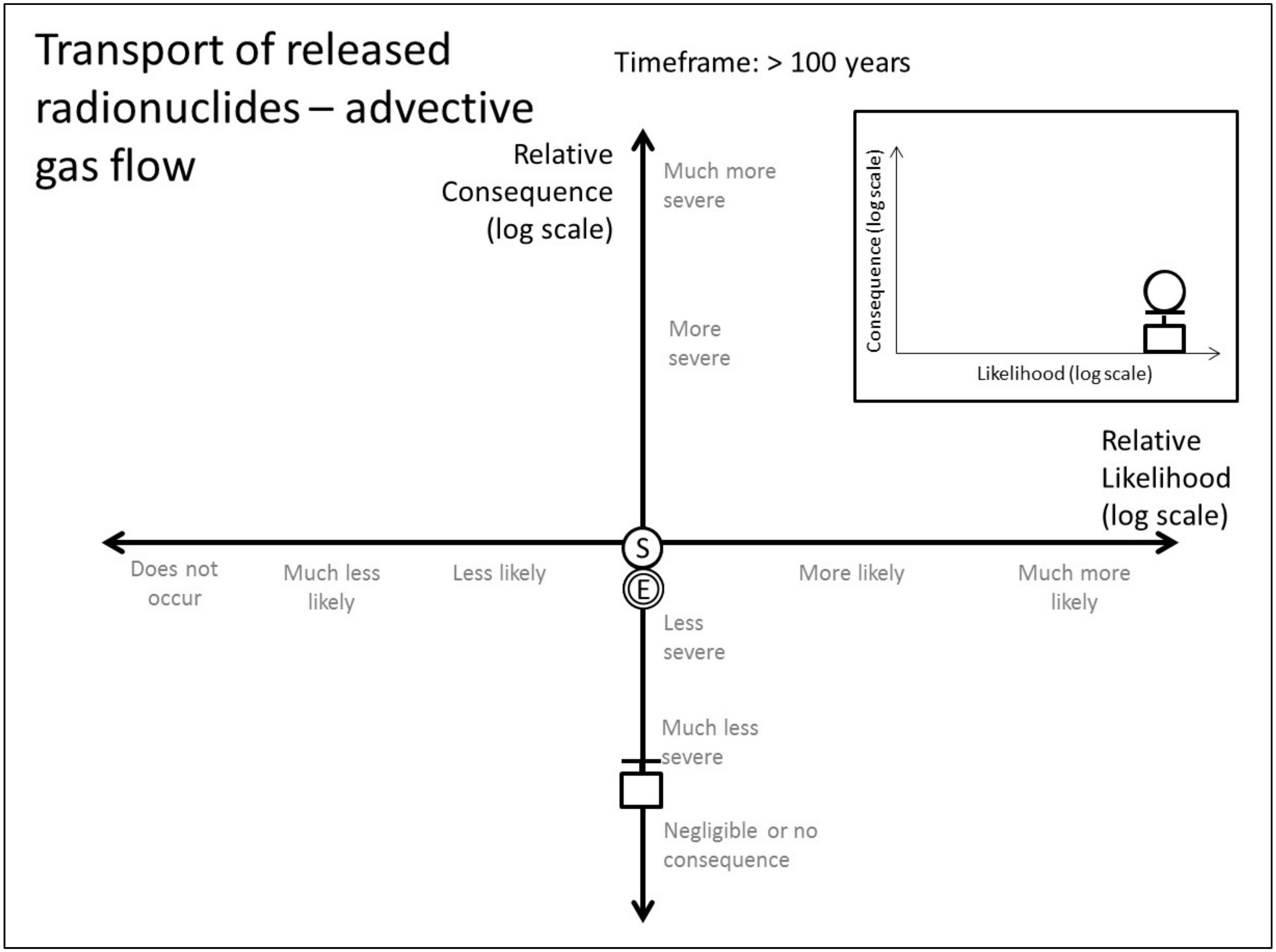


Figure 12. Relative and absolute risk diagrams for transport of released nucleotides – advective gas flow (>100 years).

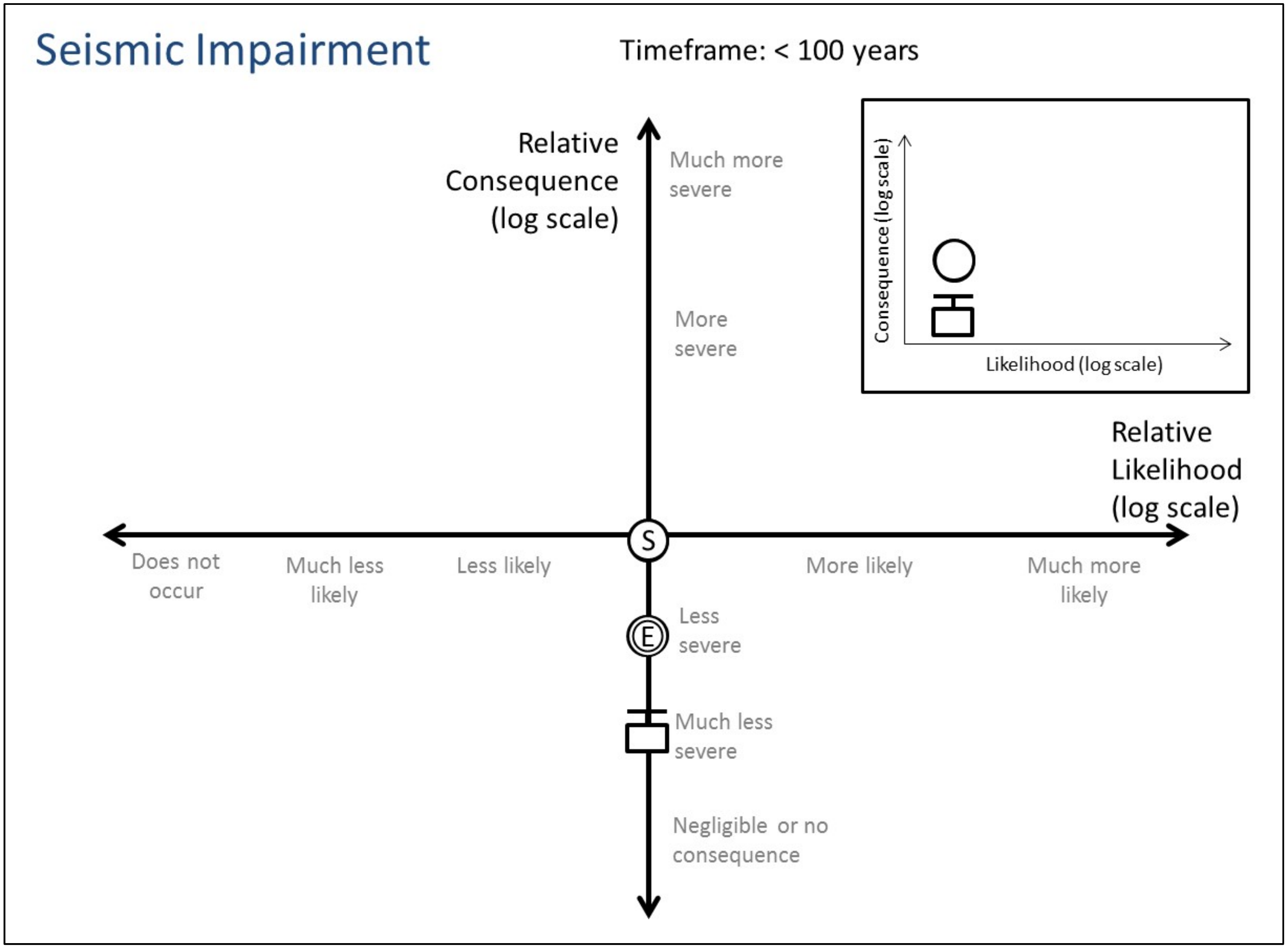


Figure 13. Relative and absolute risk diagrams for seismic impairment (first 100 years).

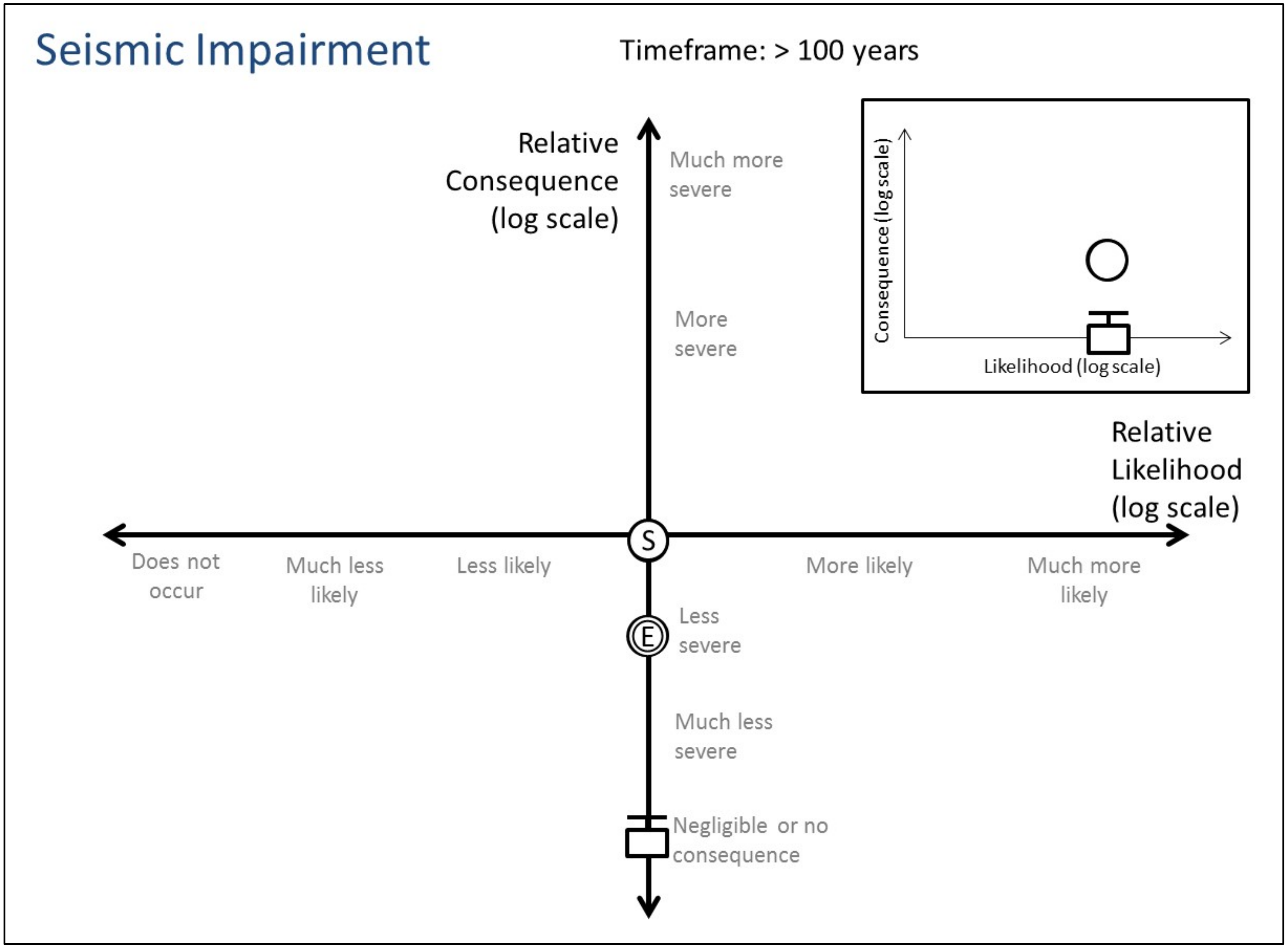


Figure 14. Relative and absolute risk diagrams for seismic impairment (>100 years).

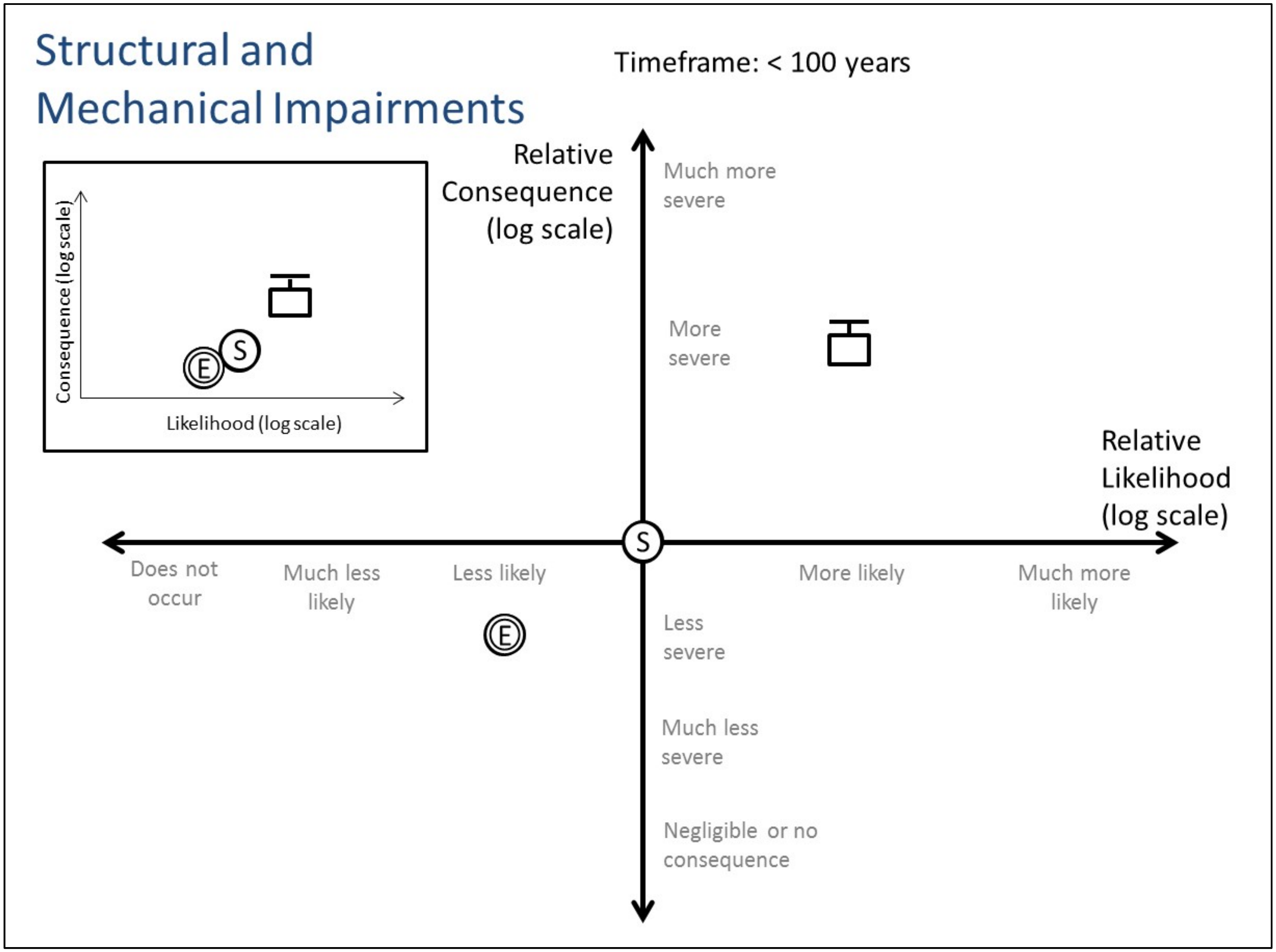


Figure 15. Relative and absolute risk diagrams for structural and mechanical impairments (first 100 years).

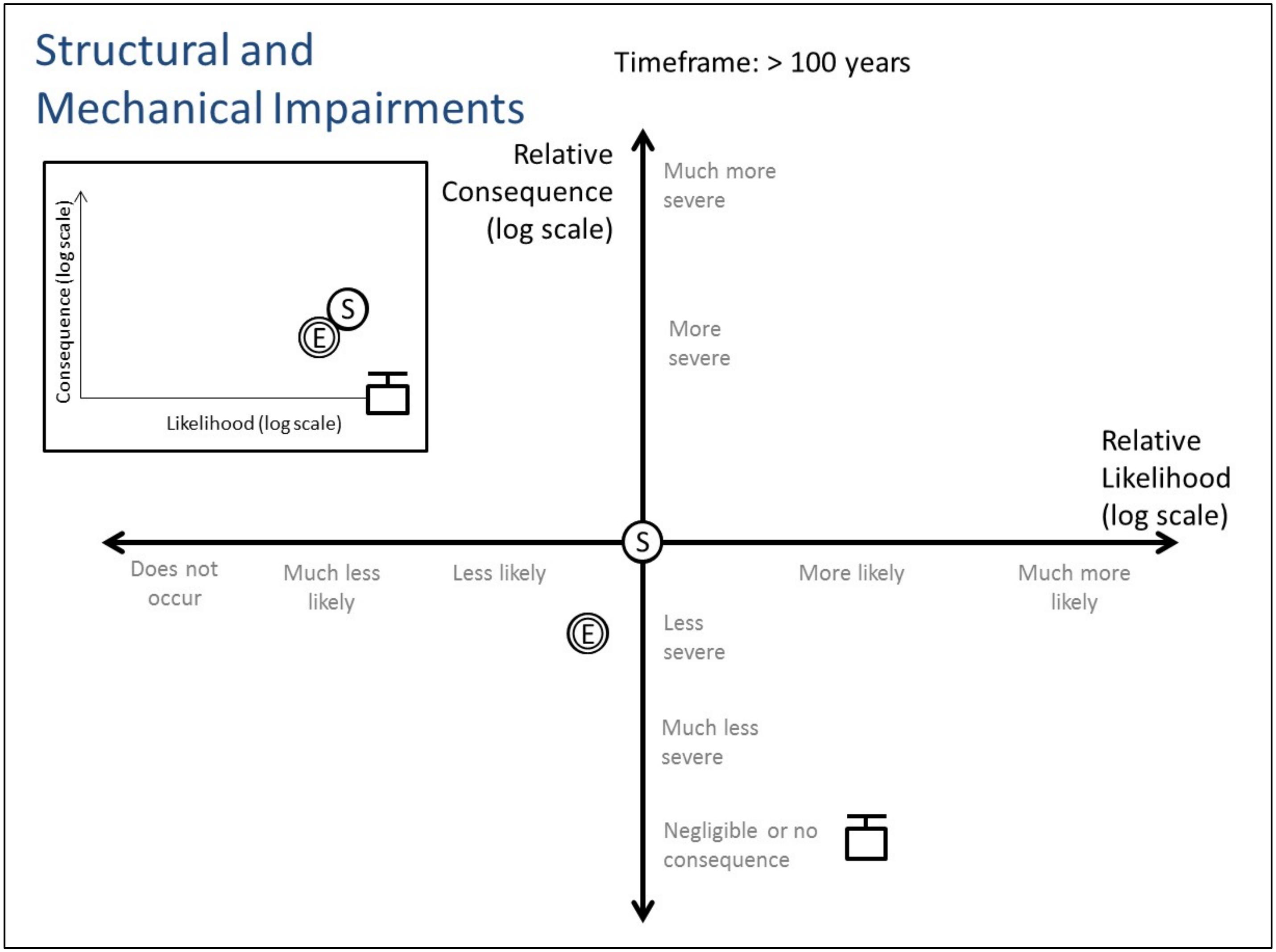


Figure 16. Relative and absolute risk diagrams for structural and mechanical impairments (>100 years).

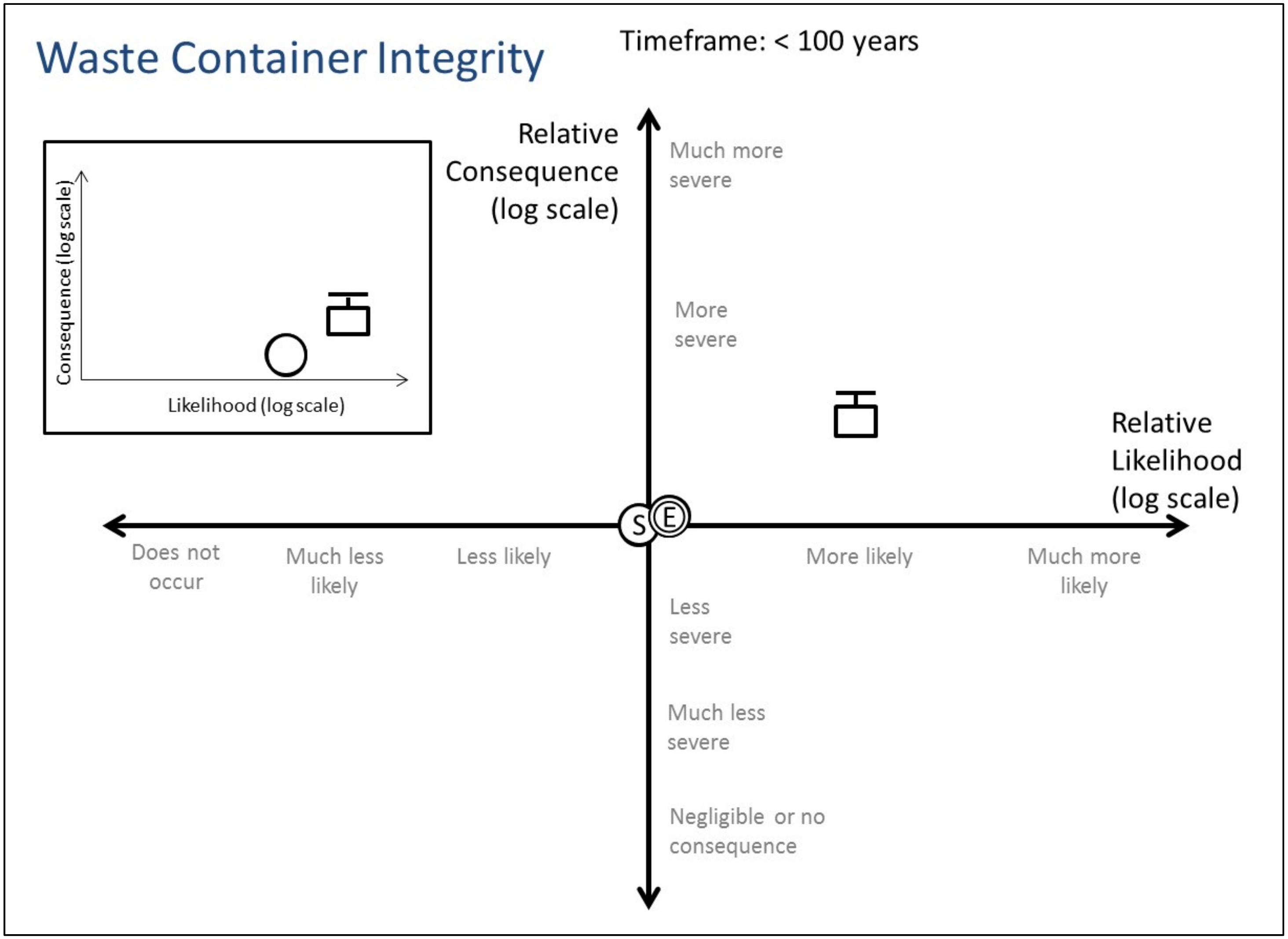


Figure 17. Relative and absolute risk diagrams for waste container integrity (first 100 years).

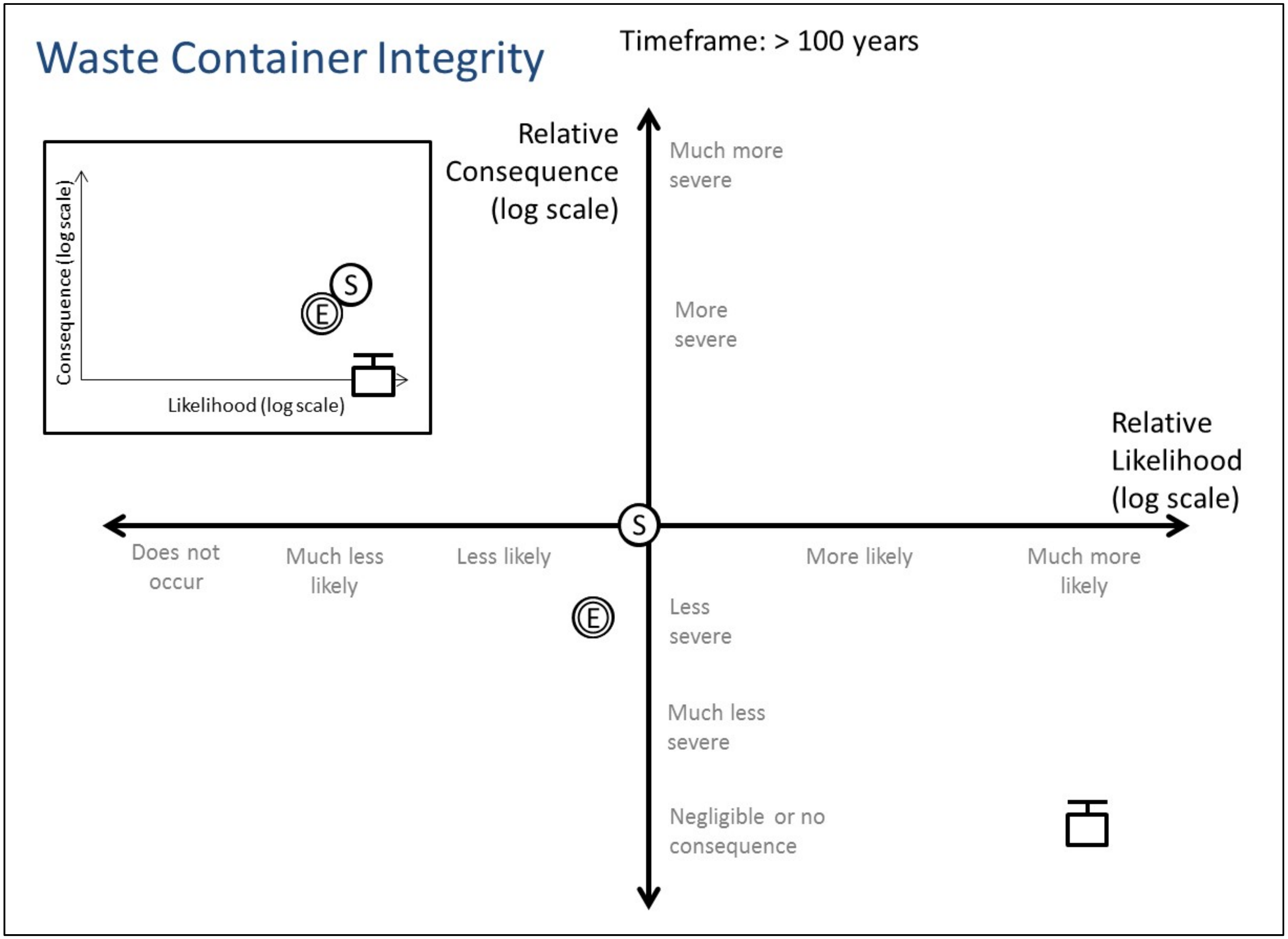


Figure 18 Relative and absolute risk diagrams for waste container integrity (>100 years).

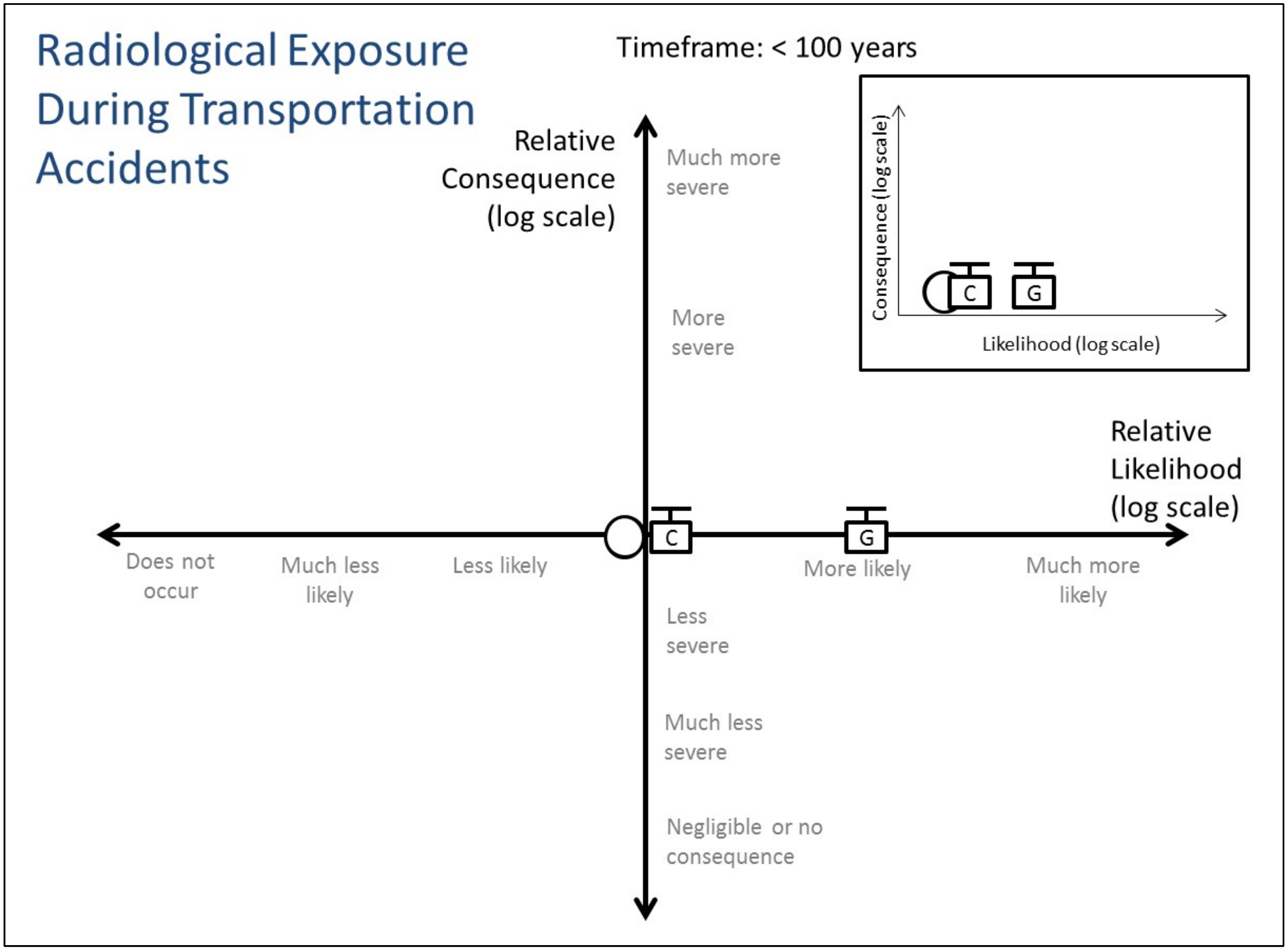


Figure 19. Relative and absolute risk diagrams for radiological exposure during transportation accidents (first 100 years).

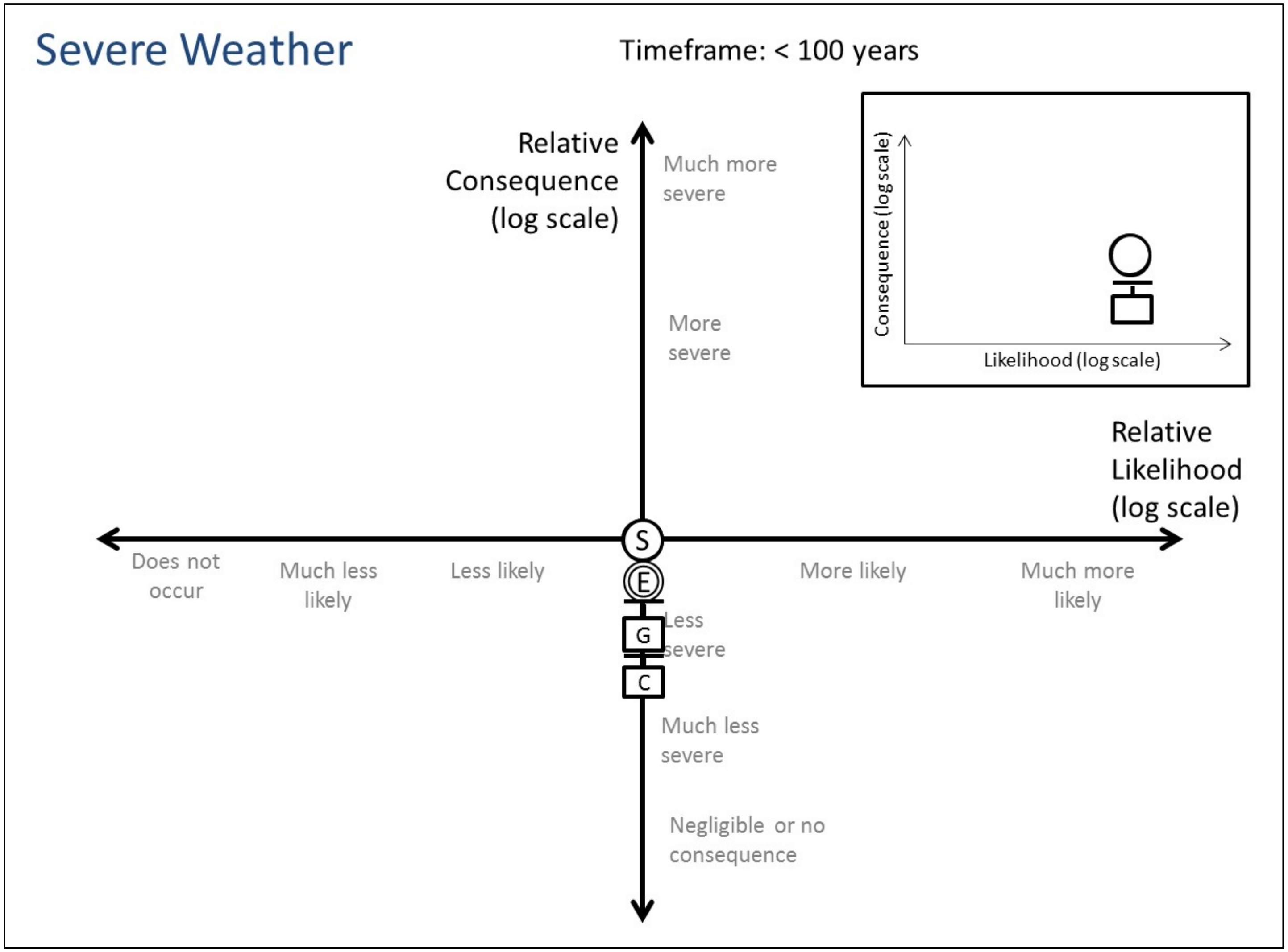


Figure 20. Relative and absolute risk diagrams for severe weather (first 100 years).

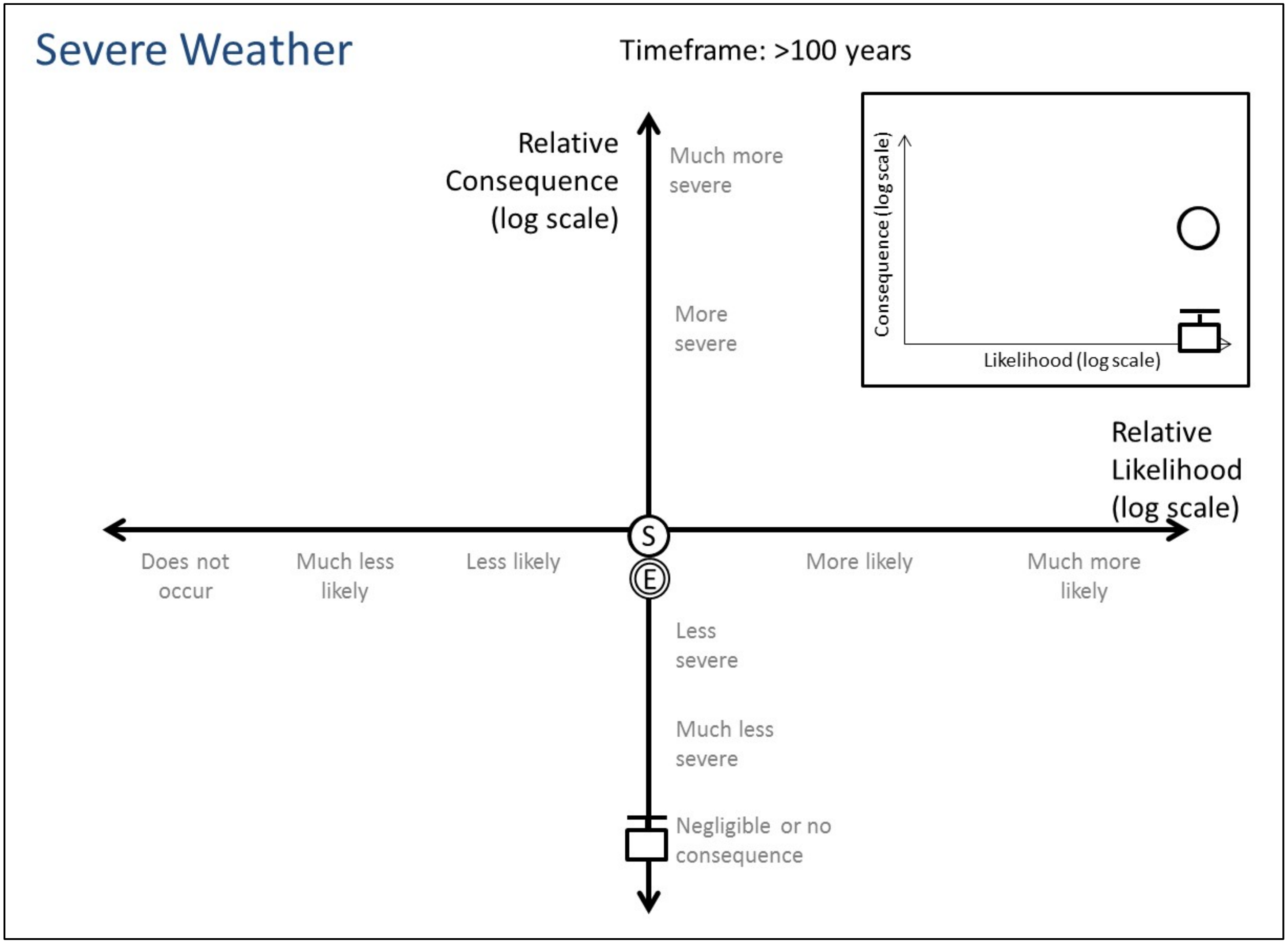


Figure 21. Relative and absolute risk diagrams for severe weather (>100 years).

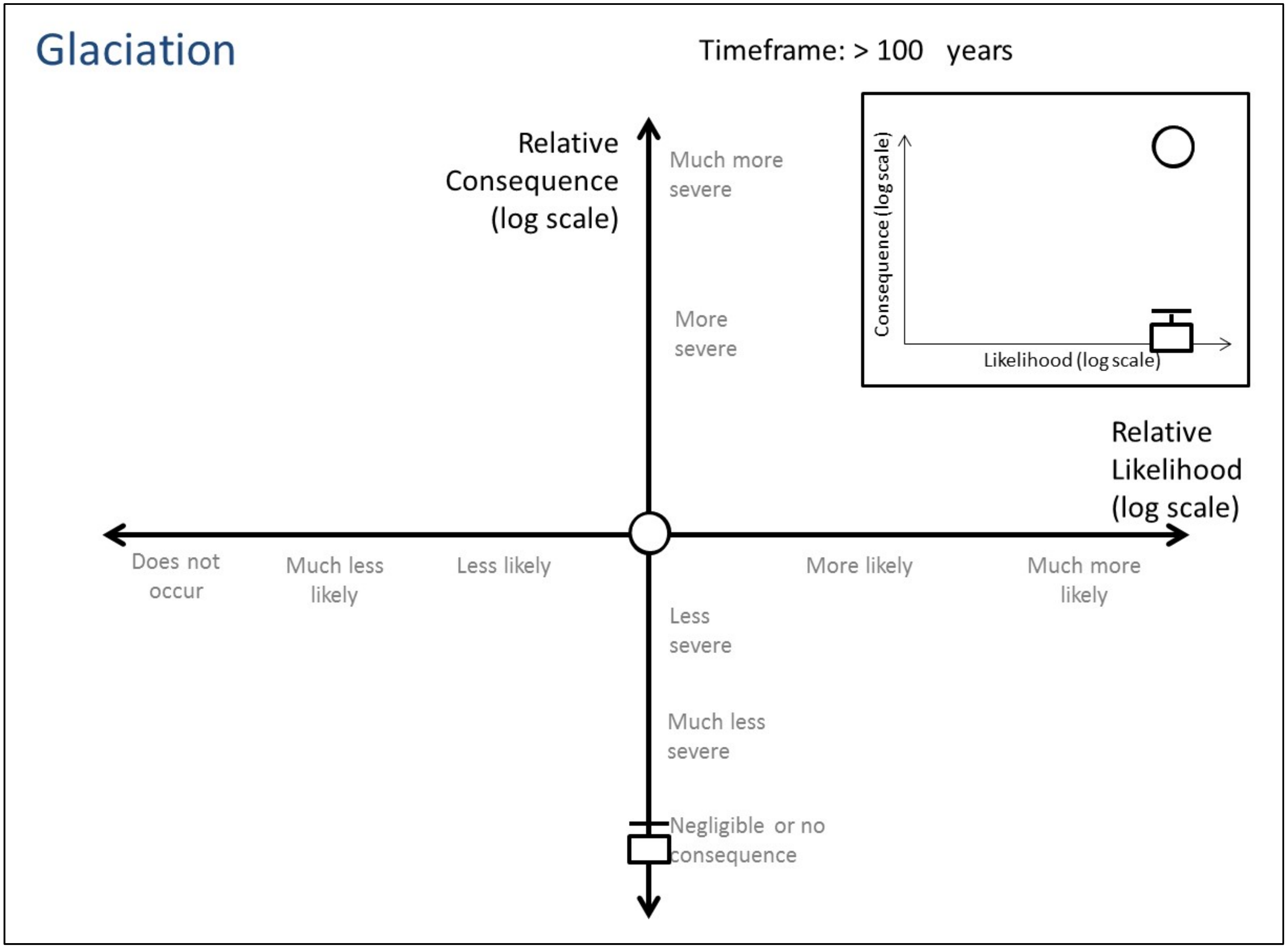


Figure 22. Relative and absolute risk diagrams for glaciation (>100 years).

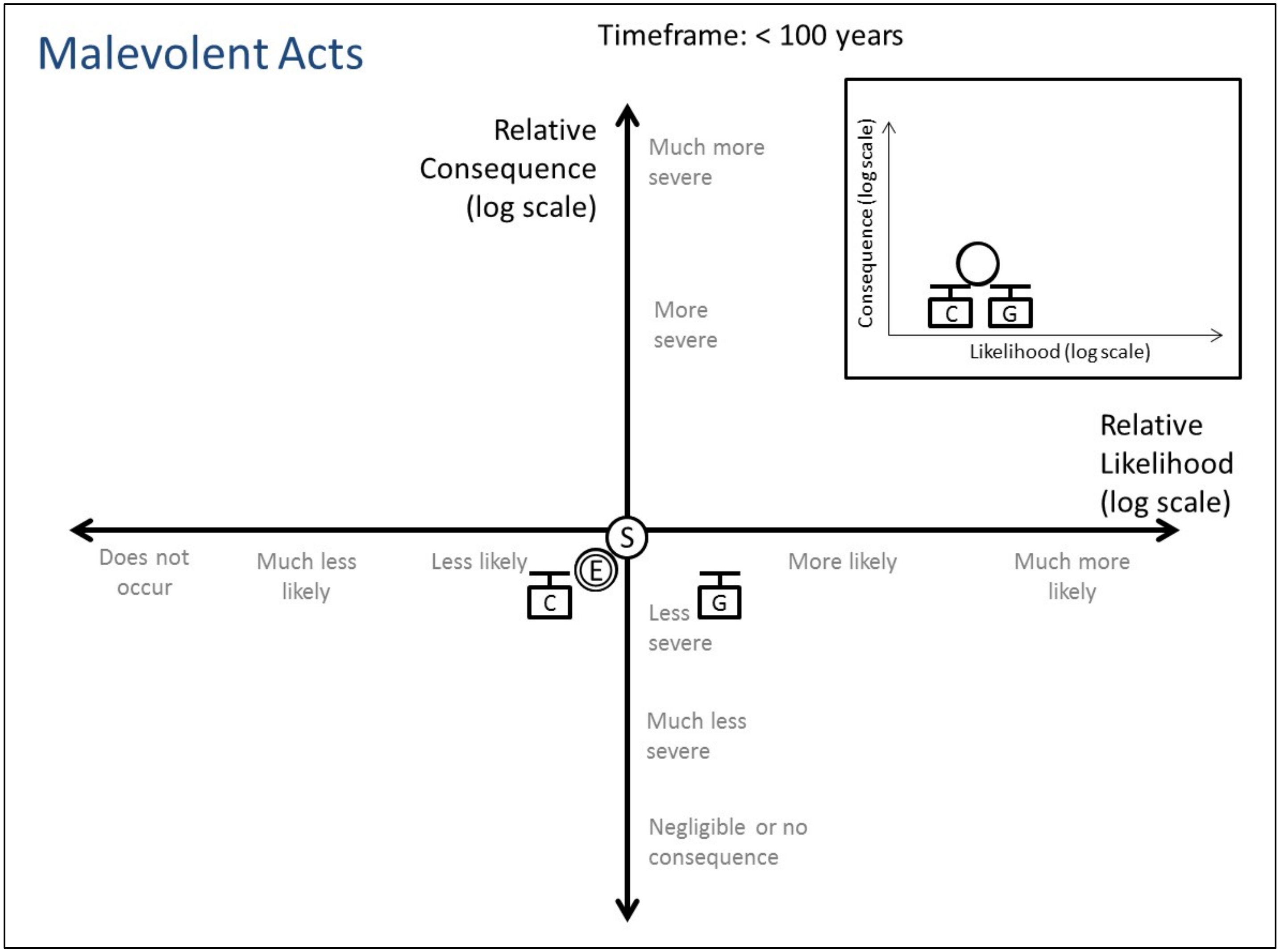


Figure 23. Relative and absolute risk diagrams for malevolent acts (first 100 years).

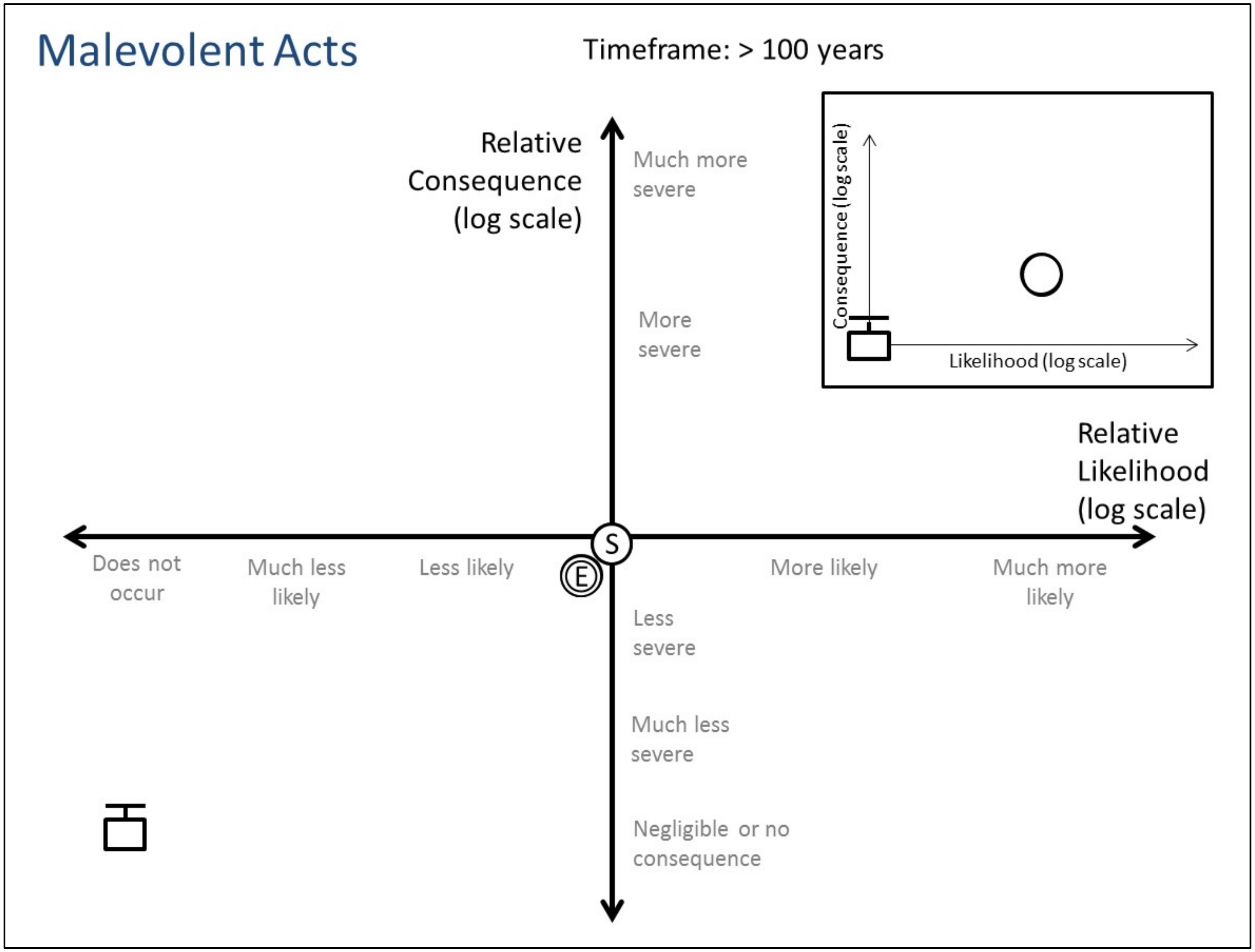


Figure 24. Relative and absolute risk diagrams for malevolent acts (>100 years).

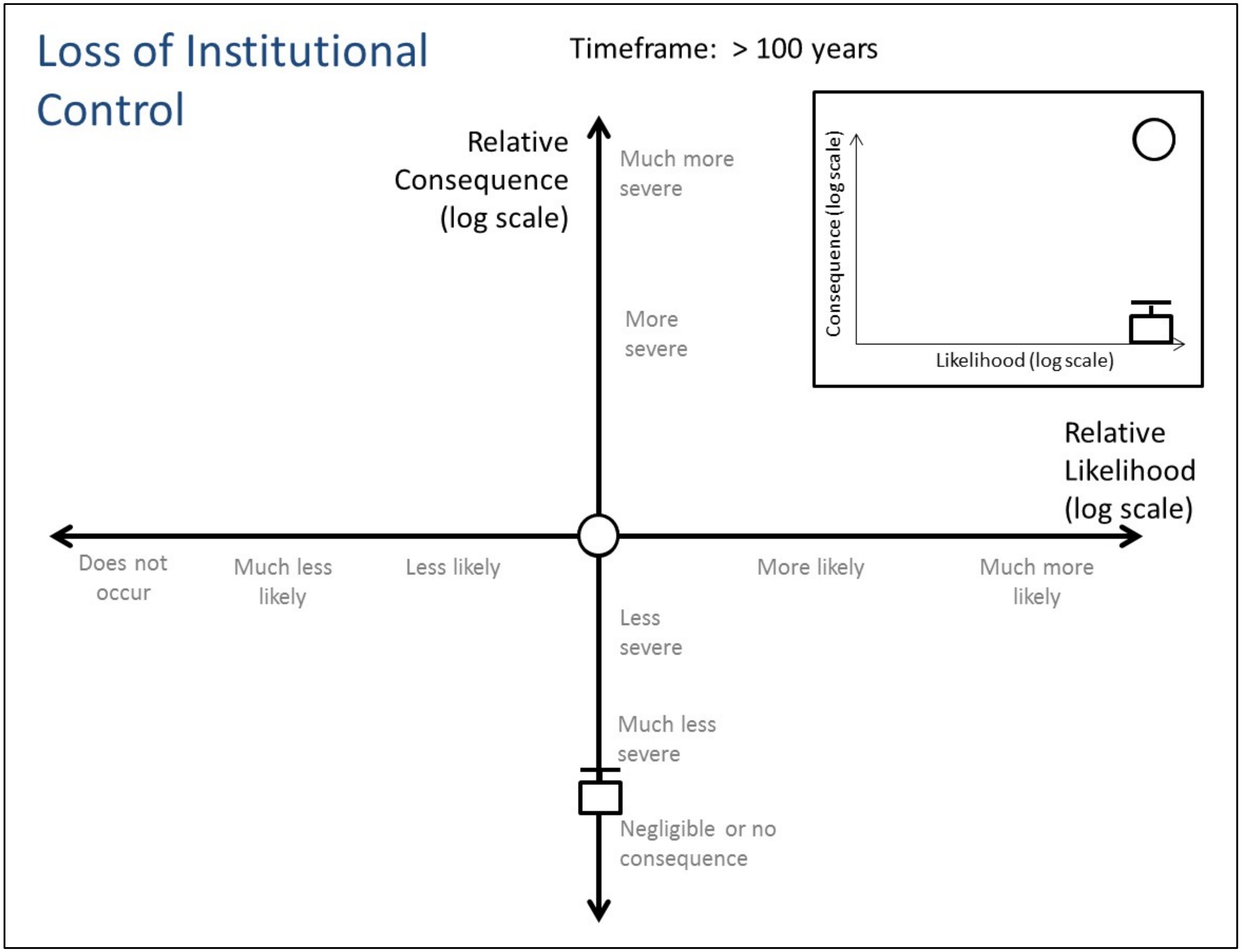


Figure 25. Relative and absolute risk diagrams for loss of institutional control (>100 years).

ATTACHMENTS

TO

OPG RESPONSE TO IR-EIS-13-514

ATTACHMENT A

TO

OPG RESPONSE TO IR-EIS-13-514

POSTCLOSURE SAFETY IMPLICATIONS OF REVISED PRESSURE TUBE INVENTORIES

CONTENTS

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LIST OF FIGURES

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 Nuclear Waste Management Organization, on behalf of OPG, has prepared the Environmental Impact Statement (EIS) (OPG 2011a) and Preliminary Safety Report (PSR) (OPG 2011b) for the proposed repository. The EIS and PSR and supporting documentation were submitted for regulatory review in April 2011, as part of the application for a site preparation and construction licence.

The supporting documentation included a postclosure safety assessment (the “2011 PostSA”) of the long-term safety of the proposed facility undertaken by Quintessa and its subcontractors, Geofirma Engineering Limited and SENES Consultants Limited (Quintessa et al. 2011).

The safety assessment was conducted based on the projected final DGR inventory presented in OPG's 2010 Reference Inventory report (OPG 2010). Some of the inventory projections were based on estimates. An ongoing OPG waste characterization programme was underway to reduce uncertainties in these estimates. A revised inventory is planned to be prepared in support of the future application for an operating licence.

During the review process of the current Preliminary Safety Report, the estimates for the inventories of some radionuclides in pressure tube wastes have been specifically identified as significantly underestimated. The Joint Review Panel has issued an information request (EIS 13-514) asking for “the results and evaluations of the re-runs of postclosure safety assessment models at a similar level of detail and clarity as that provided in NWMO DGR-TR-2011-25 Postclosure Safety Assessment”.

The current Technical Memorandum addresses this request.

Rather than reproduce the entire content of the Postclosure Safety Assessment report (Quintessa et al. 2011), this memorandum focuses on the changes made, in particular:

- modifications to the inventory (Section 2);
- modifications to the models (Section 3);
- results and analysis (Section 4); and
- conclusions (Section 5).

All other aspects of the 2011 PostSA, such as the repository, geosphere and biosphere descriptions and the scenarios assessed, are not modified by the changes to the pressure tubes inventory and so are not replicated in the main body of this memorandum. This approach allows the impact of the revised pressure tubes inventory on the postclosure safety assessment to be evaluated in a clear and concise manner.

2. MODIFICATIONS TO THE INVENTORY OF RADIONUCLIDES IN THE PRESSURE TUBES

Pressure tubes from reactor mid-life retubing are one of more than 20 waste types considered in the reference inventory. The 2010 Reference Inventory report (OPG 2010) recognized that some radionuclides with pressure tubes would be present as a result of surface deposition from coolant, and included an estimate of this contribution.

Based on actual pressure tube data, and including the inventory of garter springs which are disposed along with pressure tubes, some radionuclides have been identified as being underestimated in the reference inventory. These are being addressed in the ongoing waste characterization programme, and revised inventory values will be used in future updates to the reference inventory. However, in this Technical Memorandum, the specific effects of these changes in radionuclide inventories on the 2011 postclosure safety assessment are presented.

The revised inventory data for the pressure tubes are provided in Table 1, including garter springs. These are interim values based on recent analysis. A more complete revision including current measurement programmes would be used as part of a future safety case update, in particular in support of an operating licence.

Table 1 also provides the revised total inventory for each radionuclide (summed over all waste streams) compared with that considered in the 2011 PostSA, and the ratio of the revised total inventory to the 2011 PostSA total inventory.

Note that the pressure tubes are not a key contributor to the total DGR inventory for many radionuclides; consequently Table 1 shows that the total DGR inventory is only increased by more than 10% for Ni-59, Ni-63, Cs-137 and Cm-244.

Table 1: Reference and Revised Inventory Data at 2062 (Assumed DGR Closure)

Radionuclide	Inventory in Pressure Tubes and Garter Springs (Bq)		Total Inventory in the DGR (Bq)		
	2011 PostSA Inventory	Revised Inventory	2011 PostSA Inventory	Revised Inventory	Revised to Reference Ratio
H-3	2.4E+11	7.8E+13	1.0E+15	1.1E+15	1.1
Cl-36	1.3E+12	1.3E+12	1.4E+12	1.4E+12	1.0
Mn-54	3.6E-01	3.1E-01	2.7E+02	2.7E+02	1.0
Fe-55	3.2E+11	3.6E+11	5.5E+13	5.5E+13	1.0
Co-60	9.3E+12	5.0E+13	9.0E+14	9.4E+14	1.0
Ni-59	2.7E+11	1.7E+13	3.6E+13	5.3E+13	1.5
Ni-63	7.5E+13	4.8E+15	3.9E+15	8.6E+15	2.2
Zr-93	1.5E+14	1.5E+14	2.1E+14	2.1E+14	1.0
Nb-94	4.6E+15	4.6E+15	4.6E+15	4.6E+15	1.0
Sb-125	1.2E+09	4.5E+09	5.7E+11	5.7E+11	1.0
Cs-134	1.5E+06	4.4E+06	3.1E+10	3.1E+10	1.0
Cs-137	6.6E+09	1.5E+13	1.1E+14	1.2E+14	1.1
U-235	2.1E+05	3.1E+05	2.3E+07	2.3E+07	1.0
U-238	1.7E+07	7.8E+07	6.0E+09	6.1E+09	1.0
Pu-238	4.6E+09	3.1E+10	5.0E+11	5.3E+11	1.1
Pu-239	8.3E+09	1.0E+10	9.2E+11	9.2E+11	1.0
Pu-240	1.1E+10	1.7E+10	1.3E+12	1.3E+12	1.0
Am-241	1.4E+10	6.9E+10	2.4E+12	2.4E+12	1.0
Cm-244	0.0E+00	1.9E+12	2.9E+11	2.2E+12	7.5
All others [a]	5.8E+14	5.8E+14	6.2E+15	6.3E+15	1

Notes:
[a] Inventory for all other radionuclides in the pressure tubes in unchanged from Table 3.16 of Quintessa and Geofirma (2011a).

Of the radionuclides listed, Mn-54, Fe-55, Co-60, Sb-125 and Cs-134 were screened out for consideration in the 2011 postclosure safety assessment by the calculations presented in Appendix A of Quintessa and Geofirma (2011a), primarily due to their short half-lives (all about 5 years or less). The revised total radionuclide inventory for these radionuclides changes very little (less than 5%) in comparison to the 2011 PostSA, so these radionuclides are also not included in the calculations presented below.

3. MODIFICATIONS TO THE MODELS

The 2011 PostSA models were implemented in three software codes.

- Assessment-level (system) models were implemented in AMBER, which is a compartment-model code that represents radioactive decay, package degradation, radionuclide transport through the repository, geosphere and surface environment, and evaluates the associated potential impacts such as dose. AMBER calculations were undertaken for both the Normal Evolution Scenario (Quintessa 2011) and Disruptive Scenarios (Quintessa and SENES 2011). They drew directly on detailed groundwater and gas modelling calculations undertaken with the following codes.

- Detailed groundwater flow and transport calculations were implemented in the 3-D finite element/finite-difference code FRAC3DVS-OPG (Geofirma 2011).

- Detailed gas generation and transport calculations were implemented in T2GGM (Geofirma and Quintessa 2011), a code that couples the Gas Generation Model (GGM) and TOUGH2 (Quintessa and Geofirma 2011b). GGM is a project-specific code that was used to model the generation of gas within the DGR due to corrosion and microbial degradation of the metals and organics present. TOUGH2 modelled the subsequent two phase transport of gas through the repository and geosphere.

The FRAC3DVS-OPG and T2GGM calculations are unaffected by the modifications to the inventory information. FRAC3DVS-OPG was primarily used for groundwater flow calculations, and radionuclide transport calculations were only undertaken for Cl-36 as this is an important radionuclide for groundwater transport but which is unaffected by the revised pressure tubes inventory. T2GGM calculations did not consider radionuclide transport; their focus was on the calculation of repository gas pressures and bulk gas transport. There is therefore no need to re-run any of the detailed groundwater and gas model calculations that support the 2011 PostSA.

The revised pressure tubes inventory has been introduced into the AMBER model for the 2011 PostSA so that results can be compared for all the AMBER calculation cases considered in the 2011 PostSA.

The pressure tubes inventory is represented in the AMBER model as being present within the metal of the pressure tubes. In the 2011 PostSA, radioactivity in the pressure tubes was released based on the corrosion rate for zirconium alloys of 10^{-8} m/a under anaerobic saline conditions[1] and a metal thickness of 5 mm (described as a “congruent release” model).

The revised inventory for some radionuclides associated with the pressure tubes will be present as surface (or near-surface) contamination. Other radionuclides will be present as activation products within the matrix of the metal. To reflect potential for surface contamination to be more-readily released, the model for pressure tubes has been adapted to use an instant release model for the following radionuclides: Ni-59, Ni-63, Cs-137, U-235, U-238, Cm-244 and for the plutonium and americium radioisotopes. The release model for all other radionuclides in the pressure tubes remains the same as used in the 2011 PostSA.

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[1] Table 3.20 of Quintessa and Geofirma (2011a).

These changes have been made to the inventory and waste thickness parameters in the AMBER model for the near field and geosphere.[2] The calculations have been undertaken in AMBER 5.7.1[3].

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[2] AMBER case files AMBER_V2_NF&GEOv1.01_pt.cse and AMBER_V2_BIOv1.01.cse

[3] AMBER 5.7.1 is the latest version of the AMBER software, released December 2013. AMBER 5.3 was used for the original 2011 PostSA calculations in 2011. To demonstrate that the software developments in the intervening time have not significantly affected the calculated results, the 2011 PostSA case files have been re-run with AMBER 5.7.1 and the results are in agreement.

4. RESULTS AND ANALYSIS

A summary of the calculation cases and a comparison of revised calculations against the 2011 PostSA results are presented in Section 4.1. Further information and a greater degree of detail is then presented for a sub-set of key calculation cases for the Normal Evolution Scenario, Human Intrusion Scenario and Severe Shaft Seal Failure Scenario in Sections 4.2, 4.3 and 4.4, respectively.

4.1 OVERVIEW OF RESULTS FOR ALL CALCULATION CASES

All of the AMBER cases for radionuclide release and migration, and potential exposure[4] considered in the 2011 PostSA have been re-run with the revised pressure tubes inventory and release model. For convenience, Table 2 and Table 3 provide summaries of each of the calculation cases for the Normal Evolution Scenario and for the Disruptive Scenarios, respectively.

Table 2: Assessment Modelling Cases for the Normal Evolution Scenario

Case ID	Case Description
NE-RC-A*	Reference Case parameters based on inventory, original preliminary design and site characterization data. Based on detailed groundwater and gas modelling reference cases. Considers: • instantaneous and congruent contaminant release; • source terms with release for certain radionuclides (e.g., C-14) partitioned between gas and groundwater; • no sorption or solubility limitation in repository (except for carbon solubility limitation); • gas generation and gradual repository resaturation; • no consumption (or production) of water by corrosion and degradation reactions; • 10 m rockfall at closure; • sorption of limited number of contaminants in shaft and geosphere; • steady state Cambrian overpressure (+165 m); • initial Ordovician underpressures with subsequent transient evolution towards equilibrium; • initial gas saturations of 10% in the Ordovician; • no salinity profile in the geosphere; • no horizontal groundwater flow in the Cambrian, Guelph or Salina A1 upper carbonate; • no explicit representation of glacial cycling; • self-sufficient farming family.

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[4] The inventory of non-radioactive contaminants in the DGR is unchanged by the revised pressure tube inventory, therefore calculations for non-radioactive contaminants did not need to be re-run. Note that probabilistic calculations were undertaken for Cl-36 and I-129 in the PostSA (NE-PC-A); however, the inventory for these radionuclides is unaffected by the changes to the pressure tube inventory. Therefore the case did not need to be re-run.

Case ID	Case Description
NE-PD-RC-A	As NE-RC-A but adopting the final preliminary design, including: • additional ventilation drifts; and • ILW filters & elements, irradiated core components, and IX columns disposed to ILW shield containers rather than concrete arrays.
NE-SBC-A*	As NE-RC-A but with: • no underpressures in the Ordovician; and • no initial gas saturation in the Ordovician.
NE-RS-A	As NE-RC-A but with: • immediate water resaturation of repository (including shaft); and • no gas generation in repository.
NE-EDZ1-A	As NE-SBC-A but with excavation damaged zone (EDZ) hydraulic conductivities increased to maximum values in the Data report, i.e.: • shaft inner EDZ increased by two orders of magnitude (i.e., four orders of magnitude greater than rock mass); • shaft outer EDZ increased by an order of magnitude (i.e., two orders of magnitude greater than rock mass); and • repository EDZ increased by an order of magnitude, (i.e., four orders of magnitude greater than rock mass).
NE-HG-A	As NE-SBC-A but with: • horizontal groundwater flow in the Guelph (gradient of 0. 0026) and Salina A1 upper carbonate formations (gradient of 0.0077); and • 1.25 km travel path along Guelph and Salina A1 upper carbonate to lake.
NE-GT5-A	As NE-GG1-A but with: • asphalt seal in shaft replaced by bentonite/sand; • gas entry pressure for shaft materials reduced by factor of two to 5×10^6 Pa; and • bentonite/sand hydraulic conductivity increased by an order of magnitude to 10^{-10} m/s.
NE-PD-GT5-A	As NE-GT5-A but with final preliminary design (as for NE-PD-RC-A).
NE-BF-A	As NE-SBC-A but with repository backfilled with coarse aggregate material with a porosity of 0.3.
NE-GG1-A	As NE-SBC-A but with: • increased metal inventory (~ 25% increase); and • corrosion and organic degradation rates increased to maximum rates in the Data report (up to an order of magnitude increase).
NE-GG2-A	As NE-SBC-A but with organic degradation rates decreased to minimum rates in the Data report (by up to an order of magnitude decrease)
NE-NM-A	As NE-SBC-A but with no methanogenic reactions, which includes both methane generation from organic degradation and also the conversion of H_2 and CO_2 to CH_4.

Case ID	Case Description
NE-RT1-A	As NE-RC-A but with: • immediate water resaturation of repository; • no gas generation in repository; • instantaneous release of radionuclides to repository water; and • no radionuclides sorbed or solubility limited in repository or geosphere.
NE-RT2-A	As NE-SBC-A but with: • immediate water resaturation of repository; • no gas generation in repository; • instantaneous release of radionuclides to repository water; and • no radionuclides sorbed or solubility limited in repository or geosphere.
NE-IV-A	As NE-RC-A but with radionuclide inventory increased by a factor of ten.
NE-ER-A	As NE-RC-A but with removal of 100 m of geosphere due to erosion over 1 million years.
NE-CC-A	As NE-RC-A but with alternative constant state biosphere (i.e., tundra rather than temperate).
NE-CG-A	As NE-HG-A but with dose to a Site Shore Resident Group and a Downstream Resident Group exposed via consumption of lake fish and water from the near shore and the South Basin of Lake Huron, respectively.

Notes: Based on Table B.1 of Quintessa et al. (2011). ‘A’ in the case ID indicates that an AMBER calculation was included in the 2011 PostSA. Refer to the original report for further details.
* A version of this case was also run using gas flow information from the T2GGM water-limited version that accounts for the effect of the consumption (or production) of water by corrosion and degradation reactions.

Table 3: Assessment Modelling Cases for the Disruptive Scenarios

Case ID	Case Description
HI-BC-A	As NE-RC-A but with: • exploration borehole drilled from surface down into Panel 1 at some time after controls are no longer effective (i.e., 300 years); • borehole terminated at repository depth; • repository largely unsaturated; • short-term surface release of contaminated gas immediately following intrusion; and • retrieval of contaminated drill core.
HI-GR2-A	As NE-RC-A but with: • exploration borehole drilled from surface down into Panel 1 at some time after controls are no longer effective (i.e., 300 years); • borehole penetrates down to the pressurized Cambrian; • repository rapidly resaturated; • borehole poorly sealed resulting in a hydraulic conductivity of 10^{-4} m/s and porosity of 0.25; and • long-term release of radionuclides in water from the repository to the Shallow Bedrock Groundwater Zone.
SF-BC-A	As NE-RC-A but with: • hydraulic conductivity of 10^{-9} m/s for bentonite/sand, asphalt and concrete in shafts; • porosity of 0.3 for bentonite/sand, asphalt and concrete in shafts; • effective diffusion coefficient of 3×10^{-10} m^2/s for bentonite/sand, asphalt and concrete in shafts; • sorption values for bentonite/sand given in the Data report reduced by an order of magnitude; • zero capillary pressure for shaft sealing material; and • repository and shaft EDZ hydraulic conductivity increased to maximum values in the Data report.
SF-ED-A	As SF-BC-A but increased bentonite/sand, asphalt and concrete hydraulic conductivity (10^{-7} m/s) in order to understand the sensitivity of system performance to shaft seal properties. This is in the range of a fine sand/silt material, about 4-5 orders of magnitude more permeable than the design-basis bentonite/sand and asphalt seals.
BH-BC-A	As NE-RS-A but with: • poorly sealed site investigation/monitoring borehole from surface down to Precambrian located 100 m from the southeast edge of Panel 2; • hydraulic conductivity of 10^{-4} m/s for borehole seal; • porosity of 0.25 for borehole seal; and • no sorption on borehole seal.
VF-BC-A	As NE-RS-A but with a hypothetical transmissive vertical fault: • 500 m northwest of the repository; • from Cambrian to Guelph; • width of 1 m; • hydraulic conductivity of 10^{-8} m/s;

Case ID	Case Description
	• porosity of 0.1; and • no sorption in fault. In addition: • horizontal groundwater flow in the Cambrian (gradient of 0.0031), the Guelph (gradient of 0.0026) and Salina A1 upper carbonate formations (gradient of 0.0077); and • ~1 km travel path along Guelph from fault to lake.
VF-AL-A	As for the VF-BC-A case but with hypothetical transmissive vertical fault 100 m southeast of the repository.

Note: Based on Table B.2 of Quintessa et al. (2011). 'A' in the case ID indicates that an AMBER calculation was included in the 2011 PostSA. Refer to the original report for further details.

The maximum calculated effective doses for all of the calculation cases that have been re-run are summarized in Table 4 and Table 5 and compared against the 2011 PostSA results. The results for the Normal Evolution Scenario calculation cases are presented in Figure 1 and those for the base case Disruptive Scenarios in Figure 2. Note that the calculated doses within the shaded range of Figure 1 and Figure 2 are negligible and the magnitude of the values within this area is illustrative.

Table 4 and Table 5 demonstrate that the maximum calculated effective dose is relatively unaffected by the revised inventory for all of the calculation cases. This is principally because the inventories for key radionuclides contributing to the maximum calculated dose are unchanged. The tables show the key contributing radionuclides to the maximum calculated effective dose in each calculation case. The tables demonstrate that none of the radionuclides with increased inventories in Table 1 are the main contributors to the maximum calculated dose in any of the calculation cases. Ra-226 and its progeny are important to three calculation cases; these are from in-growth from U-238 and Pu-238 which are listed in Table 1, however, the total inventories for these radionuclides are increased by less than 10%.

In addition to the increased inventory for some radionuclides, the model for radionuclide release from the pressure tubes has also been changed; the revised model explicitly represents some of the radionuclides as being present as surface contamination on the pressure tubes, such that the inventory for these radionuclides is released more quickly (Section 3). Table 4 and Table 5 demonstrate that these changes, combined with the changes in the inventory for some radionuclides in the pressure tube waste stream, only have a small effect on the maximum calculated doses; the changes are small enough to not be discernible in Figure 1 and Figure 2.

Table 4: Maximum Calculated Dose to Adults for the Normal Evolution Scenario Calculation Cases

Basis	Case ID	Brief Description	Max. Calculated Dose (mSv/a)		Difference	Key radionuclide(s)
			2011	Revised		
Reference Case	NE-RC	Reference Case	1.5E-15	1.5E-15	+0.28%	I-129
	NE-PD-RC	Reference Case, final preliminary design	1.8E-15	1.8E-15	+0.22%	I-129
	NE-RC (WL)	Reference Case, water limited	4.1E-16	4.1E-16	+0.31%	I-129
	NE-CC	Tundra climate state	7.1E-15	7.1E-15	+0.32%	I-129
	NE-ER	100 m surface erosion	1.3E-13	1.3E-13	+0.28%	I-129
	NE-IV	Increased inventory	1.5E-14	1.5E-14	+0.29%	I-129
	NE-RS	Instant resaturation, no gas generation	4.0E-14	4.3E-14	+7.5%	I-129
	NE-RT1	Instant resat. & release, no sorption, no gas gen.	4.2E-09	4.3E-09	+1.1%	Ra-226 chain
Simplified Base Case	NE-SBC	Simplified Base Case	9.8E-14	9.9E-14	+0.64%	I-129
	NE-SBC (WL)	Simplified Base Case, water limited	6.2E-14	6.3E-14	+0.50%	I-129
	NE-EDZ1	Increased permeability of shaft and repository EDZs	1.9E-11	2.0E-11	+3.1%	Cl-36
	NE-EG	Alternative critical groups	6.1E-16	6.3E-16	+3.8%	I-129/Ra-226 chain
	NE-HG	Horizontal g/w flow in Guelph and Salina A1 upper carbonate	4.5E-16	4.6E-16	+1.2%	I-129
	NE-RT2	Instant resat. & release, no sorption, no gas gen.	4.5E-09	4.7E-09	+2.7%	Ra-226 chain
	NE-NM	No methanogenic gas reactions	5.1E-14	5.1E-14	+0.0%	C-14
	NE-GG1	Increased gas generation rates	9.3E-11	9.3E-11	+0.0%	C-14
	NE-GG2	Decreased degradation rates	9.5E-14	9.5E-14	+0.52%	I-129
	NE-GT5	Increased gas gen. & reduced shaft seal performance	4.9E-07	4.9E-07	+0.0%	C-14
	NE-PD-GT5	Increased gas gen. & reduced shaft seal perf., final prelim. design	2.7E-07	2.7E-07	+0.0%	C-14

Note that the results are presented to two significant figures to aid comparison. The degree of uncertainty associated with postclosure safety assessments of this nature means that it is ordinarily appropriate to present results rounded to one significant figure to avoid an undue implication of precision.

Table 5: Maximum Calculated Dose to Adults for the Disruptive Scenario Calculation Cases

Case ID	Brief Description	Max. Calculated Dose (mSv/a)		Difference	Key radionuclide(s)
		2011	Revised		
HI-BC	Human Intrusion, base case	1.0E+00	1.0E+00	+0.13%	Nb-94
HI-GR2	Human Intrusion, shallow groundwater release	3.4E+01	3.4E+01	+0.0%	C-14
SF-BC	Severe Shaft Failure, base case	1.1E+00	1.1E+00	+0.0%	C-14
SF-ED	Severe Shaft Failure, extreme degradation	7.5E+01	7.5E+01	+0.0%	C-14
BH-BC	Poorly Sealed Borehole, base case	4.3E-08	4.2E-08	-0.60%	Zr-93/Nb-93m
VF-BC	Vertical Fault, base case	4.6E-10	4.6E-10	+0.70%	Zr-93/Nb-93m
VF-AL	Vertical Fault, alternative location	4.6E-10	4.6E-10	+0.63%	Zr-93/Nb-93m

Note that the results are presented to two significant figures to aid comparison. The degree of uncertainty associated with postclosure safety assessments of this nature means that it is ordinarily appropriate to present results rounded to one significant figure.

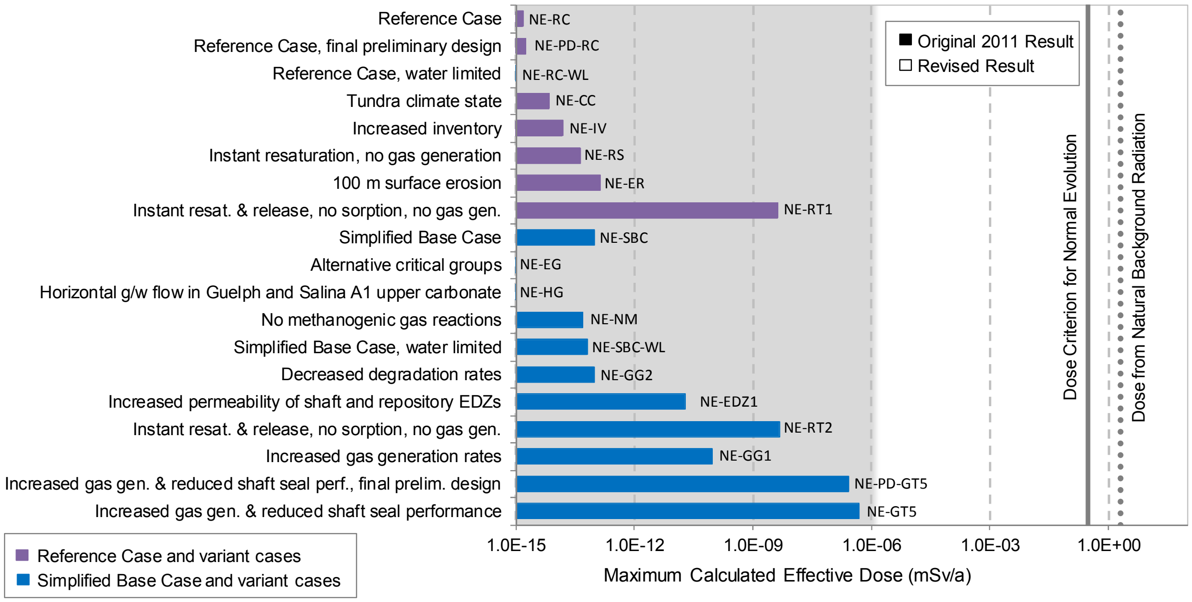

Figure 1: Maximum Calculated Doses for the Normal Evolution Scenario Calculation Cases showing 2011 PostSA and Revised Results (Note that differences in results are too small to be visible on this scale.)

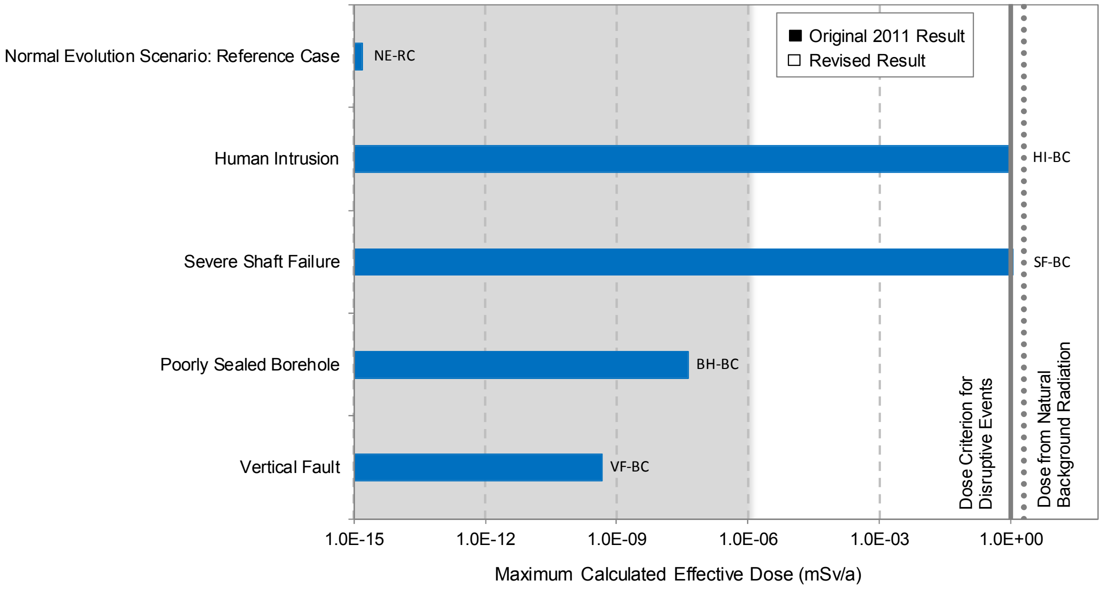

Figure 2: Maximum Calculated Doses for the Base Case Disruptive Scenarios showing 2011 PostSA and Revised Results (Note that differences in results are too small to be visible on this scale.)

In addition to presenting maximum doses for all calculation cases, the results for a sub-set of calculation cases are explored in more detail in the following sub-section. Key base cases are explored for the Normal Evolution Scenario (NE-RC and NE-SBC), together with two of the higher impact variants (NE-RT1 and NE-GT5) in Section 4.2. The highest impact disruptive scenarios (Human Intrusion and Severe Shaft Seal Failure) are then explored in Sections 4.3 and 4.4.

Potential impacts on non-human biota were assessed in the 2011 PostSA by comparison of maximum calculated radionuclide concentrations against ‘no effect concentrations’ for non-human biota for eleven radionuclides[5]. Of the eleven radionuclides for which no effect concentrations are available, Pb-210[6], Po-210[7], Ra-226[7], U-238 and Np-237[7] are affected by the changes to the inventory in the pressure tubes. The inventory of the associated parent radionuclides is changed by less than 10% in the revised analysis, so the conclusions of the 2011 PostSA remain valid and are not revisited in detail in this Technical Memorandum.

4.2 NORMAL EVOLUTION SCENARIO CALCULATION CASES

The results for the Reference Case are explored in Section 4.2.1, the Simplified Base Case in Section 4.2.2 and three variant cases in Section 4.2.3.

4.2.1 The Normal Evolution Scenario Reference Case (NE-RC)

The Reference Case (NE-RC) assumes instant rockfall at closure and draws on detailed groundwater and gas flow calculations that represent the limited degree of repository resaturation and explicitly represent the underpressures observed in the Ordovician formations. All waste packages are assumed to fail at closure and the release of radionuclides from the waste is explicitly modelled, although solubility limitation of releases is ignored. The detailed gas modelling shows that no free gas reaches the shafts, so radionuclides can only migrate from the repository into the host rock and up the shafts by diffusion and advection in groundwater. Potential exposure is considered of a site resident group, who live over the shafts and draw water for domestic and agricultural use from potable shallow groundwater via a well drilled into the flow path between the shafts and Lake Huron. The group has a self-sufficient lifestyle and consumes fish taken from local water courses and the lake. The case is summarized in Table 2 and in Figure 3.

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[5] The ‘no effect concentrations’ are given for C-14, Cl-36, Zr-93, Nb-94, Tc-99, I-129, Pb-210, Po-210, Ra-226, Np-237 and U-238 in Table 7.11 of Quintessa and Geofirma (2011a).

[6] Potential to in-grow from U-238 and Pu-238.

[7] Potential to in-grow from Am-241.

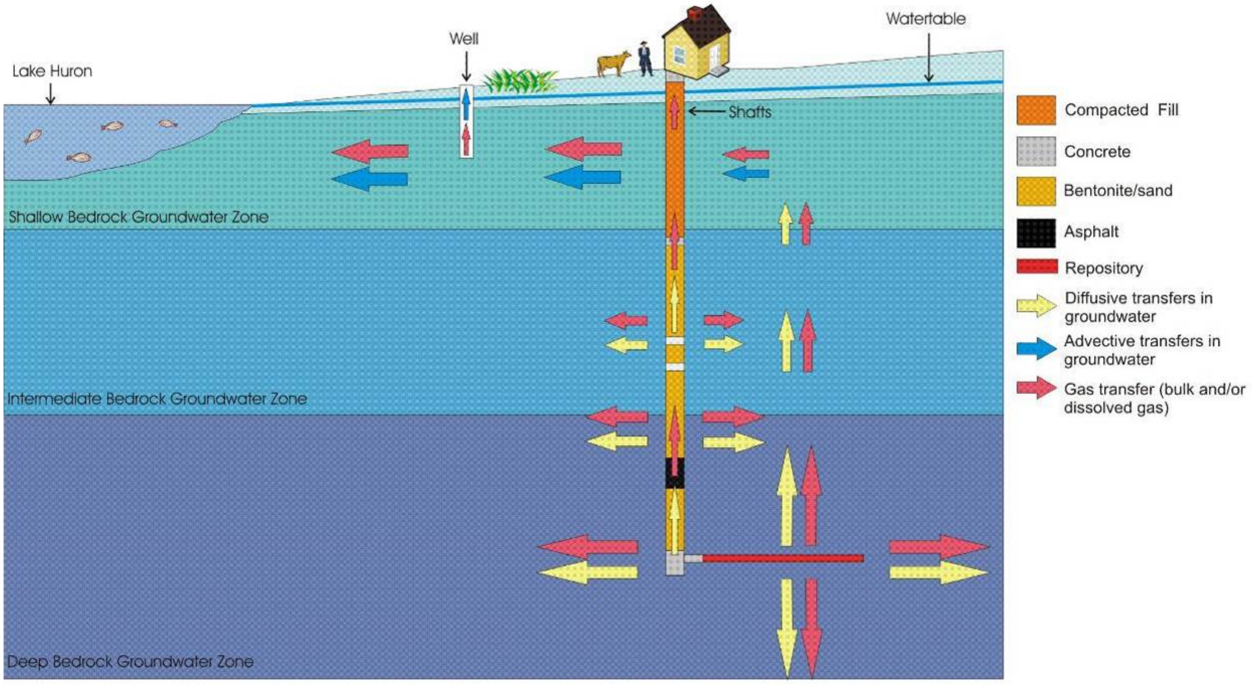

Figure 3: Schematic Representation of Potential Transport Pathways for the Normal Evolution Scenario

The results for the Reference Case including the changes to the pressure tubes inventory and release model are described in the sub-sections below and compared against the 2011 PostSA results[8].

Containment of Contaminants in the Repository

Radionuclides are initially present in the wastes within the waste packages. It is assumed in the safety assessment that all waste packages fail at closure. Radionuclides may be released either as gas (mainly C-14 and H-3) or after contact of the wastes with repository water. The release to repository water is either instant on contact with water, or determined by the corrosion/degradation rate of the associated wasteform.

The water level in the DGR determines the degree to which the wastes are contacted by water and, therefore, their potential to release radionuclides into the repository water. The detailed gas modelling indicates that the repository would not resaturate completely with the Reference Case assumptions and that the water level would remain very low (not exceeding about 10 cm over several million years). These results are unchanged by the change to the pressure tube inventory and radionuclide release model.

H-3 is assumed released instantly to the gas phase in the DGR and C-14 is released relatively rapidly to the gas phase. However, the small degree of repository resaturation means that other radionuclides remain within the wastes as they are only released on contact with water. Most of the total radioactivity decays without being released. This is illustrated in Figure 4, which shows

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[8] The format for the results reflects that used in Section 7.1 of Quintessa et al. (2011).

the amount of radioactivity that is released from the waste but remaining within the DGR, and that released from the DGR to the host rock and shafts. For comparison, the figure also shows the natural radioactivity in the rocks above the repository as a horizontal grey band. The upper part of this band corresponds to the Bruce nuclear site; the lower part of this band corresponds to the DGR footprint.

Figure 4 shows that the revised pressure tubes inventory results in a small increase in the total inventory in the DGR. The figure also shows that the changes to the pressure tubes results in a higher release of radionuclides from the DGR on a timescale of up to about 1000 years. This reflects the more rapid release of surface contamination from the pressure tubes. However, the maximum amount of radioactivity released from the DGR in comparison to the initial inventory remains very small at 0.2%, which compares to 0.03% in the 2011 PostSA.

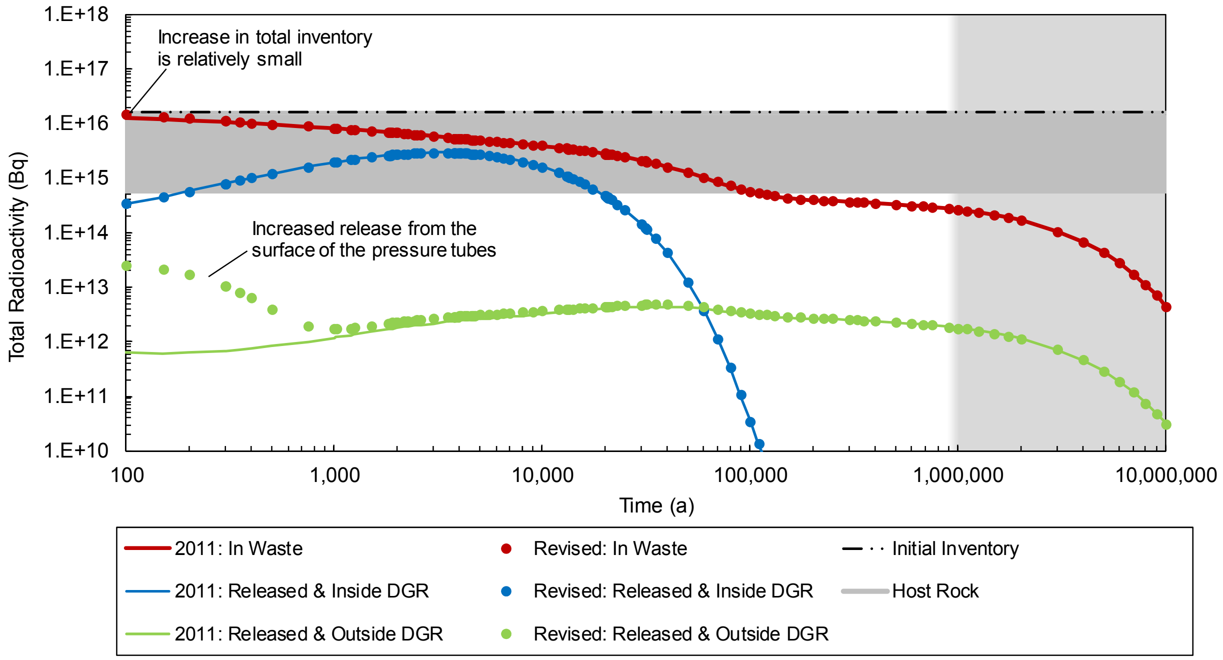

Figure 4: Total Radioactivity in the Reference Case (NE-RC)

Radionuclides in the DGR water can be released to the host rock via diffusion from the repository floor, and can be released to the shafts (and their EDZs) via diffusion and flow through the concrete monolith and its associated damaged zones. The detailed T2GGM modelling shows that free gas is not released from the DGR; this is unaffected by the change to the pressure tubes inventory and release model.

Figure 5 provides a summary of the radionuclide transfer fluxes from the DGR and shows that diffusion into the host rock dominates over contaminant migration to the shafts by more than three orders of magnitude due to the relatively large interface with the host rock compared to the small interface with the shafts via the monolith and its damaged zones together with low rates of groundwater advection. The perturbations in the radionuclide transfer flux from the repository to the monolith reflect fluctuations in groundwater flow rates. The increased release from the surface of the pressure tubes is evident in an increased transfer flux to the host rock on a timescale of up to about 1000 years.

Radionuclide transfer fluxes via the monolith to the shafts increase when groundwater flow away from the repository commences after 25,000 years for the Reference Case, indicating that groundwater advection dominates over diffusion as a process for contaminant migration to the shafts (see Figure 5).

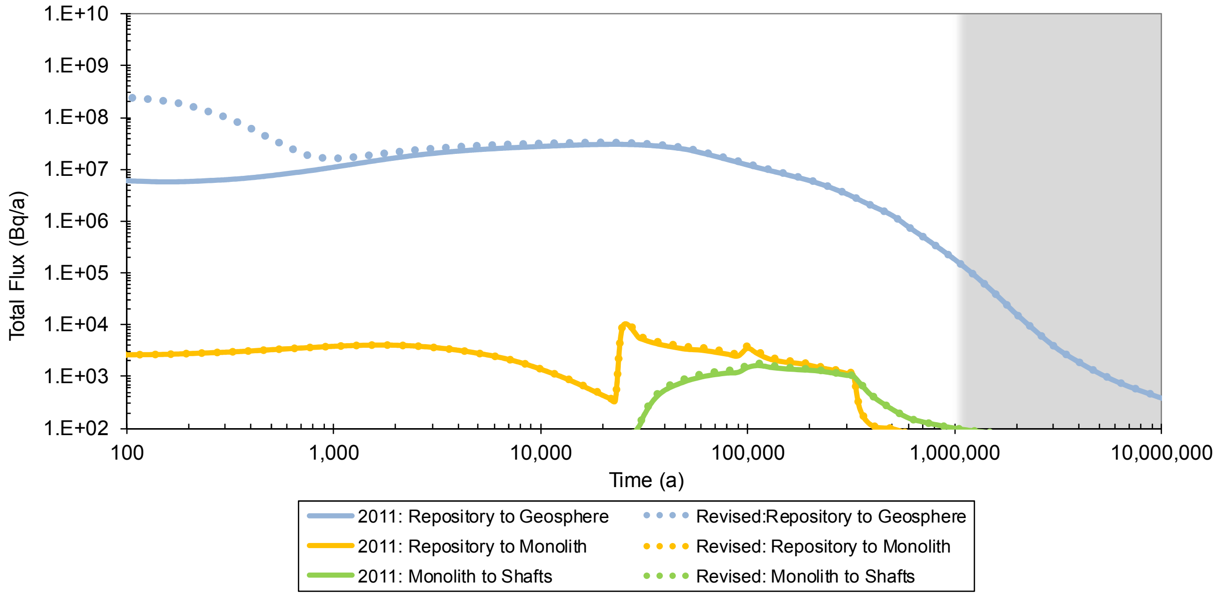

Figure 5: Radionuclide Transfer Fluxes from the DGR for the Reference Case (NE-RC)

The transfer flux from the DGR into the host rock is shown by radionuclide in Figure 6. The figure shows the diffusive flux via groundwater into the repository highly damaged zone (HDZ) and is indicative of the radionuclides present in the repository water. The figure shows that C-14, Zr-93, Nb-93m and Nb-94 are dominant radionuclides on a timescale beyond 1000 years. The amounts of these radionuclides in the pressure tubes are unaffected by the change in the inventory (see Table 1). However, Figure 6 shows that the increase in the Ni-63 inventory within pressure tubes, combined with its more rapid release as surface contamination, makes it the dominant radionuclide on timescales up to about 1000 years in the revised calculations. Ni-63 has a half-life of 100 years and has decayed on longer timescales.

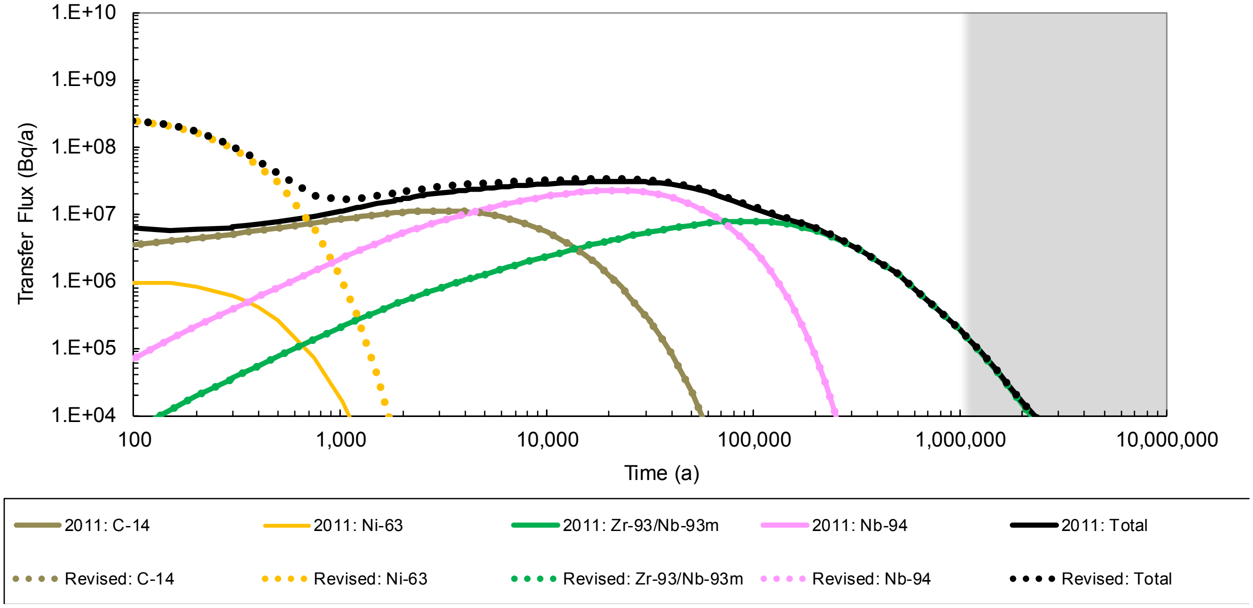

Figure 6: Radionuclide Transfer Flux from the DGR to the Host Rock Due to Diffusion in Groundwater for the Reference Case (NE-RC)

Containment of Contaminants in the Geosphere and Shafts

The host rock surrounding the DGR has very low permeability, such that transport of contaminants away from the repository is diffusion dominated. Figure 7 shows the total calculated concentrations in host rock above the DGR. The figure illustrates the decline in calculated concentrations with distance from the DGR. Calculated concentrations decline further with greater distance from the DGR and do not exceed 1 Bq/m^3 of rock beyond the Queenston formation at the top of the Deep Bedrock Groundwater Zone.

Nb-94 and Zr-93 (and its decay product Nb-93m) dominate the releases from the DGR on timescales beyond a few thousand years. Their greater sorption on the shales rather than limestone means that concentrations in the Collingwood formation exceed those in the Cobourg formation, which is closer to the DGR, after about 100,000 years. The increased flux of Ni-63 on a timescale up to about 1000 years is evident in Figure 7. The increased inventory of other radionuclides in the pressure tubes is evident in some visibly higher concentrations at longer times.

The shales in the vicinity of the DGR contain about 3 x 10^6 Bq/m^3 of natural radioactivity (mostly K-40 and U-238). This is also illustrated in Figure 7, which shows that the calculated concentrations in the host rock above the DGR, arising from radionuclides released from the DGR, do not exceed the natural background concentration for the Reference Case.

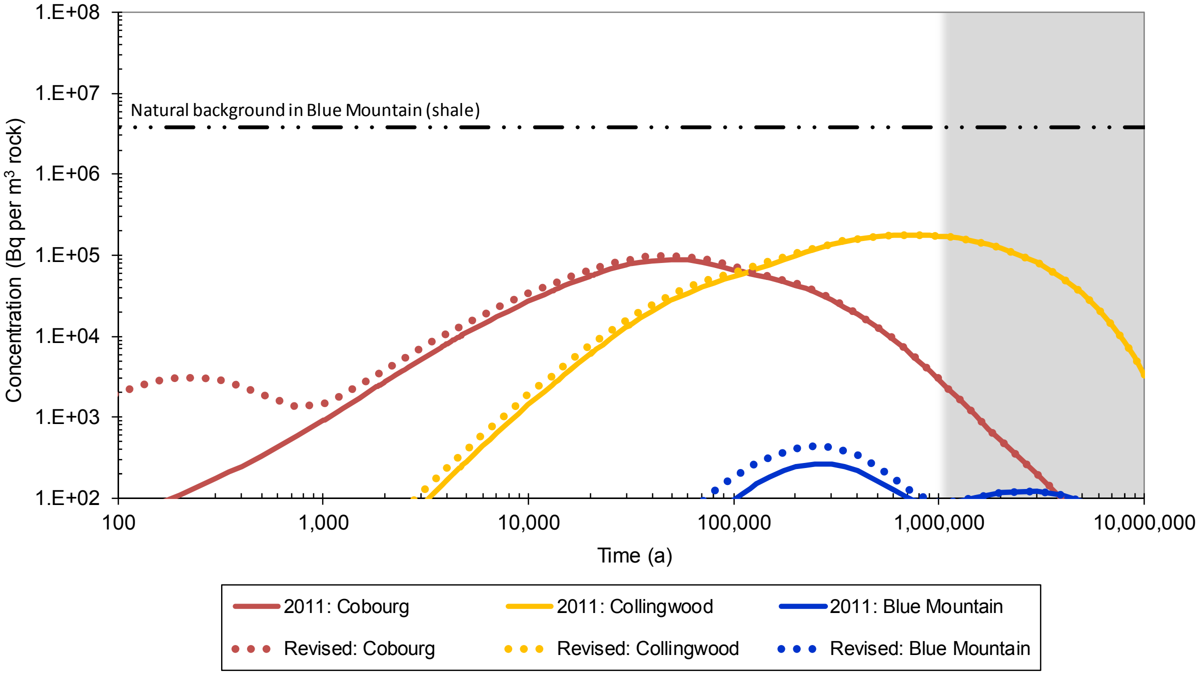

Figure 7: Radionuclide Concentration in the Deep Bedrock Groundwater Zone above the DGR for the Reference Case (NE-RC)

The shafts are also not a pathway for contaminants. Figure 5 indicates that a relatively small amount of radionuclides (up to 1 x 10^4 Bq/a) reaches the base of the shafts. Figure 8 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 as the distance from the DGR increases. No concentrations greater than 1 Bq/m^3 are calculated above the top of the Asphalt seals between the Georgian Bay and Queenston formations for the Reference Case, in-spite of a small increase in concentrations resulting from the revised pressure tube release model. Figure 8 also shows that calculated concentrations in the shafts continue to remain below natural background concentrations at the points shown for the Reference Case.

The concentrations in the shafts are low because contaminant transport via the shafts is dominated by diffusion in the Reference Case. Groundwater flow via the shafts in the upper regions of the Ordovician remains downwards throughout the assessment period due to the underpressure in the Ordovician rocks. Therefore, contaminant transport up through the shafts towards the Shallow Bedrock Groundwater Zone needs to be both diffusive and to operate against the direction of groundwater flow.

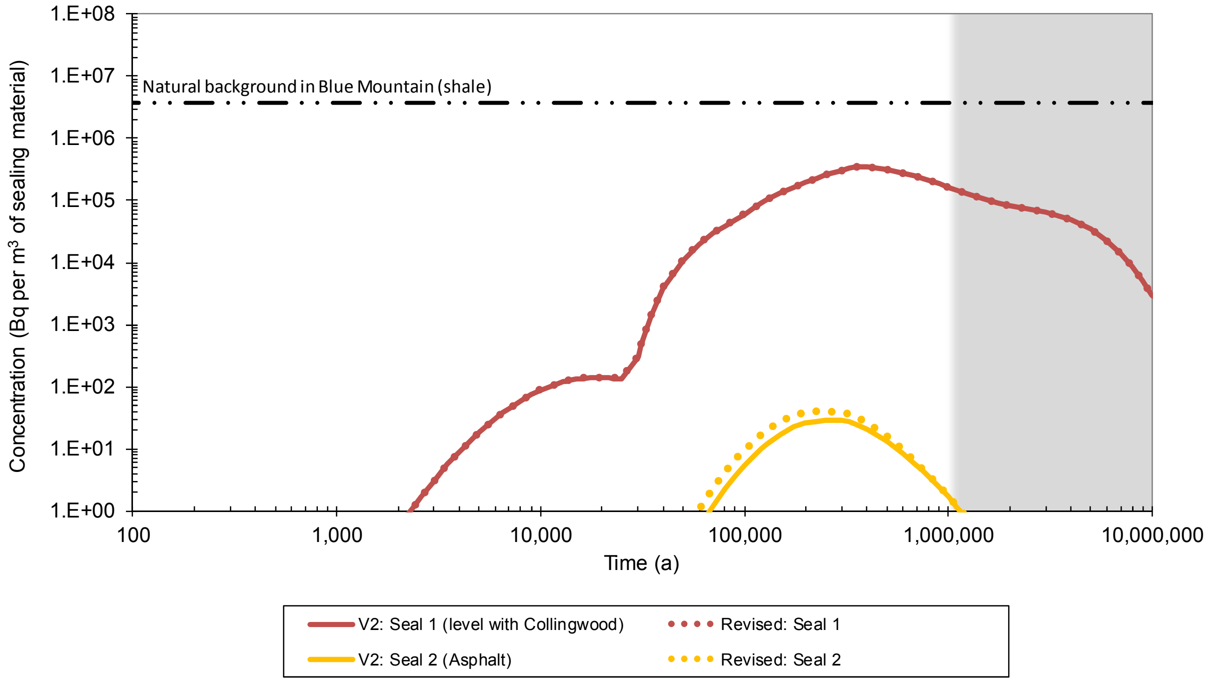

Figure 8: Radionuclide Concentration in Shafts for the Reference Case (NE-RC)

The low and slow level of repository resaturation, combined with the very low permeability of the host rock and the effectiveness of the shaft seals means that effectively no contamination enters the Shallow Bedrock Groundwater Zone (see Table 6). I-129 and Cl-36 dominate the small calculated radionuclide flux due to the sorption of other radionuclides to the bentonite/sand seals in the shafts (notably radioisotopes of Zr and Nb). The very small fluxes given in Table 6 can be compared against an estimated present-day flux of around 4 MBq/a in the flowing groundwater within the shallow system.

Neither I-129 nor Cl-36 are affected by the change in the inventory in the pressure tubes (see Table 1) and neither is associated with surface contamination on the pressure tubes. Therefore, the maximum calculated radionuclide flux to the shallow groundwater is unaffected and remains negligible (see Table 6).

Table 6: Maximum Calculated Flux to the Shallow Bedrock Groundwater Zone for the Reference Case (NE-RC)

Calculation Case	Maximum Calculated Flux	Time of Maximum Calculated Flux	Main Contaminant Contributing to the Peak
2011 PostSA	3 x 10^{-6} Bq/a	> 1 Ma	I-129
Revised Result	3 x 10^{-6} Bq/a	> 1 Ma	I-129

After any contaminants enter the Shallow Bedrock Groundwater Zone via the shafts and their EDZs, at 144 m below ground surface, horizontal groundwater flow takes the contaminants towards the lake (see Figure 3).

Vertical dispersion and the draw resulting from groundwater extraction will enable contaminants to reach the groundwater well, which is drilled to a depth of 80 m below ground surface. The well depth is typical of wells in the region. It is consistent with the more permeable near-surface formations, and avoids the higher salinity groundwater at greater depths. The well demand is consistent with the needs for a self-sufficient farm. The well is placed downstream from the shaft, so as to intercept the plume, but not so far downstream that there is much dilution. The detailed groundwater modelling results show that the well captures a small fraction of the contaminant plume in the Shallow Bedrock Groundwater Zone (see Section 5.2.2.2 of Geofirma 2011).

Consistent with the small calculated fluxes to the Shallow Bedrock Groundwater Zone listed in Table 6, Table 7 shows the small calculated fluxes to the biosphere for the Reference Case. Two biosphere discharge points are considered – the well and the lake. Consistent with the observations above, the maximum calculated fluxes to the biosphere are unaffected by the changes to pressure tubes and remain negligible.

Table 7: Maximum Calculated Flux to the Biosphere for the Reference Case (NE-RC)

Calculation Case	Biosphere Receptor	Max. Calculated Flux	Time of Max. Calculated Flux	Main Contaminant Contributing to the Max.
2011 PostSA	Well Lake	4 x 10^{-8} Bq/a 3 x 10^{-6} Bq/a	> 1 Ma	I-129
Revised Result	Well Lake	4 x 10^{-8} Bq/a 3 x 10^{-6} Bq/a	> 1 Ma	I-129

Impact of Contaminants

The very small release of contaminants to the biosphere results in very small calculated concentrations. Maximum calculated total concentrations in biosphere media are shown in Table 8 for the Reference Case. The table shows that the maximum calculated concentrations are unaffected by the changes to the pressure tubes and remain negligible.

For comparison, surface waters have provincial background concentrations ranging from 0.02 to 0.19 Bq/L gross-beta (Section 5.6 of AMEC NSS 2011). Lake sediments from the Regional Study Area have Cs-137 concentrations of around 0.2 Bq/kg, and naturally occurring K-40 of around 250 Bq/kg (Section 5.7.1 of AMEC NSS 2011). Soils have concentrations of K-40 and Cs-137 ranging from 446 to 500 Bq/kg and 2.7 to 3.9 Bq/kg (respectively) at provincial background locations (Section 5.8.4 of AMEC NSS 2011).

Table 8: Summary of Maximum Calculated Biosphere Concentrations for the Reference Case (NE-RC) and the Main Contributing Radionuclide (in brackets)

Calculation Case	Well Water (Bq/L)	Soil (Bq/kg)	Surface Water (Bq/L)	Sediment (Bq/kg)
2011 PostSA	6 x 10^{-15} (I-129)	5 x 10^{-15} (Cl-36)	1 x 10^{-17} (I-129)	1 x 10^{-14} (I-129)
Revised Model	6 x 10^{-15} (TBD)	5 x 10^{-15} (Cl-36)	1 x 10^{-17} (I-129)	1 x 10^{-14} (I-129)

The extremely small calculated concentrations result in equivalently negligible calculated doses to the Site Resident group, which are shown in Table 4. I-129 and Cl-36 dominant the small calculated doses, which are therefore unaffected by the changes to the pressure tubes and remain negligible.

4.2.2 The Normal Evolution Scenario Simplified Base Case (NE-SBC)

The Simplified Base Case for the Normal Evolution Scenario (NE-SBC) is the same as the Reference Case, except in that the initial underpressures observed in the Ordovician formations are assumed to not be present (see Table 2). The absence of the underpressures increases the potential for groundwater to flow up the shafts and their EDZs.

Containment of Contaminants in the Repository

The water level in the DGR determines the degree to which the wastes are contacted by water and, therefore, their potential to release radionuclides into the repository water. Figure 9 compares the water level for the Simplified Base Case with that of the Reference Case, based directly on the results of the detailed T2GGM calculations (these are unaffected by the changes to the pressure tubes inventory and release model). The figure shows that the water level in the DGR continues to increase in the Simplified Base Case, whereas it peaks after a few thousand years in the Reference Case before declining. However, the water level remains well below the top of the DGR (the emplacement rooms are 7 m high plus assumed 10 m of rockfall) throughout the calculations in both cases.

Figure 10 shows the calculated radionuclide release rates from the DGR for the Simplified Base Case. As was the case for the Reference Case, the figure shows an increase in the radionuclide flux from the DGR to the rock on timescales up to about 1000 years, due to the increased inventory and rate of release of Ni-63 from pressure tubes. Beyond 1000 years calculated radionuclide fluxes from the DGR are similar in both the revised and 2011 PostSA calculations.

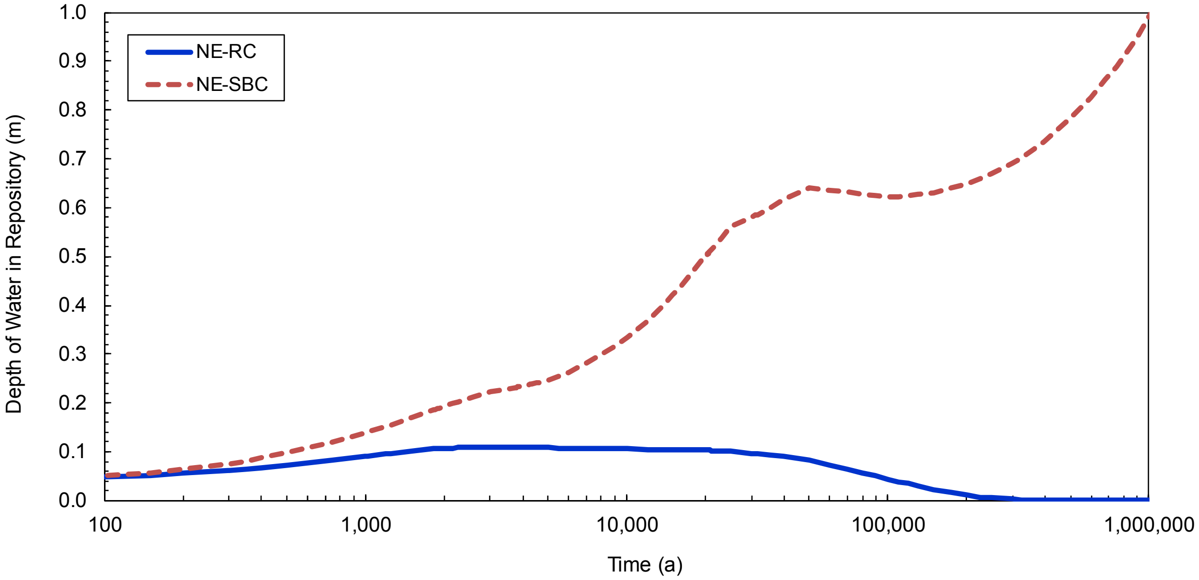

Figure 9: Depth of Water in the Repository for the Reference Case (NE-RC) and Simplified Base Case (NE-SBC)

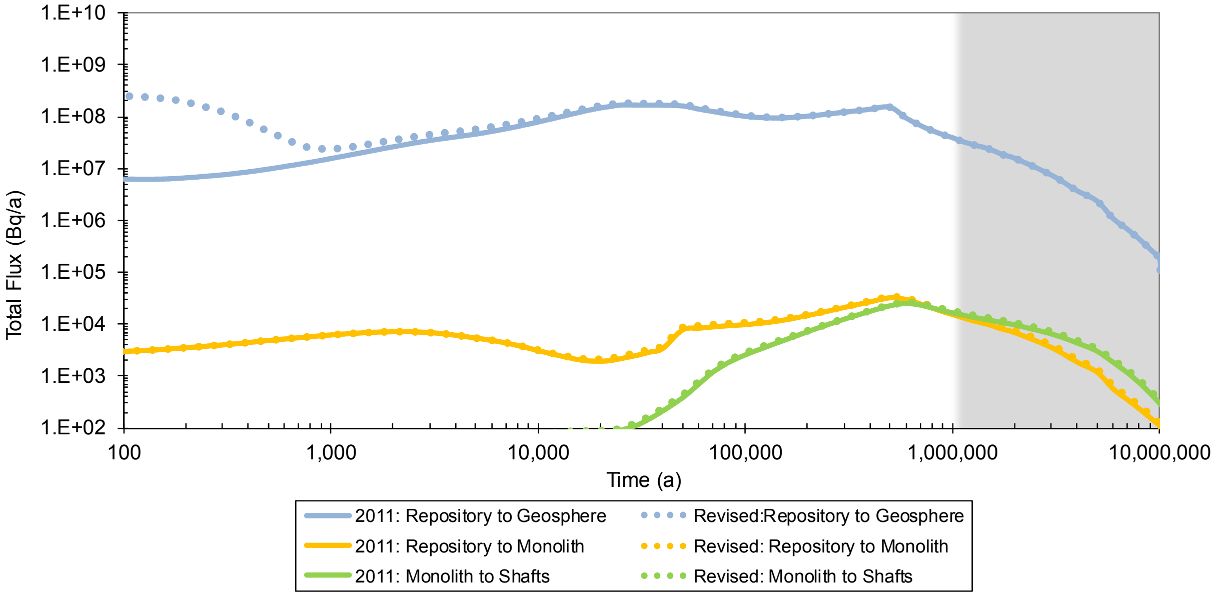

Figure 10: Radionuclide Transfer Fluxes from the DGR for the Simplified Base Case (NE-SBC)

Containment of Contaminants in the Geosphere and Shafts

The host rock and shafts remain extremely effective in isolating the DGR from the shallow groundwater for the Simplified Base Case. Table 9 shows the maximum calculated radionuclide flux to the shallow groundwater, which remains less than 1 Bq/a throughout. The table shows that the revised pressure tube inventory and release model has no effect on the peak calculated flux to the shallow groundwater. This is because the radionuclide flux to the shallow groundwater is dominated by I-129 and Cl-36, which are unaffected by the changes to the pressure tubes.

Table 9: Maximum Calculated Flux to the Shallow Bedrock Groundwater Zone for the Simplified Base Case (NE-SBC)

Calculation Case	Maximum Calculated Flux	Time of Maximum Calculated Flux	Main Contaminant Contributing to the Peak
2011 PostSA	2 x 10^{-3} Bq/a	> 1 Ma	Cl-36
Revised Result	2 x 10^{-3} Bq/a	> 1 Ma	Cl-36

The small calculated radionuclide fluxes to the shallow groundwater are reflected in the calculated fluxes to the biosphere for the Simplified Base Case (see Table 10). Most of any contamination reaching the Shallow Bedrock Groundwater Zone discharges to Lake Huron, while about 1.15% is intercepted by the well and used for domestic and agricultural purposes by the Site Resident group.

Table 10: Maximum Calculated Flux to the Biosphere for the Simplified Base Case (NE-SBC)

Calculation Case	Biosphere Receptor	Max. Calculated Flux	Time of Max. Calculated Flux	Main Contaminant Contributing to the Max.
2011 PostSA	Well Lake	2 x 10^{-5} Bq/a 2 x 10^{-3} Bq/a	> 1 Ma	Cl-36
Revised Result	Well Lake	2 x 10^{-5} Bq/a 2 x 10^{-3} Bq/a	> 1 Ma	Cl-36

Impact of Contaminants

The extremely small calculated radionuclide fluxes to the biosphere are reflected in the negligible calculated concentrations in biosphere media (see Table 11). The changes to the pressure tubes have very little effect on the calculated concentrations in the biosphere; the only difference evident in Table 11 results from a small change to the maximum calculated concentration in well water, which is sufficient to cause a rounding difference.

Table 11: Summary of Maximum Calculated Biosphere Concentrations for the Simplified Base Case (NE-SBC) and the Main Contributing Radionuclide (in brackets)

Calculation Case	Well Water (Bq/L)	Soil (Bq/kg)	Surface Water (Bq/L)	Sediment (Bq/kg)
2011 PostSA	3×10^{-12} (Cl-36)	4×10^{-12} (Cl-36)	6×10^{-15} (Cl-36)	3×10^{-13} (Cl-36)
Revised Model	4×10^{-12} (Cl-36)	4×10^{-12} (Cl-36)	6×10^{-15} (Cl-36)	3×10^{-13} (Cl-36)

The maximum calculated doses for the Simplified Base Case are shown in Table 4. The table shows that I-129 is the main contributing radionuclide to the calculated dose, which remains many orders of magnitude below the dose criterion. I-129 is relatively unaffected by the change in the pressure tube inventory and release model, so the maximum calculated dose to the Site Resident increases very little (by less than 1%).

4.2.3 Other Normal Evolution Scenario Cases

Results for two further Normal Evolution Scenario calculation cases are explored further below. The cases are (see Table 4 and Figure 1):

- the NE-RT1 case, which results in the highest calculated effective doses for variants based on the Reference Case; and
- the NE-GT5 case, which results in the highest calculated effective doses for variants based on the Simplified Base Case.

Instant Resaturation, Instant Release, No Sorption and No Gas Generation (NE-RT1)

This variant is based on the Reference Case (i.e., it includes the observed underpressures in Ordovician formations). In addition to the conservatisms inherent in the Reference Case (including rockfall at closure), the case assumes that the repository is fully resaturated, the full inventory is released to the groundwater at closure and the case ignores sorption on engineering materials and the host rock. Although unfeasible, the case was used in the 2011 PostSA to maximise the potential impact of the groundwater pathway for contaminants.

The instantaneous release of all radionuclides to groundwater in the DGR at closure means that the inventory is the only difference between the original and revised NE-RT1 calculations (i.e., the change in the release model for pressure tubes has no effect due to the instantaneous release). There is therefore little difference in the total radionuclide releases from the DGR (see Figure 11). The relatively small differences are propagated through to the dose assessment, which shows a small (1.1%) increase with the revised pressure tube inventory (see Table 4), which remain many orders of magnitude below the dose criterion.

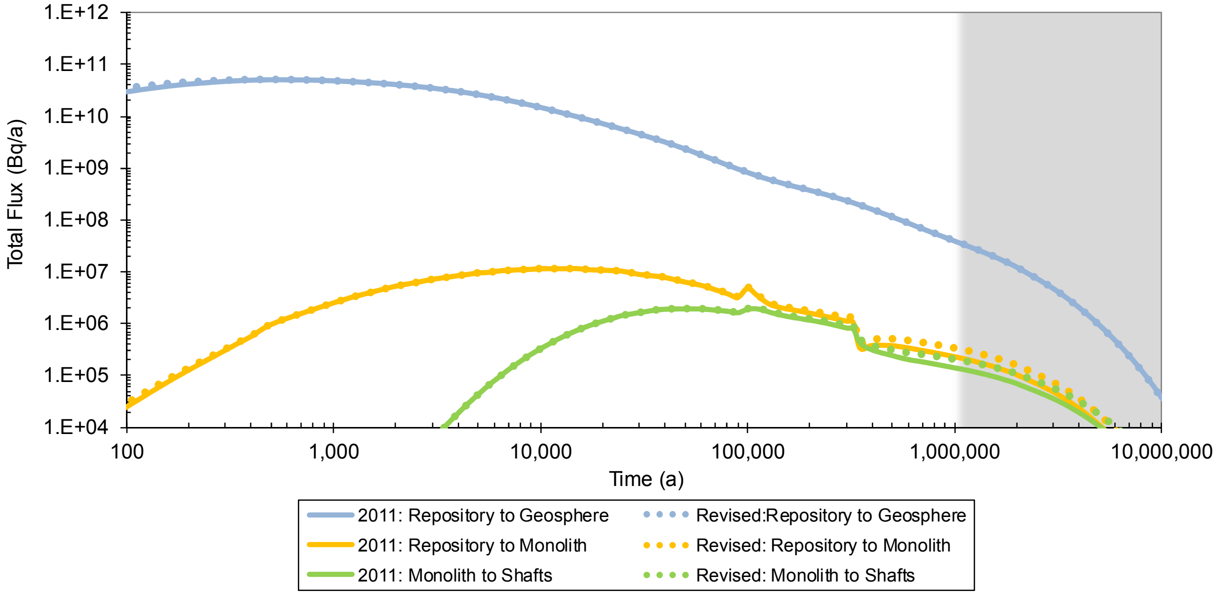

Figure 11: Radionuclide Transfer Fluxes from the DGR for the NE-RT1 Case

Increased Gas Generation & Reduced Shaft Seal Performance (NE-GT5)

This variant to the Simplified Base Case (i.e., ignoring the observed underpressures in Ordovician formations) explores the gas pathway through increased gas generation rates and amounts, along with lower gas entry pressures for the shaft sealing materials. The detailed gas modelling for the 2011 PostSA showed that free gas could migrate part of the way up the shaft in this case. The key radionuclide is C-14, which is carried part of the way up the shafts with the free gas before dissolving in groundwater.

The amount of C-14 in the DGR is unaffected by the changes to the pressure tube inventory. C-14 is not present as surface contamination, so it is also unaffected by the changes to the release model for the pressure tubes. The changes to the pressure tubes therefore have no discernible effect on the Normal Evolution Scenario case that has the highest calculated doses and they remain more than five orders of magnitude below the dose criterion, as shown in Table 4 and Figure 1.

4.3 HUMAN INTRUSION SCENARIO CALCULATION CASES

Deep geologic disposal isolates the wastes from the surface environment and minimises the potential for human intrusion during the period that the wastes remain hazardous. The Human Intrusion Scenario allows a “what if” style assessment of potential consequence of direct intrusion into the DGR, bypassing the significant geological barrier. Large scale excavation is extremely unlikely; therefore, the scenario addresses the potential for borehole intrusion (see Figure 12).

For the Human Intrusion Base Case (HI-BC), potential exposures are assessed from: gas releases as the borehole intrudes into the pressurised repository; retrieval of contaminated raw waste with the drill core; and release of contaminated slurry to the surface. Exposures to the drill crew, a technician examining the core, a nearby resident and potential future residents on an area contaminated by the material brought up by the borehole are considered.

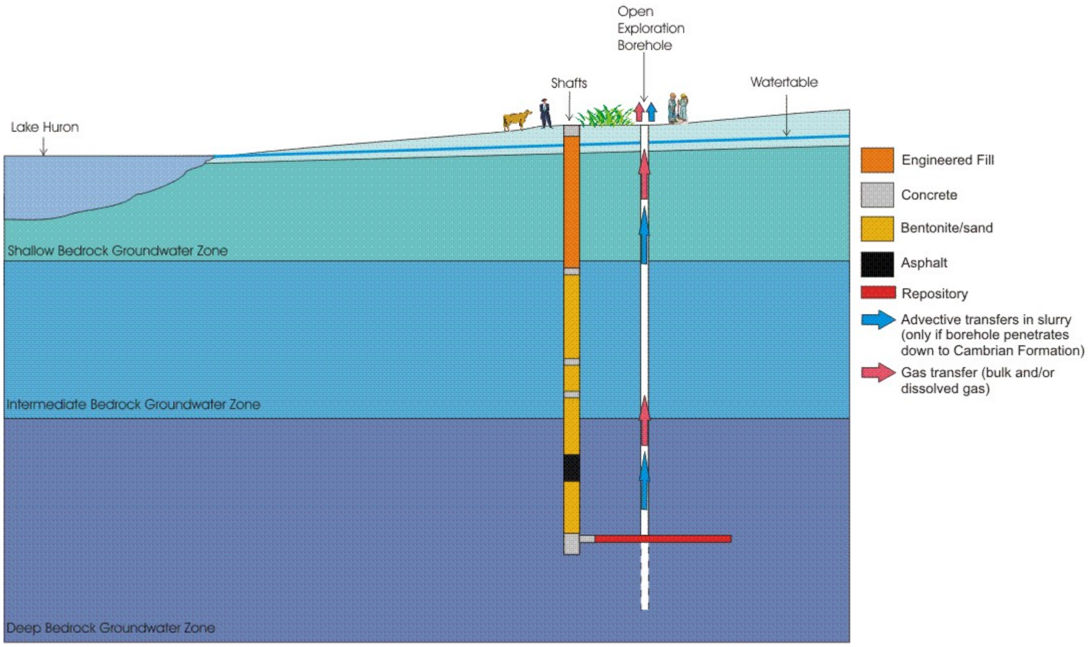

Figure 12: Schematic Representation of the Human Intrusion Base Case

The calculated dose rates for the Human Intrusion Base Case are shown in Figure 13. External irradiation from Nb-94 dominates the peak calculated dose rates to those groups directly exposed to raw waste, which are the drill crew, laboratory technician and future resident. C-14 dominates the peak calculated dose to the nearby resident group, which is only exposed via release of gas from the intruding borehole and its dispersion 100 m downwind. Neither Nb-94 nor C-14 are affected by the changes to the inventory in the pressure tubes. Neither C-14 nor Nb-94 are primarily present as surface contamination on the pressure tubes; therefore they are unaffected by the changes to the release model for the pressure tubes.

Although some of the calculated doses for the Human Intrusion Base Case are close to the dose criterion shown in Figure 13, the scenario has a low probability of occurrence at about 10^{-5}/a (see Section 2.5.3 of Quintessa and SENES 2011). Based on a health risk of 0.057/Sv (ICRP 2007), the associated risk of serious health effects for the future resident is around 6 x 10^{-10}/a, well below the reference health risk value of 10^{-5}/a given in Section 3.4.2 of Quintessa et al. (2011). This conclusion is therefore unaffected by the changes to the pressure tubes inventory and release model.

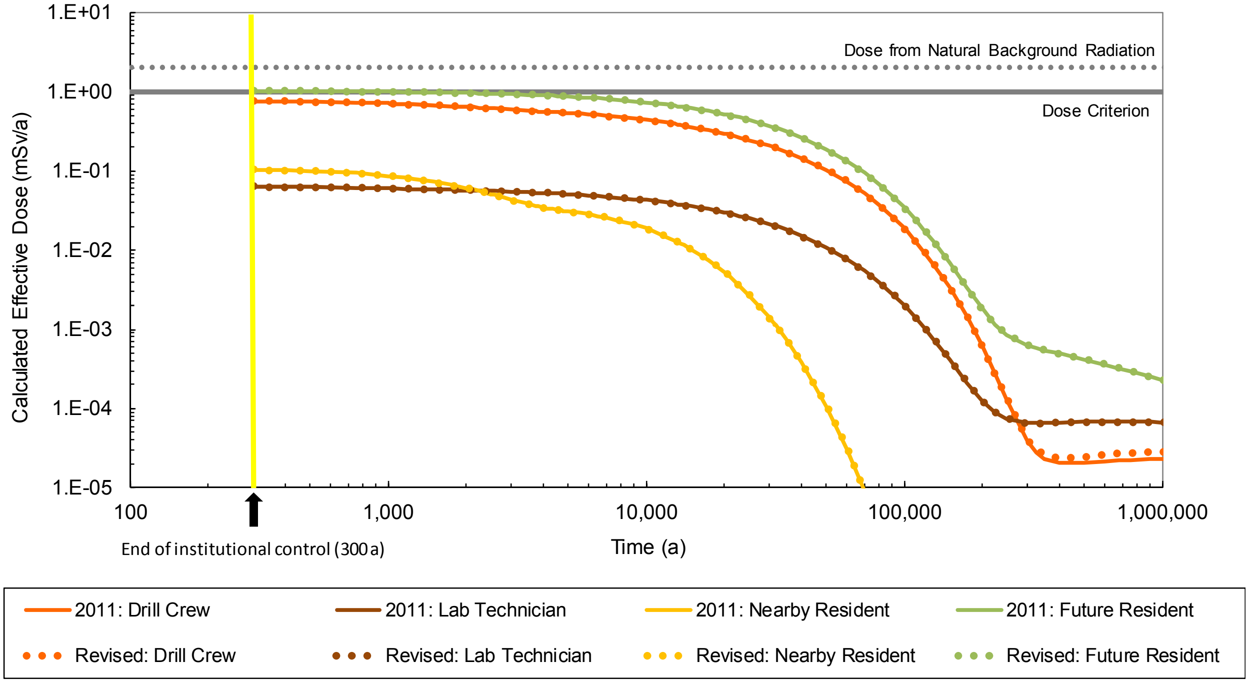

Figure 13: Calculated Effective Doses from Surface Release of Gas and Drill Core Resulting from Human Intrusion, as a Function of the Time of Intrusion, for the Human Intrusion Base Case (HI-BC)

A variant calculation case was also considered in the 2011 PostSA in which the intruding borehole extended beyond the DGR to the pressurised Cambrian formation and was not properly sealed, so that it provided a direct groundwater pathway to the shallow groundwater (HI-GR2). The case is based on a repository that is fully resaturated at the time of the borehole intrusion. For this case, C-14 in groundwater is the key radionuclide contributing to the calculated doses (see Table 5). C-14 is not effected by the change to the inventory in the pressure tubes and it is not present as surface contamination, so it is also unaffected by the changes to the release model. The maximum calculated dose for the HI-GR2 case is therefore unchanged from the 2011 PostSA.

Assuming the same probability of occurrence for the HI-GR2 case as for intrusion into the repository (thereby conservatively assuming the probability of continuing into the Cambrian and poorly sealing the borehole is unity), the peak dose equates to a risk of serious health effects that remains around 2 x 10^{-8}/a, more than two orders of magnitude below the reference health risk value of 10^{-5}/a. This remains unchanged from the conclusions of the 2011 PostSA.

4.4 SEVERE SHAFT SEAL FAILURE SCENARIO CALCULATION CASES

The shafts represent a potentially important pathway for contaminant release and, therefore, the repository design includes specific measures to provide good shaft seals, taking into account the characteristics of the geosphere. The Normal Evolution Scenario considers the likely behaviour of the shaft seals and the repository/shaft EDZs; it includes some expected degree of degradation of the seals with time. The Severe Shaft Seal Failure Scenario considers the same evolution of the DGR system and the same exposure pathways as the Normal Evolution Scenario, the difference being that there is rapid and extensive shaft seal degradation and the repository/shaft EDZs have significantly degraded properties (see Figure 14). Like the other Disruptive Scenarios, the scenario is a bounding "what if" scenario that is designed to investigate the robustness of the DGR system.

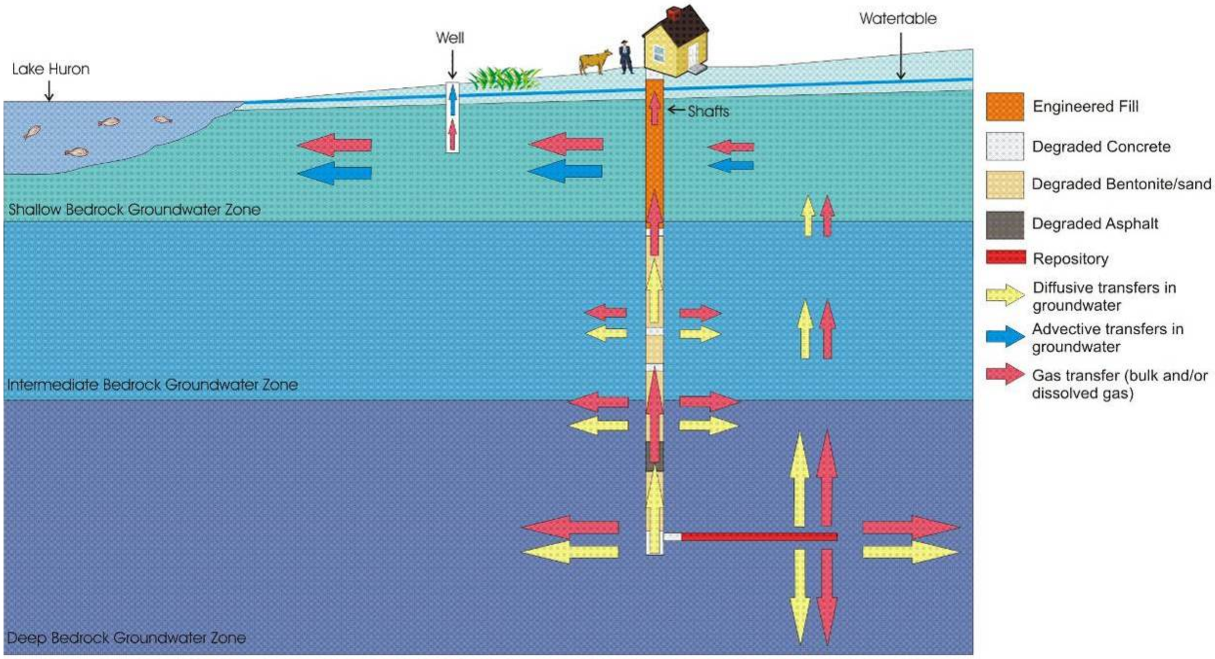

Figure 14: Schematic Representation of Severe Shaft Seal Failure Scenario

The calculated doses to the Site Resident Group for the Severe Shaft Seal Failure Scenario's Base Case are shown in Figure 15. C-14 dominates the calculated exposures due to a direct gas pathway being created from the DGR via the severely degraded shafts to the shallow groundwater and surface after about 20,000 years. C-14 is not affected by the change to the inventory in the pressure tubes and it is not present as surface contamination, so it is also unaffected by the changes to the release model. Therefore, the peak calculated dose for the SF-BC case is unaffected, as shown in Figure 15.

It is noted that, consistent with the 2011 PostSA, a scenario likelihood of around 10^{-1} or less per year would result in the risk of serious health effects being less than the reference health risk value of 10^{-5}/a. The probability of severe shaft seal degradation combined with a house positioned directly above one of the shafts can reasonably be considered to be significantly lower than this.

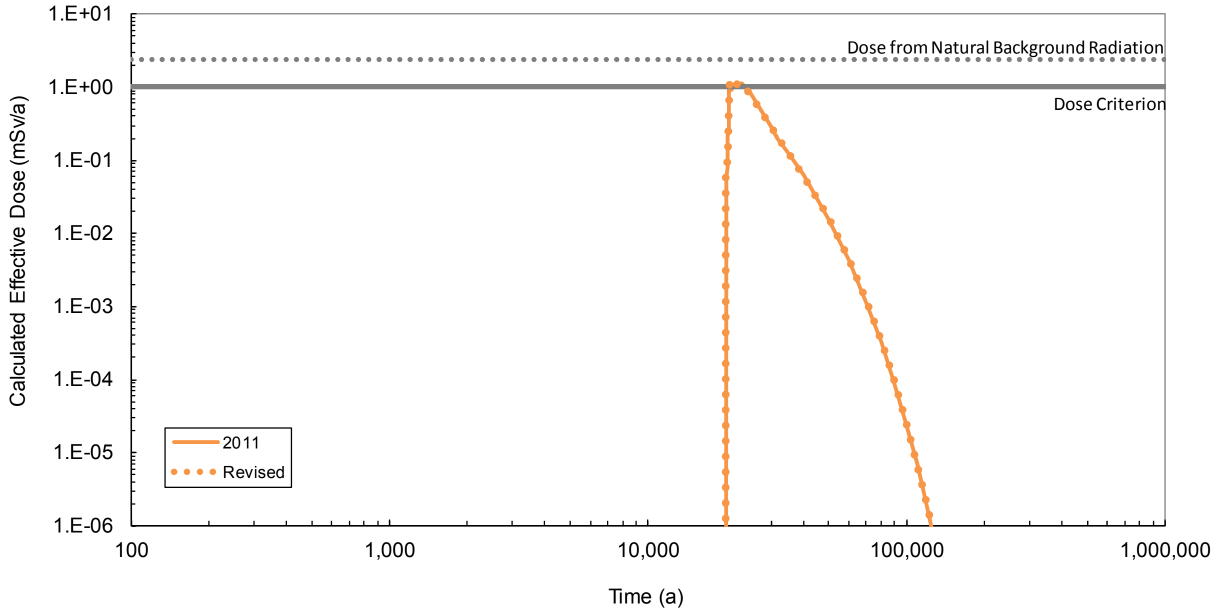

Figure 15: Calculated Effective Dose to Adults for the Site Resident Group for the Severe Shaft Seal Failure Scenario Base Case (SF-BC)

A variant to the Severe Shaft Seal Failure Base Case was also considered in the 2011 PostSA, representative of a bounding case with an even greater degree of shaft seal degradation (SF-ED). The case is representative of potential impacts should the shaft seals perform like fine silt and sand from the point of closure. Table 5 shows that the changes to the pressure tube release model result in the calculated effective dose to someone living directly above the shafts remains unchanged at 75 mSv/a. The peak calculated impact occurs due to C-14 after about 3800 years, coincident with peak calculated gas flows via the shafts of close to 10,000 kg/a. It is emphasized that this calculation case is an extremely conservative case and was undertaken with the purpose of investigating the sensitivity of dose impacts to shaft seal properties.

These Severe Shaft Seal Failure cases would require around 500 m of low-permeable shaft seals to degrade so as to have an effective conductivity of 10^{-9} m/s or higher. This is very unlikely under the DGR conditions of low-flow, low-temperature, and use of multiple low-permeable seal materials. It is also noted that this scenario would have little consequence if the degradation occurred after about 60,000 years when C-14 would have significantly decayed. This is also the earliest time that ice-sheets from the next glacial cycle might be expected, so glacial cycles are not an important factor.

5. CONCLUSIONS

All of the assessment-level cases for the 2011 PostSA have been recalculated to explore the effect of changes to the radionuclide inventory in pressure tubes and a change in the release model for pressure tubes permitting more rapid release of some of the associated radionuclides. The detailed gas and groundwater calculations that support the assessment-level modelling are unaffected by the changes and therefore have not been revised.

The calculations demonstrate that the revised inventory has very little effect on the calculated effective doses. This is because the inventories of only four radionuclides in the DGR are increased by more than 10% in comparison to the 2011 PostSA (Ni-59, Ni-63, Cs-137 and Cm-244) and none of these nor their progeny are important contributors to maximum calculated effective doses.

Since the revised radionuclides are largely present as surface-deposit or as thin garter springs, the radionuclide release model for the pressure tubes has been changed to enable radionuclides present as surface contamination to be released more quickly than activation products present within the metal itself. The pressure tubes are an important source for some of the radionuclides present as surface contamination, notably representing more than 50% of the total inventory for Ni-63. The more rapid availability of these radionuclides is evident when exploring calculated radionuclide fluxes in the DGR system, although they do not contribute significantly to calculated effective doses.

For the Normal Evolution Scenario cases, in <u>all calculation cases</u> considered, the maximum calculated effective dose remains more than five orders of magnitude below the public dose criterion of 0.3 mSv/a for the revised inventory.

Some small differences in the Normal Evolution Scenario results between the revised inventory and the 2011 PostSA are given below:

- maximum calculated effective doses increase by less than 1% for the Reference Case and Simplified Base Case; and
- maximum calculated effective doses increase by less than 10% in all 19 calculation cases.

For the “what if” calculations exploring potential disruptive scenarios:

- maximum calculated effective doses for the Human Intrusion Scenario Base Case increase by less than 1%, due to the relative unimportance of the release model for this case;
- maximum calculated effective doses for the Severe Shaft Seal Failure cases are unaffected, due to the dominance of C-14 and its being unchanged by the revisions to the pressure tube inventory and release model;
- maximum calculated effective doses for the Poorly Sealed Borehole and Vertical Fault cases change by less than 1%, due to the dominance of Zr-93/Nb-93m, which are unaffected by the revisions to the pressure tube inventory and release model; and
- potential risks associated with all of the “what if” disruptive cases remain substantially less than the reference health risk value of 10^{-5}/a, once the low likelihood of occurrence is taken into account.

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ATTACHMENT B

TO

OPG RESPONSE TO IR-EIS-13-514

PRECLOSURE SAFETY IMPLICATIONS OF REVISED PRESSURE TUBE INVENTORIES

CONTENTS

LIST OF TABLES

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 Nuclear Waste Management Organization, on behalf of OPG, has prepared the Environmental Impact Statement (EIS) (OPG 2011a) and Preliminary Safety Report (PSR) (OPG 2011b) for the proposed repository. The EIS, PSR and supporting documentation were submitted for regulatory review in April 2011, as part of the application for a site preparation and construction licence.

The preclosure safety assessment is documented in Chapter 7 of the Preliminary Safety Report, which deals with normal operations and accidents. Dose estimates for the Malevolent Acts Scenarios are provided in OPG’s response to the Information Request EIS-06-248 (OPG 2012).

The safety assessment was conducted based on the projected final DGR inventory presented in OPG's 2010 Reference Inventory report (OPG 2010). Some of the inventory projections were based on estimates. An ongoing OPG waste characterization program is underway to reduce uncertainties in these estimates.

During the review process of the current Preliminary Safety Report, the estimates for the inventories of some radionuclides in pressure tube wastes have been identified as significantly underestimated. Pressure tubes from reactor mid-life retubing are one of over 20 waste types considered in the reference inventory. The Joint Review Panel has issued an Information Request EIS-13-514 asking for an assessment of how the revised inventory will affect the preclosure safety assessment of the DGR. This Technical Memorandum addresses this request.

2. MODIFICATIONS TO THE RADIONUCLIDE CONCENTRATIONS IN THE PRESSURE TUBES

The revised radionuclide concentration data for the pressure tubes containers, including garter springs, are provided in Table 1. This table shows the source term for normal operations shielding calculations and for accident assessment. Radionuclide concentrations for normal operations shielding calculations are given in the 2011 Preliminary Safety Report (PSR) (Table 7-18 of OPG 2011b). The net volume of a retube container for pressure tube wastes (RWC-PT) is 0.8 m^3.

For normal operations, the main concern is the external dose to workers during handling. As a result, the list of radionuclides focussed on gamma emitters and was not comprehensive for alpha and beta emitters (Table 7-18 of OPG 2011b). The original values were based on a plausible 10-year decay period at surface before emplacement in the DGR. The modelled retube waste package was compliant with the DGR Waste Acceptance Criteria (WAC) for package dose rate.

The revised pressure tube container concentrations in Table 1 simply reflect the recent changes to the inventories, decayed for 10 years. This results in a package dose rate that is higher than WAC. *Such a waste package would not be accepted at the DGR without further shielding or decay. However for conservatism and as a direct comparison, it is assumed to be accepted as-is at the DGR.*

For the accident assessment, as in the PSR Report, the radionuclide concentrations in Table 1 have been increased by a factor of 10 to represent an accident involving a small number of packages in which, conservatively, the radionuclide concentrations are higher than typical values. This higher-inventory package is assumed to have decayed for 15 years, which helps bring the implied package dose rates within the WAC. *As with the normal operation example above, for the revised concentrations, it was conservatively ignored whether the changes would result in the package dose rate exceeding WAC.*

Table 1: Radionuclide Concentrations in Pressure Tube Packages

Radionuclide	Half-Life (Years)	Normal Operations (Shielding Calculations)	Accident Assessment
		Revised Concentrations (Bq/m^3) [a]	Revised Concentrations (Bq/m^3) [b]
Am-241	4.3E+02	3.5E+08	3.4E+09
C-14	5.7E+03	2.6E+12	2.6E+13
Ce-144	7.8E-01	2.5E+00	2.9E-01
Cm-244	1.8E+01	8.2E+09	6.7E+10
Co-60	5.3E+00	2.1E+13	1.1E+14
Cs-134	2.1E+00	3.1E+09	5.9E+09
Cs-137 [c]	3.0E+01	1.5E+11	1.4E+12
Eu-152	1.3E+01	3.1E-01	2.3E+00
Eu-154	8.8E+00	4.2E+03	2.8E+04
Fe-55	2.7E+00	1.2E+13	3.2E+13

Radionuclide	**Half-Life (Years)**	**Normal Operations (Shielding Calculations)**	**Accident Assessment**
		Revised Concentrations (Bq/m^3) [a]	**Revised Concentrations (Bq/m^3) [b]**
Fe-59	1.2E-01	3.7E-12	1.1E-23
H-3	1.2E+01	2.7E+12	2.0E+13
Mn-54	8.6E-01	2.7E+08	4.7E+07
Ni-59	7.5E+04	8.9E+10	8.9E+11
Ni-63	9.6E+01	3.3E+13	3.2E+14
Nb-94	2.0E+04	2.3E+13	2.3E+14
Nb-95	9.5E-02	1.4E-08	2.1E-23
Pu-238	8.8E+01	1.5E+08	1.5E+09
Pu-239	2.4E+04	5.2E+07	5.2E+08
Pu-240	6.5E+03	9.3E+07	9.3E+08
Pu-241	1.4E+01	7.5E+08	5.9E+09
Ru-106	1.0E+00	2.7E-07	8.3E-08
Sb-124	1.7E-01	2.4E-06	3.4E-14
Sb-125	2.8E+00	1.2E+11	3.5E+11
Sn-119m	8.0E-01	3.8E+08	5.0E+07
Sr-90 [c]	2.9E+01	1.2E+10	1.0E+11
Te-125m	1.6E-01	1.0E+01	4.0E-08
U-235	7.0E+08	1.6E+03	1.6E+04
U-238	4.5E+09	4.1E+05	4.1E+06
Zr-93	1.5E+06	6.9E+11	6.9E+12
Zr-95	1.8E-01	2.0E-01	8.8E-09

Notes:

a. Revised pressure tube concentrations, including garter springs. 10 years decay before transfer to DGR.

b. Revised pressure tube concentrations, including garter springs. 15 years decay before transfer to DGR. The concentrations have also been increased by a factor of 10 to represent a maximum package inventory for accidents involving a small number of packages.

c. Cs-137 and Sr-90 assumed in secular equilibrium with their short-lived daughters.

3. PRECLOSURE SAFETY ASSESSMENT METHODOLOGY

The preclosure safety assessment methodology is described in Section 7.4 of the PSR for normal operations and Section 7.5 for accidents, specifically:

- Section 7.4.4.1 for assessment of external radiation on workers and public during normal operations; and
- Section 7.5.3 for methodology for consequence assessment for accidents.

Malevolent Acts scenarios are described in Section 6 of the Malfunctions, Accidents and Malevolent Acts Technical Support Document (AMEC NSS 2011). The methodology used in calculating dose to a member of the public was described in OPG's response to the Information Request EIS-06-248 (OPG 2012).

A member of the public is conservatively assumed to be at the nearest Bruce nuclear site boundary from the DGR.

4. RESULTS

4.1 RADIOLOGICAL SAFETY DURING NORMAL OPERATIONS

4.1.1 Radiological Assessment of Air and Water Emission from DGR on Workers and Public

During normal operations, the retube waste package arriving at the DGR is sealed tight (Section 8.3.3.1 of OPG 2006). Therefore, radioactive release to air and water and potential exposure to public during normal operations is not expected. In addition, there is no inhalation dose to the workers as the package is air tight.

4.1.2 Assessment of External Radiation on Workers and Public

Shielding calculations were carried out for workers handling representative low level and intermediate level containers during normal operations (Section 7.4.4.1 of OPG 2011b).

This scenario considers the handling of a single pressure tube waste container (RWC-PT) in the Waste Package Receipt Building (WPRB) (Scenario 2). Figure 7-6 of OPG (2011b) illustrates the receptor locations. The worker external dose results are given in Table 7-22 of OPG (2011b).

Table 2 shows the estimated external worker dose due to the handling of a RWC-PT for the revised pressure tube radionuclide concentrations. As discussed in Section 7.4.4.2 of OPG (2011b), the calculations indicate potentially high dose rate in the WPRB for the RWC-PT, and show that a wall around the WPRB staging area similar to WWMF Low Level Storage Building walls will need to be incorporated in the detailed design to ensure that the external dose rate outside of the WPRB remains below 25 µSv/h and that the dose rate in the office/main control room is below 10 mSv/year. These will be addressed during the detailed design.

Furthermore, the waste packages would be required to meet DGR WAC for package dose rate. These packages with the revised concentrations would not be consistent with the WAC, and therefore either further shielding or further decay would be included before the packages were accepted at the DGR. *That is, the results presented in Table 2 are conservative.*

Since RWC-PT containers are not stored in the WPRB staging area, the dose rate to the member of the public at the Bruce site boundary (about 1 km distant) due to handling of RWC-PT would be very low even with the revised inventories.

Table 2: Worker External Dose Rates for Retube- Pressure Tube (Scenario 2)

Receptor Location [a]	Location Description	Estimated Worker Dose Rate - PSR Results (Table 7-22 of OPG 2011b) (mSv/h)	Estimated Worker Dose Rate due to Revised Radionuclide Concentrations (mSv/h) [b]	Allowable Occupancy - PSR Results [c] (Table 7-22 of OPG 2011b) (h/year)	Allowable Occupancy at Estimated Dose Rate due to Revised Radionuclide Concentrations [b,c] (h/year)
R1	In the adjacent offices and control room	(d)	(d)	(d)	(d)
R2	Standing outside the WPRB [e]	5.7E-03	2.2E-02	1800	440
R3	Inside the package loading area (forklift driver moving waste packages, 2 m away)	4.8E-02	1.9E-01	210	53
R4	On the roof directly above the source	7.7E-04	3.1E-03	>2000	>2000

Notes:

a. Receptor location is shown in Figure 7-6 of OPG (2011b).
b. Modelled waste package exceeds DGR WAC for dose rate, and would require additional shielding or decay to be accepted at DGR. But this is conservatively ignored in this analysis.
c. Allowable occupancy without other mitigating measures, based on OPG occupational dose target of <10 mSv/year (footnote in Table 7-22 of OPG 2011b).
d. Detailed design of WPRB building/wall will ensure that workers in this location are below 10 mSv/year dose target (footnote in Table 7-22 of OPG 2011b).
e. Based on concrete shielding wall around the staging area with thickness about 38 cm to ensure that the external dose rate outside of the WPRB is below 25 µSv/h (footnote in Table 7-22 of OPG 2011b).

4.2 ACCIDENT ASSESSMENT

The accident assessment considered the potential consequences of bounding scenarios for fire, container breach (low and high energy), and inadequate package shielding (Section 7.5.1.5 of OPG 2011b). Retube waste packages are robust and designed not to fail under accident conditions including drop from stacking height (Section 8.3.6.1 of OPG 2006). In Section 7.5.1.5 of OPG 2011b, the retube- end fittings container (RWC- EF) was considered as representative retube waste for analysis of consequences of a high energy breach due to cage fall in the underground repository.

Breach of RWC-PT is considered here to study the implication of the revised inventory in pressure tubes. Both high energy breach due to cage fall and low energy breach in the emplacement room are analysed and reported below. Fire scenario is not considered as retube waste and containers are sealed and not combustible. Inadequate package shielding is discussed in Appendix A.2.2.3 of OPG 2011b).

The assumed radionuclide concentrations for pressure tube package with revised inventory are given in Table 1. The radionuclide concentrations for pressure tube package for the PSR inventory are based on Table B.3 of OPG (2010), further decayed by 10 years and also increased by a factor of 10.

The acute accident dose limit is 1 mSv for the public and 50 mSv for the workers (Section 7.1.2.1 of OPG (2011b)).

4.2.1 Cage Fall with Retube Waste Package Breach

In a highly unlikely "what if" scenario, due to mechanical failure of the hoisting system (i.e., failure of multiple cables or the redundant braking system), the cage and a RWC-PT inside the cage are assumed to fall down the shaft into the shaft bottom located 30 m below the underground DGR working level (Appendix A.3.3.1 of OPG 2011b). The retube waste package is assumed to breach and release its entire contents.

The accident release factors for a pressure tube package are assumed to be the same as for an end fitting package, and are given in Table A-50 of OPG (2011b). The inhalation, immersion and external radiation pathways are considered, with the assumptions given in Appendix A.3.3.1 of OPG (2011b). The dose results for RWC-PT are given in Table 3 for workers and in Table 4 for the public for both the revised and PSR inventory cases. The results for RWC-EF, listed in Tables A-51 and A-52 of OPG (2011b), are also given in the following tables.

Table 3 shows that the total radionuclide doses to workers over a 5 minute period (through inhalation, immersion and external radiation) are less than the acute accident dose limit for workers (50 mSv) for both the revised and PSR retube- pressure tube inventory cases and retube- end fittings case. Similarly, Table 4 shows that the total dose to the public (through inhalation and immersion) at the nearest Bruce nuclear site boundary from the DGR over 1 hour exposure duration is much less than the acute accident dose limit for public (1 mSv) for both the revised and PSR RWC-PT inventory cases and RWC-EF case. The key dose contributors are Nb-94, Co-60 and, for the revised pressure tube inventory, Cm-244.

Table 3: Dose to Workers - Cage Fall with Retube Waste Package Breach

Selected Waste Category	Inhalation (mSv)	Immersion (mSv)	External Radiation (mSv)	Total (mSv)
Retube- Pressure Tubes (Revised Inventory)	6.3E+00	1.3E-01	< 1.0E-06	6.4E+00
Retube- Pressure Tubes (PSR Inventory)	4.5E+00	8.5E-02	< 1.0E-06	4.5E+00
Retube- End Fittings	5.6E+00	2.3E-01	< 1.0E-06	5.8E+00

Table 4: Dose to Public - Cage Fall with Retube Waste Package Breach

Selected Waste Category	Inhalation (mSv)	Immersion (mSv)	Total (mSv)
Retube- Pressure Tubes (Revised Inventory)	4.2E-03	3.8E-04	4.6E-03
Retube- Pressure Tubes (PSR Inventory)	2.1E-03	2.4E-04	2.3E-03
Retube- End Fittings	3.4E-03	6.7E-04	4.1E-03

4.2.2 In Room Retube Waste Package Breach

The retube waste package is robust and designed not to fail under accident conditions, including a drop from stacking height (Section 8.3.6.1 of OPG 2006). Therefore, releases from breached package are expected to be minimal. Because the package remains intact, potentially only gaseous radionuclides and very fine particulate might be released. Therefore potential impacts due to release of radioactive particulates/volatile species (through inhalation and immersion) are considered only.

In this scenario, a row of RWC-PTs (3) is assumed to be breached. The RWC-PT can be stacked two high and three wide in the emplacement room, so this is equivalent to the top front row of containers falling.

The accident release factor parameters for the pressure tube package, which are the same for end fittings and for pressure tubes, are given in Table 5. They are based on Tables 7-32, 7-33 and 7-34 of OPG (2011) and a leakpath factor (LPF) of 1.

Table 5: Accident Release Factor Parameters - In-Room Retube Package Breach

Selected Waste Category	# of Packages	Damage Ratio (DR)	Airborne Release Fraction (ARF)	Respirable Fraction (RF)	LPF
Retube - Pressure Tubes	3	0.05	0.0001	0.1 [a]	1

Note:

a. RF for volatile species such as gaseous C-14 as CO_2 and H-3 as tritiated water is taken to be 1. In the breach scenario, 25% of the released C-14 is considered as particulate, while 75% is considered as CO_2 (Section 7.5.3.4 of OPG 2011b). 100% of the released H-3 is volatile.

The dose results for RWC-PT are given in Table 6 for workers and Table 7 for the public for both the revised and PSR inventory cases. Table 6 shows that the total radionuclide doses to workers over a 5 minute period (through inhalation and immersion) are less than the acute accident dose limit for workers (50 mSv) for the pressure tube package. Similarly, Table 7 shows that the total dose to the public (through inhalation and immersion) at the nearest Bruce nuclear site boundary over 1 hour exposure duration is much less than the acute accident dose limit for public (1 mSv). The key dose contributors are Nb-94, Co-60 and, for the revised inventory, Cm-244.

Table 6: Dose to Workers - In-Room Breach of Pressure Tube Package

Selected Waste Category	Inhalation (mSv)	Immersion (mSv)	Total (mSv)
Retube- Pressure Tubes (Revised Inventory)	4.7E-01	2.0E-02	4.9E-01
Retube- Pressure Tubes (PSR Inventory)	3.3E-01	1.3E-02	3.5E-01

Table 7: Dose to Public - In-Room Breach of Pressure Tube Package

Selected Waste Category	Inhalation (mSv)	Immersion (mSv)	Total (mSv)
Retube- Pressure Tubes (Revised Inventory)	3.1E-04	5.7E-05	3.7E-04
Retube- Pressure Tubes (PSR Inventory)	1.6E-04	3.7E-05	1.9E-04

4.3 MALEVOLENT ACTS

The Malevolent Acts considered the following scenarios as provided in OPG's response to the Information Request EIS-06-248 (OPG 2012):

a) Deliberately driving a forklift into a package or dropping a package during handling
b) Pushing a package or vehicle into the shaft
c) Setting waste packages on fire
d) A person using an explosive or incendiary device
e) Remote military-style attack from the site boundary
f) Aircraft crash.

The public dose estimate for each of the above scenario is given in OPG's response to the Information Request EIS-06-248. The radionuclide concentrations for retube- pressure tube package are given in Table 1. The potential radiological consequences from retube- pressure tube containers to a member of the public are discussed below:

- For Scenario (a), the radiological consequence of the malevolent act would be limited to the breach of the retube waste packages directly affected. Since the retube waste packages are robust, the radiological consequence to a member of the public is limited. The public dose is estimated to be $\leq$ 0.0004 mSv for the revised inventory case and $\leq$ 0.0002 mSv for the PSR inventory case due to the breach of three RWC-PTs (Table 7).

- For Scenario (b), the radiological consequence from pushing a RWC-PT into the shaft is estimated to be about 0.005 mSv to a member of the public for the revised inventory case and about 0.002 mSv for the PSR inventory case (Table 4).

- Retube waste is not combustible, and therefore Scenario (c) is not applicable.

- For Scenario (d), the consequences would be limited by the amount of explosives that an employee could smuggle into the DGR and place near a retube waste package, e.g., during transfer to underground. As discussed in OPG's response to the Information Request EIS-06-248, the consequence of an explosion may be estimated based on experimental data on the fragmentation of metal from a pressure impulse directed outward through the material (Section 3.3.1.3 of NRC 1998). The experimental data correlates the airborne release fraction (ARF) and respirable fraction (RF) to the ratio of inert mass to the mass of high explosive, specifically, the TNT-equivalent mass, referred to as the mass ratio. The reference data provides estimates for mass ratios up to 24.

  For the purpose of this calculation, the mass of explosive is taken to be 100 kg (equivalent to about 160 kg of TNT). The retube waste package is robust and heavy (a pressure tube package weighs about 29,100 kg (pg. 122 of OPG 2010). Therefore, the mass ratio for one package is about 180. Consequently, using data for a mass ratio of 24 effectively assumes much more explosives.

  At a mass ratio of 24, the ARF and RF are found to be 0.366 and 0.0242 respectively (Table 3-6 of NRC 1998). The damage ratio (DR) and the leakpath factor (LPF) are conservatively set to 1. The public was assumed to be exposed for one hour at the nearest Bruce site boundary; the atmospheric dispersion factor (ADF) for the public is given in Table 7-36 of OPG (2011b). The public dose due to breaching of one RWC-PT resulting from detonation of explosives is estimated to be 3 mSv for the revised inventory case and 2 mSv for the PSR inventory case. This is around the annual natural background dose level of 2 mSv.

- For Scenarios (e) and (f), the radiological consequence of this malevolent act would be limited by the number of waste packages in the WPRB. Since retube waste packages are not stored in the WPRB staging area, the retube waste package is not affected by remote military-style attack from the site boundary and aircraft crash. Instead, because the retube waste packages are emplaced underground, they are protected by several hundred metres of rock.

In summary, the estimated public dose for each of the Malevolent Acts scenarios except Scenario (d) is much less than 1 mSv for both the revised and PSR pressure tube inventory cases. For Scenario (d), the estimated dose to a person at the nearest site boundary from detonation of explosives is around the annual natural background dose of 2 mSv.

5. CONCLUSIONS

Analyses were performed to show how the revised retube-pressure tube inventory affects the preclosure safety assessment of the DGR and to estimate the potential public dose of malevolent acts.

- For normal operations, there are no impacts to the public from airborne and waterborne release from the retube waste package and no inhalation dose to the workers due to air-tightness of the package. However, worker doses need to be monitored when handling the retube waste. The potential external dose rates to the workers have increased as a result of the revised retube-pressure tube concentrations, mostly due to an increase in Co-60 concentration. However, the radiation fields on all waste packages are monitored, and must meet the DGR WAC, either through additional shielding or longer decay time before transfer to the DGR. If necessary, the dose rates would be further reduced by limiting worker exposure time, use of shielded forklifts, and/or use of greater stand-off distances. This would be considered further within the context of the final ALARA assessment.

- The total doses to workers for both accident assessments (i.e., cage fall and low energy breach of retube-pressure tube packages) over a 5 minute period are less than the acute accident dose limit for workers (50 mSv) for both the revised and PSR pressure tube inventory cases. In addition, the total doses to the public at the nearest Bruce nuclear site boundary over 1 hour exposure duration are much less than the acute accident dose limit for public (1 mSv) for both the revised and PSR pressure tube inventory cases.

- For the Malevolent Acts scenarios, the estimated public doses are much less than 1 mSv for both the revised and PSR pressure tube inventory cases. The exception is the scenario involving using explosives on a retube waste package, where the estimated public dose is around the annual natural background dose of 2 mSv for both the revised and PSR pressure tube inventory cases.

For normal operations, the estimated worker external dose rates for the revised pressure tube inventory case are about 4 times higher than those for the PSR pressure tube inventory case with the same package and decay times. However, such a waste package in reality would not be accepted at the DGR without further shielding or decay if it did not meet the DGR WAC, so the actual difference would be smaller.

For accidents, malfunctions and malevolent acts, the estimated doses for the revised pressure tube inventory case are up to about twice of those for the PSR pressure tube inventory case.

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ATTACHMENT C

TO

OPG RESPONSE TO IR-EIS-13-514

WASTE INVENTORY VERIFICATION PLAN

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1. PURPOSE

The purpose of this document is to summarize the activities underway and planned at Ontario Power Generation (OPG) to continue to measure and verify the properties of the Low & Intermediate Level Wastes (L&ILW) arising from operations and refurbishment of OPG-owned or operated nuclear generating facilities and intended for disposal in the proposed Deep Geologic Repository (DGR). This document has been prepared in response to Information Request EIS-13-514. The work is implemented by formal Plans within the OPG management system.

2. OBJECTIVE

The objective of this waste inventory verification plan is to determine with reasonable confidence the radionuclide activity to be placed in the DGR. It covers the next several years leading to application for an Operating Licence.

3. BACKGROUND

OPG is proposing the development of a Deep Geologic Repository (DGR) for the long-term management of L&ILW from OPG-owned or operated nuclear generating facilities. The DGR would be located on the Bruce nuclear site.

L&ILW has been stored at the Bruce nuclear site since the start of the OPG (then Ontario Hydro) nuclear power program in the early 1970's. These wastes are currently largely stored at OPG's Western Waste Management Facility (WWMF) in interim at-surface and in-ground storage structures. Approximately 95,000 m^3 of waste packages are presently at WWMF.

L&ILW consists of a variety of waste types which are generated from activities in support of CANDU power stations, and in particular from the operations of the Pickering, Bruce and Darlington stations. It does not include high-level waste or used fuel.

All waste packages received at WWMF are characterized by dose rate measurements and other physical properties required to ensure that they meet the Waste Acceptance Criteria for either processing or storage at WWMF. Other waste characterization activities have also been underway since the 1970's to obtain more detailed information on waste streams and packages. Starting around 1999, OPG initiated a formal waste characterization program to provide consistent data on a range of alpha, beta and gamma emitting radionuclides in the L&ILW. The initial focus of this program was on operational wastes.

Operational wastes are those generated during the routine operations of the reactors, and include cleaning materials, tools, equipment and filters that are lightly contaminated during use in the reactor buildings, as well as filters, ion exchange resins and replaceable core components that are exposed to Primary Heat Transport (PHT) or moderator or other higher activity sources.

In addition to operational wastes, refurbishment wastes include components that are replaced only as part of a major reactor mid-life refurbishment. This is primarily steam generators and fuel channel components. The initial design basis for the DGR included refurbishment components from Pickering B, Bruce A and B, and Darlington. (Pickering A refurbishment wastes are stored at the Pickering site and will be disposed of during station decommissioning.)

Currently only Bruce A refurbishment components are in storage at WWMF as refurbishment of the other stations are still in the planning stages. It has also been decided not to refurbish Pickering B, so that retube waste will therefore not be generated from this station.

The preliminary design of the DGR and its supporting preliminary safety case have been based on assumptions and data that are derived primarily from these waste characterization investigations. The status of the waste information was documented in the DGR Reference Inventory report. The first comprehensive summary of information relevant to the proposed DGR was prepared as the Revision 0 (R0) Reference Inventory report in 2006. This information was used in the draft preliminary safety assessment, and served in part to identify what were the likely important radionuclides and waste types. This in turn identified priorities for future work in waste characterization.

The next Revision 1 (R1) Reference Inventory report was released in 2008, and was posted to the OPG website for public information. R2 was an internal update, and R3 was released publicly in 2010. R3 (OPG 2010) was used as the basis for the DGR Preliminary Safety Report, submitted in 2011.

The Reference Inventory report provides a comprehensive summary of the information available on the operational and refurbishment L&ILW intended for placement in the OPG DGR. It includes waste volume projections based on an assumed operating lifetime for the current OPG-owned or operated reactors. It includes radionuclides relevant to long-term safety, waste physical characteristics, and a description of the main container types. R3 (OPG 2010) was released as a public record to provide a detailed technical summary of the basis for the DGR inventory.

The R3 Reference Inventory report was based on a combination of measurements, models and estimates. Models and estimates are used in part because some of the inventories had not yet been measured. In particular, there was less information on radionuclides considered to be less important to the safety case. Also about half of the estimated 200,000 m^3 DGR capacity has been received at the WWMF. The remainder of the wastes will be generated over the next approximately 40 years of planned operation of the existing reactors. This includes most of the refurbishment wastes, which have not yet been generated. A description of the uncertainties was provided in the Reference Inventory report.

Accordingly, OPG has an ongoing waste characterization program that is improving the information and reducing uncertainties. The waste characterization program also includes characterizing the physical composition of the wastes, including the presence of hazardous elements, and the amounts of metals and organic materials.

This document presents the waste inventory verification plan. It covers the next several years leading to application for an Operating licence. It is implemented within the OPG governance system through a formal set of documents, which include the Waste Characterization Work Program, the multi-year Waste Characterization Plan, and annual work plans.

Section 4 describes key aspects of the Reference Inventory, Sections 5 to 8 describe the methods used for operational LLW, operational ILW and refurbishment L&ILW. The verification plan and timelines are described in Section 9.

4. REFERENCE INVENTORY

Table 4.1 provides an overview perspective on the waste characteristics. It groups the various waste types into eight main categories. For each category, it provides the estimate of total radioactivity and the number of containers that would be in the DGR at 2062, the earliest assumed time of closure. This information is from the 2010 Reference Inventory report.

Table 4.1 provides some perspective on the importance of the different wastes types. It indicates for example that the bulk of the radioactivity is in the Retube Waste, and that the bulk of the waste volume (represented approximately by the number of containers) is Non-Processible Waste.

The *relevant radionuclides* for the DGR are identified in the Reference Inventory report. This is based on the following considerations:

- Radionuclides that are measured to contribute significantly to the total activity in wastes as-received at WWMF.
- Radionuclides that were identified as potentially important to safety assessment using preclosure and postclosure screening analyses.
- Comparison with radionuclides tracked in similar inventory reports for other nuclear reactor waste management organizations.
- Short-lived daughter radionuclides are generally included with their parent, assuming secular equilibrium.

The *key radionuclides* for the DGR are those that dominate the dose consequences in normal or abnormal scenarios at the DGR. Based primarily on the results documented in the Preliminary Safety Report (OPG 2011) and its supporting analyses, the following are key radionuclides for preclosure and/or postclosure safety: H-3, C-14, Cl-36, Fe-55, Co-60, Ni-59, Ni-63, Zr-93, Nb-94, I-129, Cs-137, U-238, Pu-239, Cm-244.

Table 4.1: Summary Parameters

Waste Category	Total Activity at DGR in 2062 (TBq)	Number of Containers in DGR at 2062
LLW		
Incinerator ash	0.3	1,100
Compacted wastes	280	7,500
Non-processible wastes	580	32,200
Low level resins and sludges	1.6	3,900
Steam generators (from refurbishment)	17	500
Sub-total LLW	**880**	**45,200**
ILW		
Ion exchange (IX) resins	5,600	1,600
Filters, core components, miscellaneous	130	4,500
Retube (from refurbishment)	10,000	1,400
Sub-total ILW	**16,000**	**7,400**
Total	**17,000**	**52,600**

5. METHODS

The characteristics of the wastes are determined using direct measurement, scaling factors and activation calculations.

5.1 Direct Measurement

Direct measurement of radionuclides is typically by gamma spectrometry for gamma emitters, and by radiochemical analysis for alpha and beta emitters. The typical radiochemical processes involve liquid scintillation and alpha/beta proportional flow counting. The standard radiochemical methods used for some important radionuclides are listed in Table 5.1.

However for some radionuclides, especially those that are present at low levels, special method development may be needed. Of particular relevance to the post-closure safety assessment for the L&ILW DGR is Zr-93. This is a dominant radionuclide in the long-term and is mostly in retube waste. As it is long-lived and a beta-emitter, it is not readily measured, especially with the large background of stable zirconium isotopes present in the wastes. As it is not particularly important for operational safety, it has not been widely studied within prior OPG radionuclide characterization studies. Therefore, over the past two years, OPG has supported work to develop a standard radiochemical measurement approach (Wu et al 2013).

5.2 Scaling Factors

Scaling factors may be used for difficult-to-measure (DTM) radionuclides, typically alpha or beta emitters. In this approach, the amount of a DTM nuclide is estimated based on measurement of an easy-to-measure (ETM) nuclide and a scaling factor. The method is applicable when there is a correlation between the concentration of the DTM and the ETM nuclides.

Typically ETM nuclides are gamma-emitters like Co-60, Cs-137 and Nb-94.

Scaling factors may be developed based on direct measurements of DTM and ETM radionuclides (using methods as outlined in Section 5.1), or through models or calculations.

Scaling factors are semi-empirical. They have been found to be useful for a variety of radionuclides, and they are widely used internationally (ISO 2007, IAEA 2009). As they are semi-empirical, however, the specific applications need to be verified with measurements.

5.3 Activation Calculations

For in-core components, neutron activation calculations can be used to determine the radionuclide concentrations. Within Canada, ORIGEN-S is the industry standard code (ORNL 2014).

Neutron activation calculations are particularly useful for activation of primary alloying elements. For activation of trace elements, the calculation accuracy depends on knowledge of the trace element composition, or at least of bounding values from material specifications. Activation calculations are not applicable for radionuclides present from other mechanisms, such as from sorption from coolant.

Neutron activation calculations are useful for projecting the end-of-life inventory in components not presently available as a waste and in particular retube wastes. They are also suitable for estimating inventories of radionuclides that may be present in smaller amounts and not easily measured. Finally activation calculations can account for variations in inventory due to flux profiles across the reactor core.

Table 5.1: Methods Used to Measure Radioactivity of Several Radionuclides

Radionuclide	Type of Matrix	Principles of Determination	Methodology of Chemical Separation
Co-60 Cs-137 Nb-94 (gamma emitters)	• Solid • Aqueous	• Gamma spectrometry	• Chemical separation is not generally needed for important gamma emitters for purposes of waste inventory characterization. • Samples may be allowed to decay so that dominant but shorter-lived gamma emitters decay, so that less intense but longer-lived gamma emitters can be measured.
Zr-93	• Solid	• Liquid scintillation counting.	• Challenge in Zr-93 analysis for pressure tubes is that stable Zr is also the dominant constituent of the matrix. • Sample dissolved in acid and further processed using wet chemistry procedures, including cleanup with IX resins, to remove interfering species.
Sr-90	• Solid • Sample dissolved in acid; insoluble material is heat fused and combined with acid digested sample.	• Liquid scintillation or beta counting is used to measure Y-90, the daughter product in equilibrium with Sr-90. • Beta counting is the preferred technique; it is particularly useful for lower activity samples.	• Solvent extraction is performed to separate Sr-90 from other radionuclides including the existing daughter product Y-90. • Y-90 is allowed to re-equilibrate with Sr-90. The time period for this is 7-10 days. • Sr-90 is estimated from the measured Y-90 activity.
Pu-238 Pu-239/40 Am-241 Cm-242 Cm-244 (alpha emitters)	• Solid • Sample dissolved in acid; insoluble material is heat fused and combined with acid digested sample.	• Alpha spectrometry	• Precipitations are performed to remove undesired elements and radionuclides (including Ni-63 if present). The aqueous acidic phase contains the desired alpha emitting radionuclides along with Fe-55 (if present). • The aqueous phase radionuclides are transferred on to ion exchange media and then sequentially eluted. All Pu species are thus separated from Am-241 and Cm species. Fe-55 (if present) is also separated out. • The radionuclides are then precipitated, filtered and counted.

Radionuclide	Type of Matrix	Principles of Determination	Methodology of Chemical Separation
Pu-241	• Solid • Sample dissolved in acid; insoluble material is heat fused and combined with acid digested sample.	• Liquid Scintillation Counting or Induction Coupled Plasma	• See method for determining alpha emitters. • Filtered precipitates containing Pu species are re-dissolved and prepared for Pu-241 analysis.
Fe-55	• Solid • Sample dissolved in acid; insoluble material is heat fused and combined with acid digested sample.	• Liquid scintillation counting	• See method for determining alpha emitters. • Eluant from ion exchange resin column is prepared for analysis.
Ni-63	• Solid • Sample dissolved in acid; insoluble material is heat fused and combined with acid digested sample.	• Liquid scintillation counting	• See method for determining alpha emitters. • N-63 is extracted from the precipitates (see first bullet under alpha emitters).
C-14	• Solid • IX Resins	• Liquid scintillation counting	• Generally digestion in acide is required to dissolve the matrix and free up C-14 present in CO_2 form. • C-14 is stripped from IX resins using acid, where the carbonate or bicarbonate species attached to resin is released as CO_2. • If C-14 is in non-CO_2 form, then sample must be combusted to convert all C-14 into CO_2 form.
Cl-36	• IX Resins	• Liquid scintillation counting	• Chlorine in the chloride form is stripped from the resin. • Series of precipitations and extractions are performed to remove interferences. • A large sample (~50 g) is typically required to obtain an appropriate Minimum Detection Limit (MDL).
I-129	• IX Resins	• Liquid scintillation counting	• Iodine is stripped using a basic solution. • Series of extractions are performed to remove interferences; also chemical treatments are performed to convert all the iodine to the highest oxidation state. • A large sample (~50 g) is typically required to obtain an appropriate MDL.

6. OPERATIONAL LLW

Table 6.1 presents the main types of Operational LLW, and the key activities to characterize and verify the inventory in these wastes.

Figure 6.1 shows a simple gamma spectrometry configuration for a side measurement of an LLW bin.

Table 6.1: Key Verification Activities for Operational LLW

Waste Category	Waste Types	Verification
Incinerator Ash	• Baghouse and bottom ash from current and previous incinerators	• Not expected to be significant waste type with respect to radionuclide inventory. • Complete sampling and analysis in particular, DTM nuclides in old ash and new bottom ash.
Compacted Wastes	• Baled wastes (older process) • Compacted wastes with current high-force compactor.	• Further sampling and analysis, in particular, DTM nuclides in old baled wastes.
Non-Processible Wastes	• Non-processible containers • Non-processible drums • Feeder pipes • Auxiliary heat exchangers • Other wastes (sealed sources, magnetite)	• Further sampling and analysis to ensure data representativeness due to waste heterogeneity. • Further waste composition data through container sampling, and review of waste receipt records and station/WWMF data. • Gamma spectrometry of containers to extend the marker nuclide information.
Low Level Resins and Sludge	• Low Level / Active Liquid Wastes resins and sludge	• Not expected to be significant waste type. • Complete sampling and analysis for DTM nuclides.

Figure 6.1: Gamma Spectrometry of LLW Container

7. OPERATIONAL ILW

Table 7.1 presents the main types of Operational ILW, and the key activities to characterize and verify the inventory in these wastes.

Figure 7.1 shows a typical sample probe used to collect an array of resin specimens from a resin waste tank or container.

Figure 7.2 shows the equipment that can be used to obtain a gamma spectrometry profile of high-activity core components as they are being unloaded from a transport package into an in-ground container.

Table 7.1: Key Verification Activities for Operational ILW

Waste Category	Waste Types	Verification
IX Resins - primary systems	• PrimaryHeat Transport (PHT) resins • Moderator resins • IX columns (Pickering)	• Key waste types for DGR, notably C-14. • Additional sampling and analysis to ensure C-14 inventory has low uncertainty, including ensuring data representativeness (station/unit differences). • Sampling and analysis also needed to provide complete coverage for all DTM nuclides.
IX Resins - auxiliary systems	• Fuel Bay filters • Tritium Removal Facility resins • Heavy Water Upgrader resins • CANDECON resins	• Additional sampling and analysis needed to ensure sufficient coverage of range of resins, and of DTM nuclides. • Future plans for use of CANDECON to be reviewed to determine importance of further CANDECON data.
Filters	• PHT and Fuelling Machine filters • Heavy Water Upgrader filters • Moderator purification system filters • Other miscellaneous filters	• Gamma spectrometry using equipment in Figure 6.1. • Additional sampling and analysis needed to ensure sufficient coverage of DTM nuclides, especially for Fuelling Machine filters. Due to high radiation fields, it may be most feasible to characterize DTM nuclides through crud samples from various systems.
Core components	• Flux detectors	• Sampling and analysis needed to validate activation analyses.

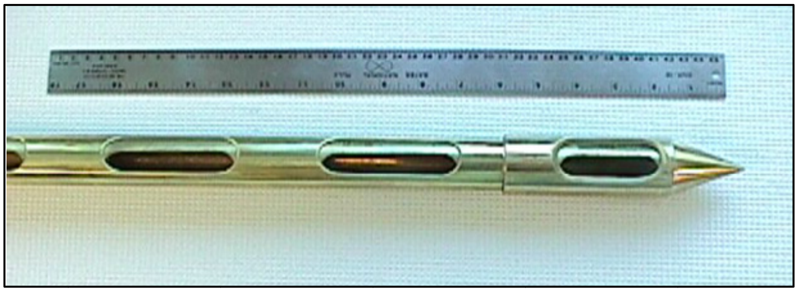

Figure 7.1: IX Resin Sample Probe

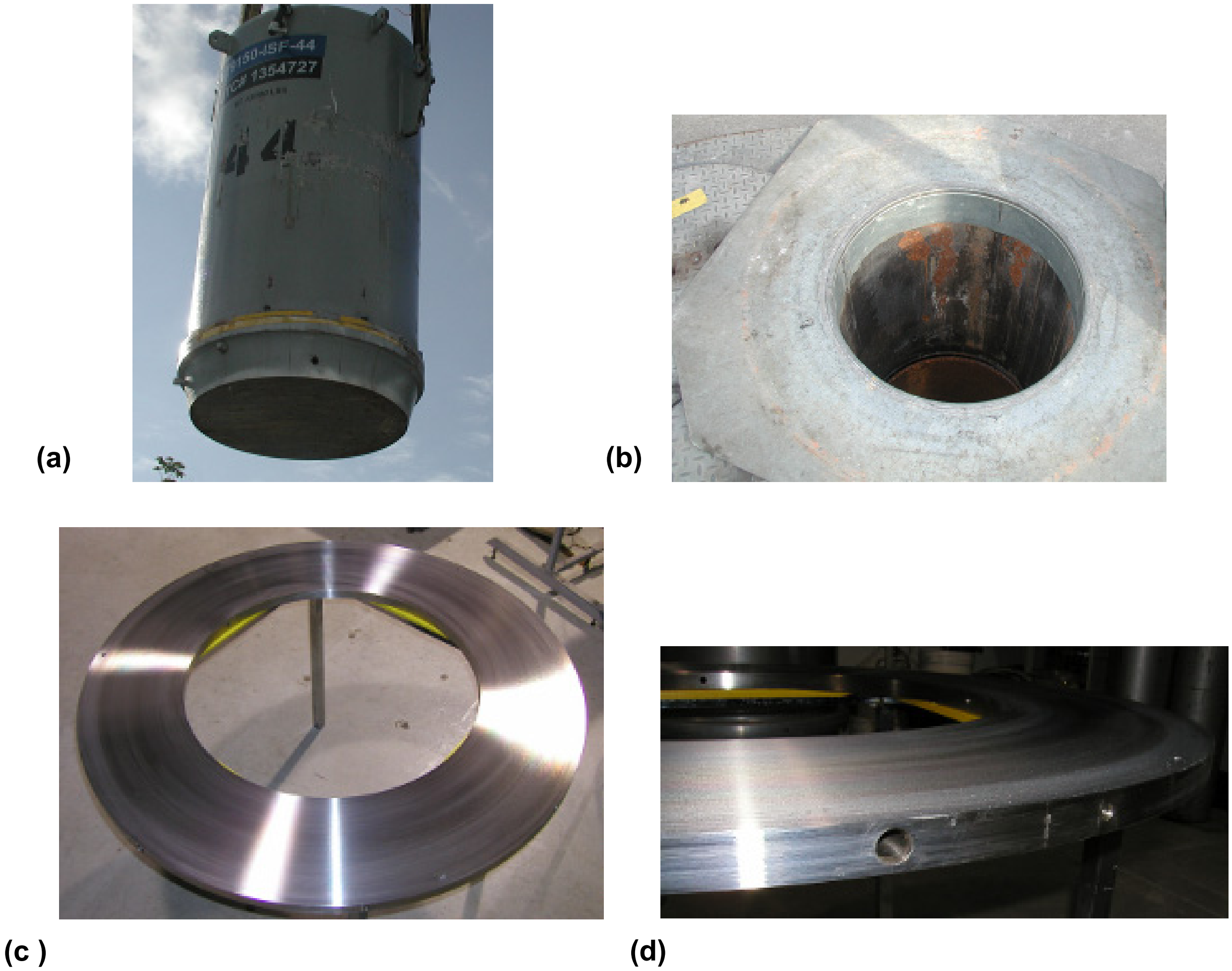

Figure 7.2: Equipment for Gamma Spectrometry of High Activity ILW Filters or Core Components during Placement into In-ground Containers

(a) Transfer Package; (b) Open In-ground Container; (c) Detector shielding disk placed between Transfer Package and In-ground Container; (d) holes in shielding disk where gamma spectrometers are placed. Measurements are obtained while the contents of the transfer packages are lowered into the in-ground containers.

8. REFURBISHMENT L&ILW

Table 8.1 presents the main types of Refurbishment L&ILW, and the key activities to characterize and verify the inventory in these wastes.

Figure 8.1 shows a photo of the oxiprobe delivery system, currently in use for obtaining axial profiles of activity along steam generator tubes.

Table 8.1: Key Verification Activities for Refurbishment L&ILW

Waste Category	Waste Types	Verification
Steam Generators (SGs)	• Shell and tubes	• SG gamma scanning data. • Complete sampling and analysis to ensure data representativeness (profile, end-of-life, data for other Bruce SGs planned for DGR).
Retube components	• Pressure tubes • Garter springs/ Girdle wires • End fittings and Shield Plugs • Calandria tubes • Calandria tube inserts	• Pressure tubes are a key DGR waste type, especially for Nb-94 and Zr-93. • Sampling and analysis to validate activation calculations for activation radionuclides and scaling factors for surface deposit radionuclides. • Data representativeness to consider all stations and axial profile. • Archived (older) samples may be used to validate the models at first, with verification against actual retube wastes after they are generated.

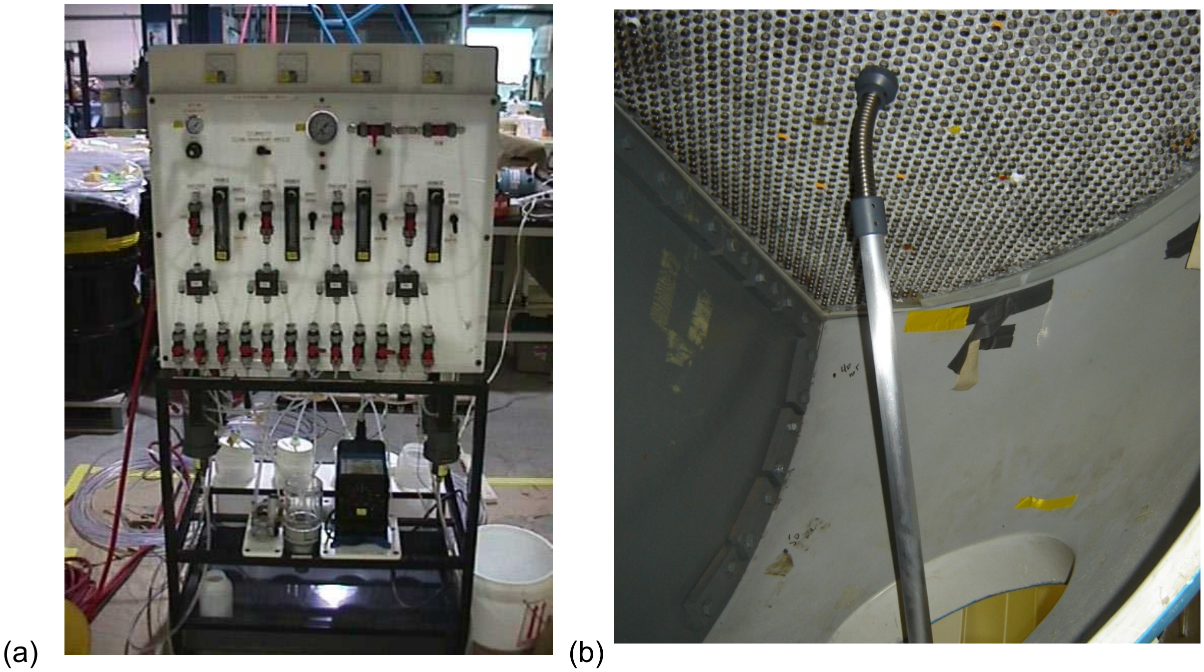

Figure 8.1: Oxiprobe System for Measuring Gamma Activity in Steam Generators

(a) Delivery system controls, (b) Mockup showing probe insertion from steam generator bottom manway access into tubesheet.

9. PLAN

The main elements of the waste characterization plan are:

- Work Program Definition
- Data Quality
- Verification.

These are discussed below. This plan is compliant with international guidelines (IAEA 2007).

9.1 Work Program Definition

The Work Program defines the corporate responsibilities and business planning authority for undertaking waste characterization activities. This ensure that waste characterization is included within the business planning cycles for the stations, WWMF and other supporting groups. The waste characterization program will incorporate this Waste Inventory Verification Plan.

Status: OPG is presently defining a new Waste Characterization Work Program. The governance is expected to be completed by end-2014. The Work Program in turn is implemented through a multi-year Waste Characterization Plan.

9.2 Data Quality

Data quality define the targets for data from waste sampling. This is a graded program that includes minimum number of sampling, and expectations regarding more sampling for more important waste types. The current waste types are listed in Tables 5.1, 6.1 and 7.1.

Status: The waste characterization program is proceeding under the following guidelines:

- Screening. Acquire at least 3 data/nuclide/waste type for radionuclides identified in the Reference Inventory report. This would primarily serve as a screening test, i.e., it could provide positive confirmation that some nuclides in some waste types were sufficiently low that they were insignificant to the overall safety case and further data was a low priority. Or conversely that they were potentially significant enough to warrant further data. It would also provide a basic validation for activation calculation models. In general, the results would require evaluation to document that this data was sufficient for specific nuclide/waste types.

- Uncertainty basis. Acquire sufficient data for radionuclides identified as potentially important to the safety case to support the calculation of statistical quantities, notably the 95th percentile upper confidence limit in mean value, using statistical software such as U.S. Environmental Protection Agency ProUCL (US EPA 2013). This upper confidence limit can be used to determine, for each nuclide/waste type, whether the uncertainty is important to the safety case and more data is desirable in order to reduce the upper confidence limit value. As a general rule, a minimum 10 data/nuclide/waste type are needed for statistical analysis. These data points should include at least 2 from each station where appropriate, and cover an extended timeframe, in order to provide basic information on variability between stations and over time.

- Data Representativeness. Additional waste sampling is conducted as needed to ensure data representativeness. This is a waste-type-specific judgement. In particular, more data would be needed if reactor-specific differences are significant (e.g. due to different fuel defect history) or if the inventory in the wastes is not uniformly distributed (e.g. steam generators, non-processible wastes). Testing for reactor differences would be guided by records of reactor operations and by monitoring for trending across the waste sampling program (e.g. whether one reactor has consistently higher inventories). This would also include checking whether waste activities are stable over time.

- Key radionuclides. For those radionuclides that are either important to the safety case, or are ETM nuclides that are widely used as a scaling factor basis, additional samples would be undertaken. This would be guided by the importance of the radionuclide, and by the uncertainty as indicated by the 95th percentile upper confidence limit. See Section 4 for a current list of key radionuclides.

9.3 Verification

Verification activities provide assurance that the inventory basis is correct.

Status:

- OPG waste characterization analyses are carried out in accredited laboratories under appropriate quality assurance programs.

- Waste characterization results are compared with those from other relevant programs, notably other CANDU reactors where available. Information that may be comparable includes scaling factors and key radionuclides.

- Reference waste characterizations are compared with measured package dose rate distribution (this provides a validation of gamma-emitting radionuclides).

- Conduct periodic interlaboratory comparisons about every 3 years, each time testing a different waste characterization aspect and guided by the importance to the DGR safety case.

In addition, in the near-term it is planned to conduct a review of the waste characterization program by an independent third party.

9.4 Analysis and Integration

The results of the waste characterization program are analyzed and integrated with prior data and models to provide, for each waste type, a best-estimate inventory, an uncertainty analysis supporting an upper bound inventory value, and.an estimate for the total projected DGR inventory.

9.5 Timeframe

Some waste characterization activities are presently underway. Other activities need to be scheduled for completion to support the application for an operating licence. Based on the current projected construction schedule, this means that the activities need to be complete by end-2021.

The approximate timeframe for these activities is as follows. The specific activities are defined as part of the five-year business planning cycle, which is updated annually.

2014

- Continue annual sampling and gamma spectrometry of various LLW containers.
- Characterization of current pressure tube samples.
- Sample and analysis of Pickering B IX resins.
- Complete development of assay method for Zr-93 in pressure tubes.

2015 - 2017

- Continue annual sampling and gamma spectrometry of various LLW containers.
- Sample and analysis of additional resin and filter specimens.
- Characterization of at least two samples of all retube waste types.
- Opportunistic analysis of other samples as become available.
- One interlaboratory comparison of measurement methods.
- Third party review of the waste characterization program.

2018-2021

- Continue annual sampling and gamma spectrometry of various LLW containers.
- Sample and analysis of additional ILW samples, including validation of the radionuclide characterization of refurbishment wastes.
- One interlaboratory comparison of measurement methods.
- Characterization to meet data quality objectives complete.

These results of the waste characterization program would be documented in technical reports, and in the container-specific information in the OPG Integrated Waste Tracking System, and summarized in an updated Reference Inventory report.

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