

April 4, 2014

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Dr. Stella Swanson
Chair, Joint Review Panel
Deep Geologic Repository Project

c/o Canadian Nuclear Safety Commission
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Dr. Swanson:

**Deep Geologic Repository Project for Low and Intermediate Level Waste –
Submission of Response to Information Request EIS-12-513**

The purpose of this letter is to provide OPG's response to Information Request (IR) EIS-12-513 from IR Package #12 (Reference 1). A response to the Panel's follow-up comments (Reference 2) on the comparison of risk perception among the four options identified in the Information Request will be submitted separately, as indicated in Reference 3.

The attachment provides OPG's response to IR-EIS-12-513 and the requested report by independent risk assessment experts, which evaluates the relative risks of the four identified options for long-term management of low and intermediate level waste.

An updated Tracking Table is provided under separate cover letter (Reference 4) showing how all submissions to date, including those for IR Package #12, link to various sections in the documents submitted on April 14, 2011 (References 5 and 6).

If you have questions on the above, please contact Allan Webster at (905) 623-6670, ext. 3326.

Sincerely,

Laurie Swami
Vice President, Nuclear Services
Ontario Power Generation

Attach.

cc. Dr. J. Archibald – Joint Review Panel c/o CNSC (Ottawa)
Dr. G. Muecke – Joint Review Panel c/o CNSC (Ottawa)
P. Elder – CNSC (Ottawa)
D. Wilson – NWMO (Toronto)

- References:
1. JRP letter from Dr. Stella Swanson to Laurie Swami, "Information Request Package #12 from the Joint Review Panel", November 8, 2013, CD# 00216-CORR-00531-00215.
 2. 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
 3. OPG Letter from Laurie Swami to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Acknowledgement of Joint Review Panel's Clarification Comments on Relative Risk Analysis of Community Acceptance in Information Request (IR) EIS-12-513", March 28, 2014, CD# 00216-CORR-00531-00229
 4. OPG letter from Laurie Swami to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12a-512", April 4, 2014, CD# 00216-CORR-00531-00227
 5. OPG letter from Albert Sweetnam to JRP Chair, "Submission of Information in Support of OPG's Licence Application for a Deep Geologic Repository for Low and Intermediate Level Waste", April 14, 2011, CD# 00216-CORR-00531-00090
 6. OPG letter from Albert Sweetnam to JRP Chair, "Submission of an Environmental Impact Statement for a Deep Geologic Repository for Low and Intermediate Level Waste", April 14, 2011, CD# 00216-CORR-00531-00091

ATTACHMENT

Attachment to OPG letter, Laurie Swami to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-513"

April 4, 2014

CD#: 00216-CORR-00531-00232

**OPG Response to Information Request EIS-12-513
from Joint Review Panel**

OPG Response to Information Request EIS-12-513 from Joint Review Panel

IR#	EIS Guidelines Section	Information Request and Response
EIS 12-513	<ul style="list-style-type: none"> Section 7.3, Alternative Means of Carrying out the Project 	<p>Information Request:</p> <p>Alternative Means Risk Analysis</p> <p><i>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.</i></p> <p><i>Options to be analyzed:</i></p> <ol style="list-style-type: none"> <i>"As is" facility at the WWMF (the status quo)</i> <i>Enhanced surface storage at the WWMF ("hardened" storage)</i> <i>Proposed DGR in the Cobourg Formation at the Bruce Power site</i> <i>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).</i> <p><i>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.</i></p> <p><i>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.</i></p> <p><i>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.</i></p> <p><i>The relative risk analysis should include the following:</i></p> <ul style="list-style-type: none"> <i>Worker Health and Safety: construction, operation and decommissioning</i> <i>Public Health and Safety: construction, operation, decommissioning and post-closure</i> <i>Risks to Safety Case:</i> <ul style="list-style-type: none"> <i>Advective water flow around and through the facility</i> <i>gas generation</i>

IR#	EIS Guidelines Section	Information Request and Response
		<ul style="list-style-type: none"> ○ <i>physical disruption</i> <ul style="list-style-type: none"> ▪ <i>seismic</i> ▪ <i>structural failures</i> ▪ <i>major fracturing</i> ○ <i>chemical/physical degradation of waste containers (assuming containers are as described in the EIS and further described in IR responses and during the Hearing)</i> <ul style="list-style-type: none"> ▪ <i>seepage</i> ▪ <i>release rates</i> ▪ <i>microbial activity</i> ○ <i>transport of released radionuclides</i> <ul style="list-style-type: none"> ▪ <i>sources</i> ▪ <i>travel times to nearest receptor (radionuclides and other constituents of concern such as metals)</i> <ul style="list-style-type: none"> · <i>near-field and far-field risks (including Lake Huron)</i> ▪ <i>air emissions</i> <ul style="list-style-type: none"> · <i>sources</i> · <i>near-field and far-field risks (including Lake Huron)</i> ○ <i>waste transportation to and on the site</i> ○ <i>requirement for institutional controls, short and long term</i> <ul style="list-style-type: none"> ▪ <i>passive and active</i> ○ <i>contribution to sustainability</i> <ul style="list-style-type: none"> ▪ <i>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</i> ○ <i>community acceptance</i> <ul style="list-style-type: none"> ▪ <i>in the Local and Regional Study Area</i> ▪ <i>Outside of the Regional Study Area</i> <p>Context:</p> <p><i>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.</i></p> <p><i>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 detailed description of the alternative means options analysis.</i></p>

IR#	EIS Guidelines Section	Information Request and Response
		<p><i>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.”</i></p> <p>OPG Response:</p> <p>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).</p> <p>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.</p> <p>References:</p> <p>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)</p> <p>IEG. 2014b. IEG letter from Dr. W. Leiss to Laurie Swami, March 28, 2014. (enclosed)</p> <p>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)</p>

Attachment to OPG Letter, Laurie Swami to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-513",
CD# 00216-CORR-00531-00232

Independent Expert Group Correspondence to OPG

University of Ottawa

R. Samuel McLaughlin Centre for Population Health Risk Assessment
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28 March 2014

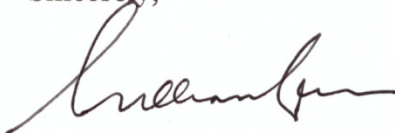
Ms. Laurie Swami
Vice-President, Nuclear Services
Ontario Power Generation
889 Brock Road
Pickering, ON L1W 3J2

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

Attachment to OPG Letter, Laurie Swami to Dr. Stella Swanson, "Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-513",
CD# 00216-CORR-00531-00232

Report of the Independent Expert Group

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:

MAURICE DUSSEULT, 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

Section 2: Narrative Description of the Four Alternative Means

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”
- V. OPG: Description of Alternative Options
- VI. Biographies of Expert Group Members
- 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.

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 m³ 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 m³ 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” [NEA²]. 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,

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

³France, 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 CO₂ and CH₄ arising from the wastes in the DGR from decomposition of the organic materials in the waste packages, as well as H₂ 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 ¹⁴C, 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 [CaCO₃, CaMg(CO₃)₂], shales (quartz-illite, sometimes with CaCO₃), 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.

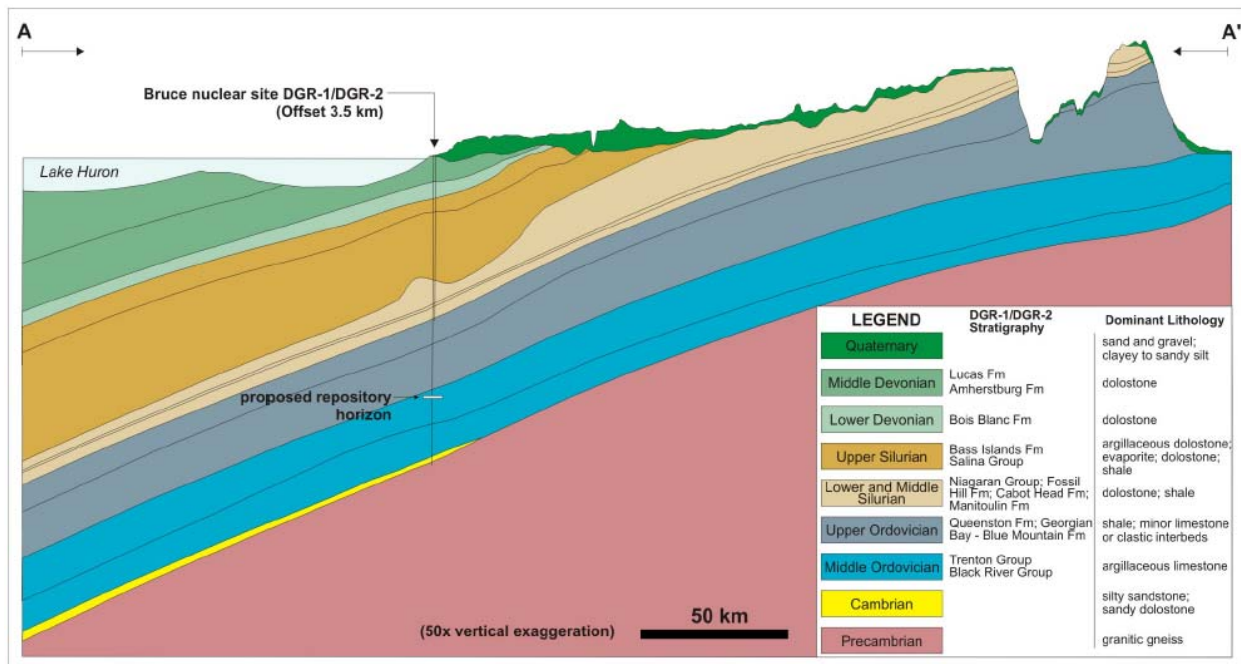


Figure 1: Geological Cross-Section of the Bruce DGR site. Figure 6.2.6-3 from the 2011 OPG Report – Environmental Impact Statement, Vol. 1 (00216-REP-07701-00001 R000). (Vertical distances are greatly exaggerated, dips are actually very low)

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 exceedingly 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 onto 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 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 than 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 $1000 \text{ m}^3/\text{year}$ (this is considered highly improbable). The average rainfall onto the $60,000 \text{ km}^2$ 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 JRP⁴ 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

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)	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Normal operations and selected accidents ○ Accidents during construction (buildings, roads, mines), mining, and decommissioning ○ Noise, dust, and nuisance ○ On-site and off-site transportation accidents ○ Radiological exposures from normal operations • Excludes <ul style="list-style-type: none"> ○ Radiological exposures from accidents 	✓	✓
Public Health and Safety (PH&S)	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Transportation on municipal roads and highways ○ Noise, dust, and nuisance off-site ○ Construction, operation, decommissioning, and post-closure phases • Excludes <ul style="list-style-type: none"> ○ Radiological exposures from normal operations and accidents (for DGR, prior to closure) 	✓	✓
Transport of Radionuclides: Advective Water Flow	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Radionuclide and other contaminants (e.g. metals) transport in the aqueous phase through existing fractures or porous media at depth or near surface ○ Transport and diffusion in surface waters (including Lake Huron for Cobourg DGR and Great Lake for granite DGR) ○ Diffusive transport was also considered ○ Dissolved gases such as carbon dioxide • Excludes <ul style="list-style-type: none"> ○ Free gas advection and atmospheric emissions 	✓	✓
Transport of Radionuclides: Advective Gas Flow	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Gas generation from waste and container degradation ○ Radionuclide transport in the gaseous phase through existing fractures or porous media ○ Direct emissions to the atmosphere from surface facilities • Excludes <ul style="list-style-type: none"> ○ Gas transportation in aqueous dissolved phase ○ Worker exposures underground 	✓	✓

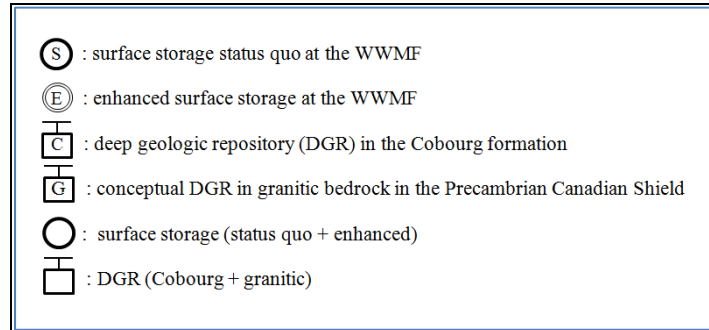
Pathway Scenario	Scope of Assessment Pathway Scenario	Timeframe	
		<100 years	>100 years
Seismic Impairment	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Any seismic event that is sufficiently large to lead to structural damage of buildings or underground shafts and tunnels ○ Major geological fracturing associated with any form of seismicity • Excludes <ul style="list-style-type: none"> ○ Long term tectonic processes 	✓	✓
Structural and Mechanical Impairments	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Buildings, equipment, impacts on building services (e.g. power loss, ventilation, and pumping equipment failure, fire, flooding) ○ Rock fall (for DGRs) ○ Mechanical failures (e.g. hoist way) ○ Equipment malfunctions • Excludes <ul style="list-style-type: none"> ○ Seismic induced failures, severe weather, and glaciation ○ Failures of packaging 	✓	✓
Waste Container Integrity	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Storage and permanent disposal ○ Seepage, release rates, and microbial activity ○ Package handling and breach • Excludes <ul style="list-style-type: none"> ○ Waste processing, structural and mechanical integrity of buildings and mine works ○ Transportation accidents 	✓	✓
Radiological Exposure During Transportation Accidents	<ul style="list-style-type: none"> • Assumes <ul style="list-style-type: none"> ○ Additional waste transport (200 – 2,000 km) to a distant granite repository from the WWMF ○ No transport after 100 years ○ Identical packaging technology in all transportation scenarios • Includes <ul style="list-style-type: none"> ○ Transfers from reactors to WWMF for all options ○ Accidents and malevolent acts • Excludes <ul style="list-style-type: none"> ○ Intra-site transfers (covered under normal operations in WH&S) ○ 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	<ul style="list-style-type: none"> • Includes <ul style="list-style-type: none"> ○ Extreme wind and hurricane ○ Tornado ○ Extreme precipitation ○ Flooding and surface erosion ○ Climate change 	✓	✓
Glaciation	<ul style="list-style-type: none"> • Assumes <ul style="list-style-type: none"> ○ 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 • Excludes <ul style="list-style-type: none"> ○ Any short-term possibilities (less than 100 years) 	x	✓
Malevolent Acts	<ul style="list-style-type: none"> • Assumes <ul style="list-style-type: none"> ○ Presence of institutional controls in perpetuity • Includes <ul style="list-style-type: none"> ○ All intentional acts regardless of motivation ○ Theft, sabotage, mischief, and politically motivated acts • Excludes <ul style="list-style-type: none"> ○ Accidental intrusion 	✓	✓
Loss of Institutional Control	<ul style="list-style-type: none"> • Assumes <ul style="list-style-type: none"> ○ Only relevant after 100 years ○ Very high probability of occurrence after 100 years and up to 100,000 years • Includes <ul style="list-style-type: none"> ○ All pathways of harm (natural, operational, accidental, malevolent) that rely on continuous presence of institutional control 	x	✓

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:



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.

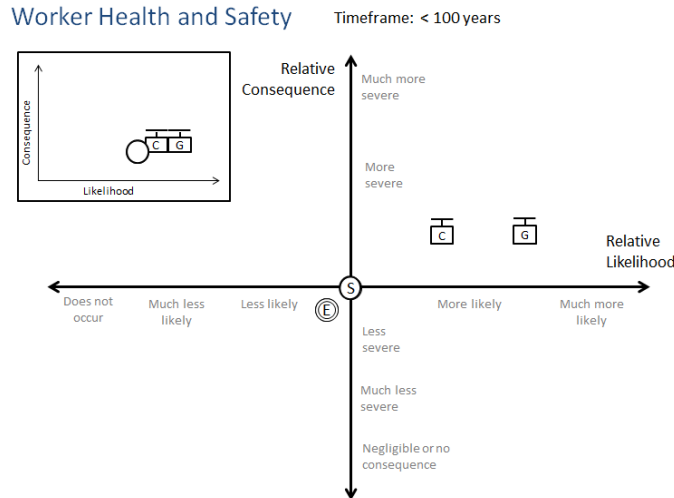


Figure 2: The visualization tool used to judge relative risk associated with the four disposal options, with the example of the Worker Health and Safety pathway of harm. Note: the Status Quo Surface Storage Option was established as the basis of comparison and is therefore always located at the centre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

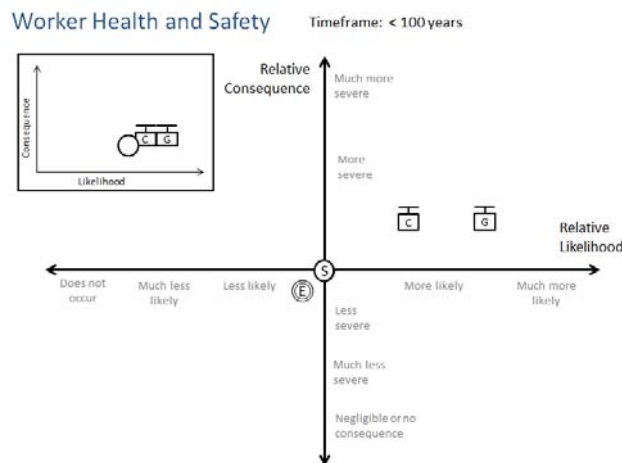


Figure 3: RR and AR diagrams for Worker Health and Safety.

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.

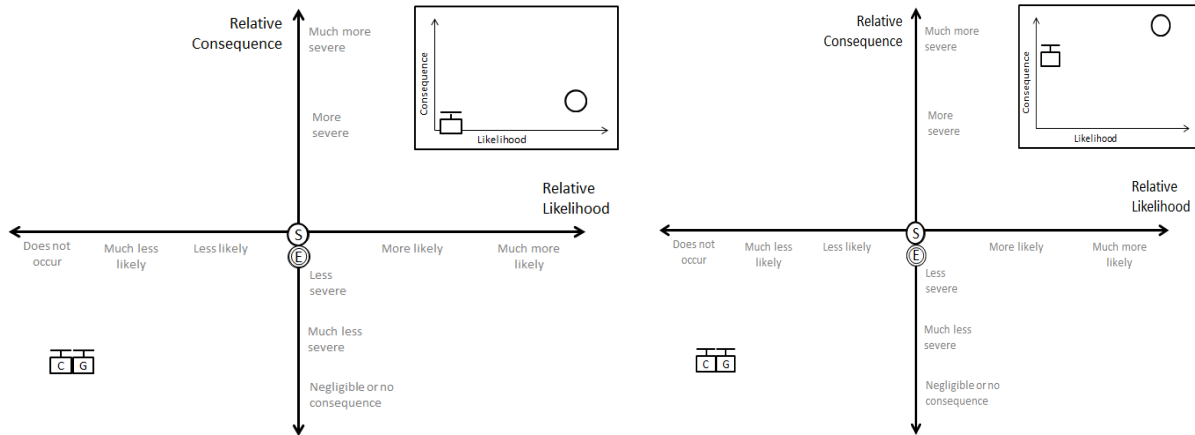


Figure 4: Hypothetical RR and AR diagrams of two different pathways. The consequences for the pathways depicted on the right are much more severe from an absolute risk perspective, though the relative risk patterns are the same.

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 ⓐ	DGR Granite ⓖ
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:

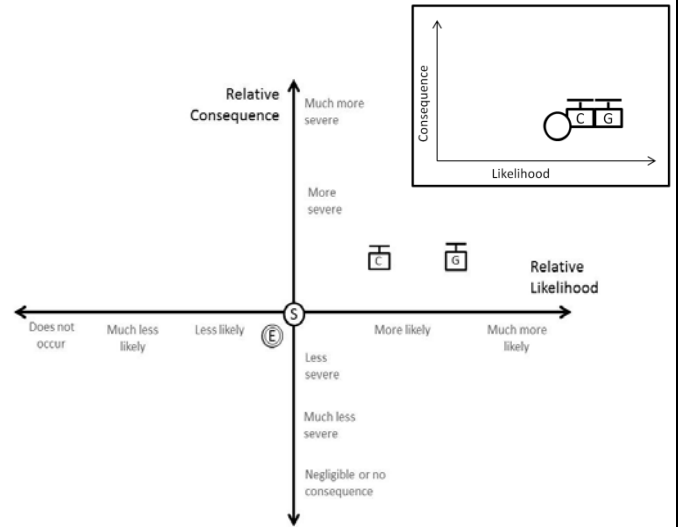
- Normal operations and selected accidents
- Construction (buildings, roads, mines) and mining accidents
- Noise, dust, nuisance
- On-site and off-site transportation accidents
- Radiological exposure from normal operations

Excludes:

- Radiological exposures from accidents are assessed in other categories

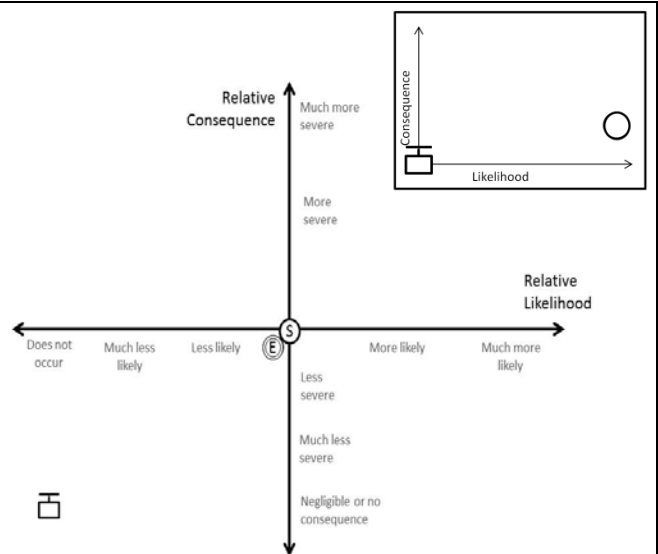
Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	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 (S)	Enhanced Surface (E)	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:

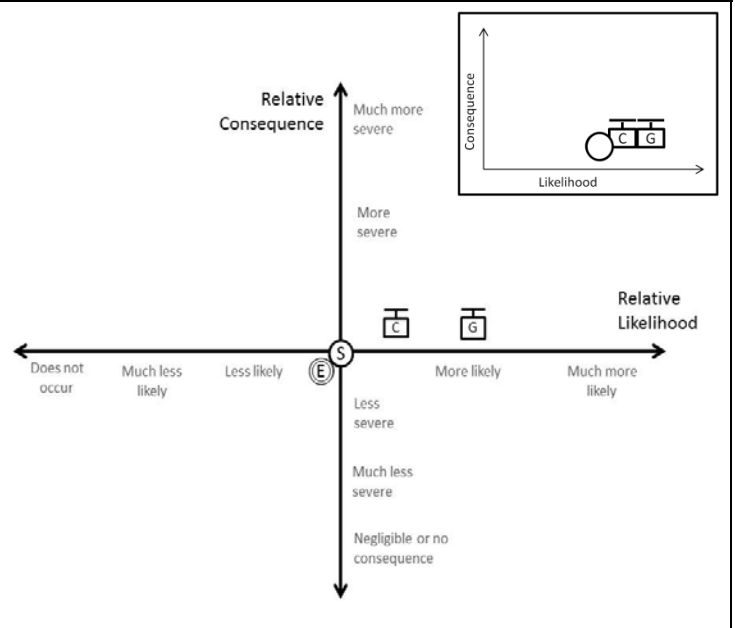
- Transportation on municipal roads and highways
- Noise, dust, and nuisance off-site
- Construction, operation, decommissioning, and post-closure phases

Excludes:

- Radiological exposures from normal operations and accidents

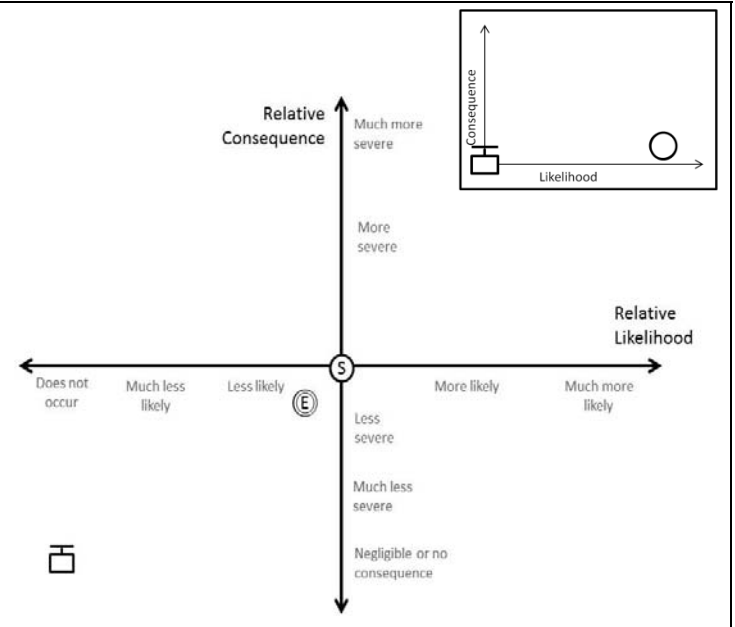
Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	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 (S)	Enhanced Surface (E)	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:

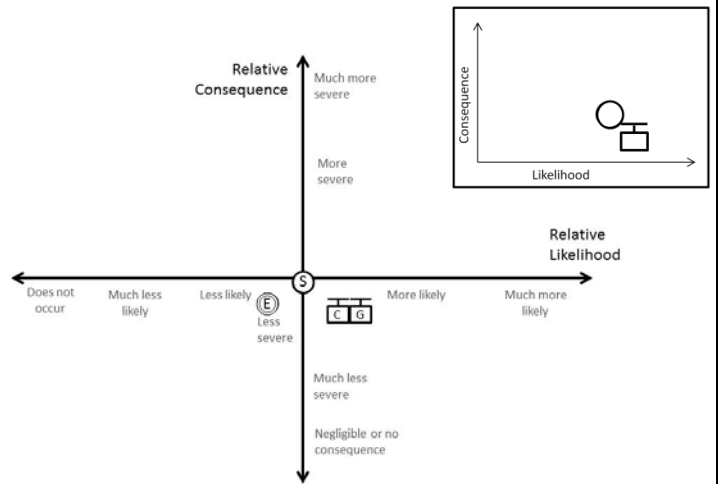
- Radionuclide and other contaminants (e.g. metals) transport in the aqueous phase through existing fractures or porous media at depth or near the surface
- Dissolved gases such as carbon dioxide

Excludes:

- Free gas advection and atmospheric emissions are covered elsewhere

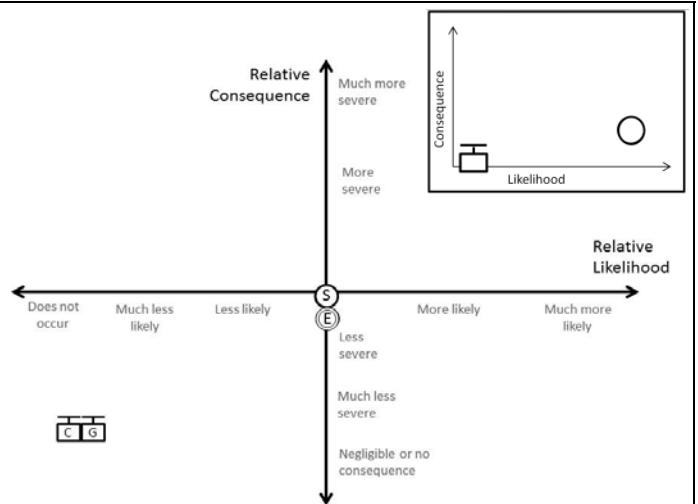
Timeframe: <100 years

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:

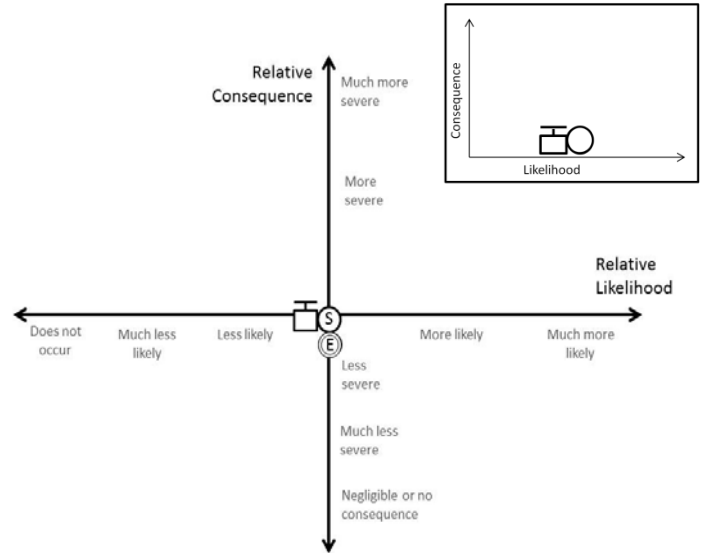
- Radionuclide transport in the gaseous phase through existing fractures or porous media
- Gas generation from waste off-gassing and degradation products
- Direct emissions to the atmosphere from surface facilities

Excludes:

- Gas transportation in aqueous dissolved phase
- Worker exposures underground

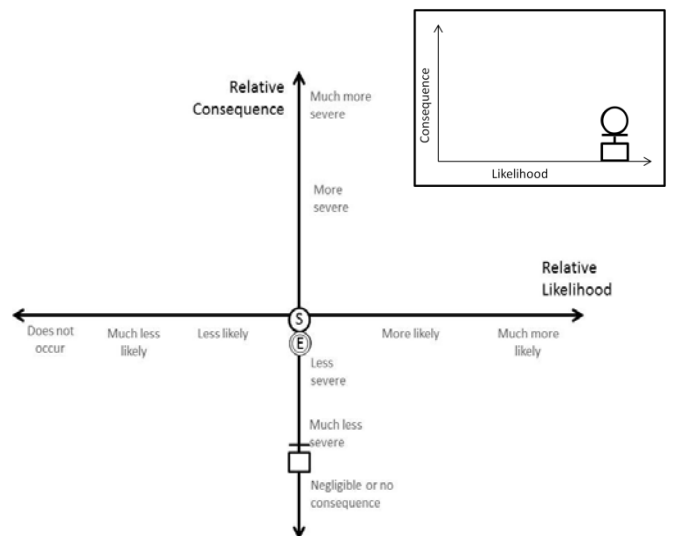
Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
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 (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
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:

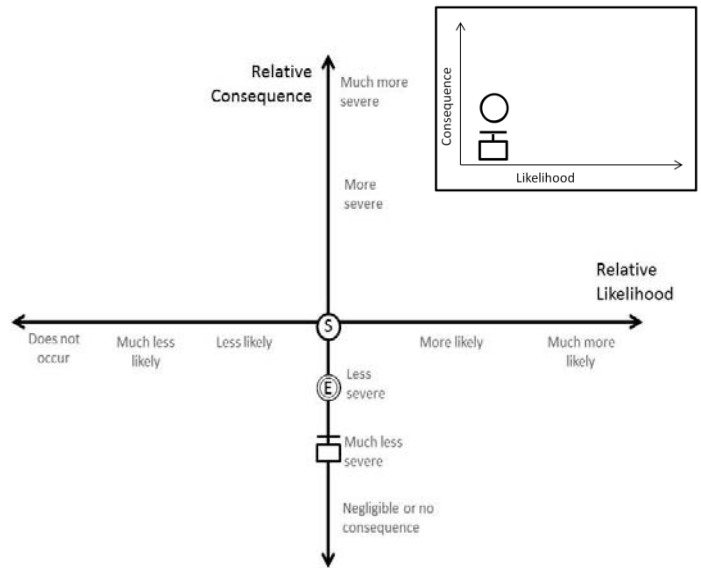
- Any seismic event that is sufficiently large to lead to structural damage of buildings or underground shafts and tunnels
- Major geological fracturing associated with any form of seismicity

Excludes

- Long term tectonic processes

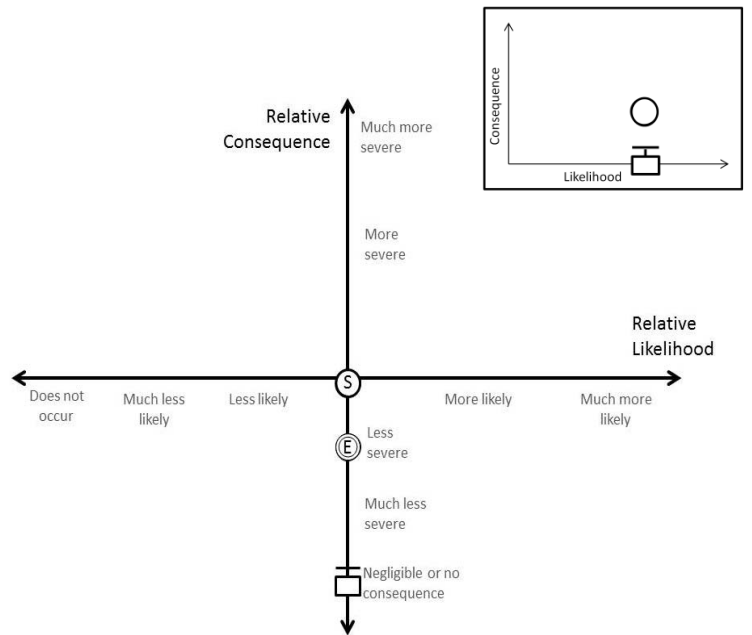
Timeframe: < 100 years

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:

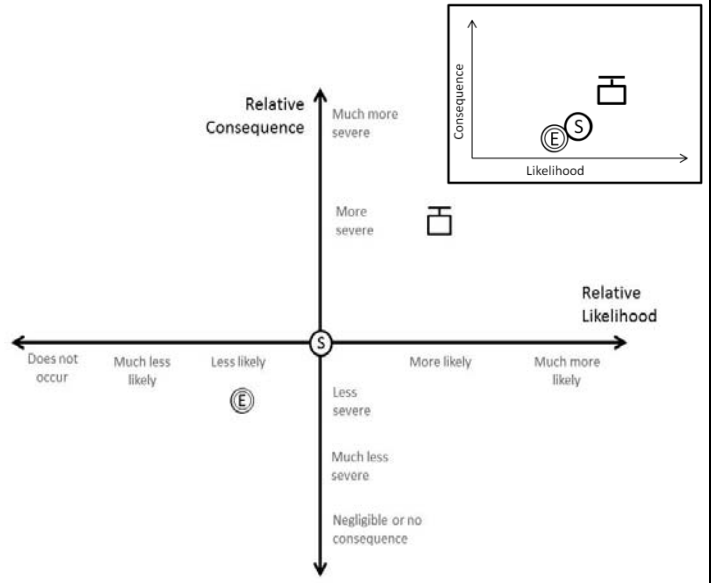
- Buildings, equipment, impacts on building services, e.g. power loss, ventilation and pumping equipment failure, fire, flooding, rock fall
- Mechanical failures (e.g. hoist way)
- Equipment malfunctions

Excludes:

- Seismic induced failures, severe weather, and glaciation
- Failures of packaging

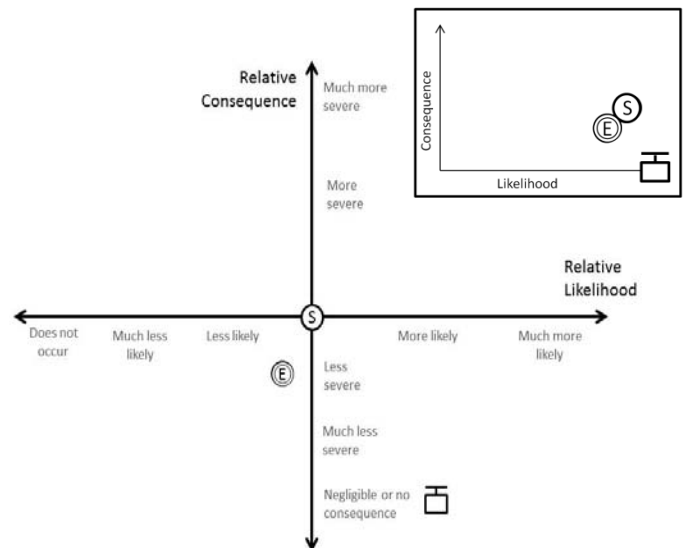
Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	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 (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 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

<p>Includes:</p> <ul style="list-style-type: none"> Storage and permanent disposal Seepage, release rates, microbial activity Package handling and breach 	<p>Excludes:</p> <ul style="list-style-type: none"> Waste processing, structural and mechanical integrity of buildings and mine works Transportation accidents
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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: <ul style="list-style-type: none"> 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 	Includes: <ul style="list-style-type: none"> Transfers from reactors to WWMF for all options Accidents 	Excludes: <ul style="list-style-type: none"> 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.

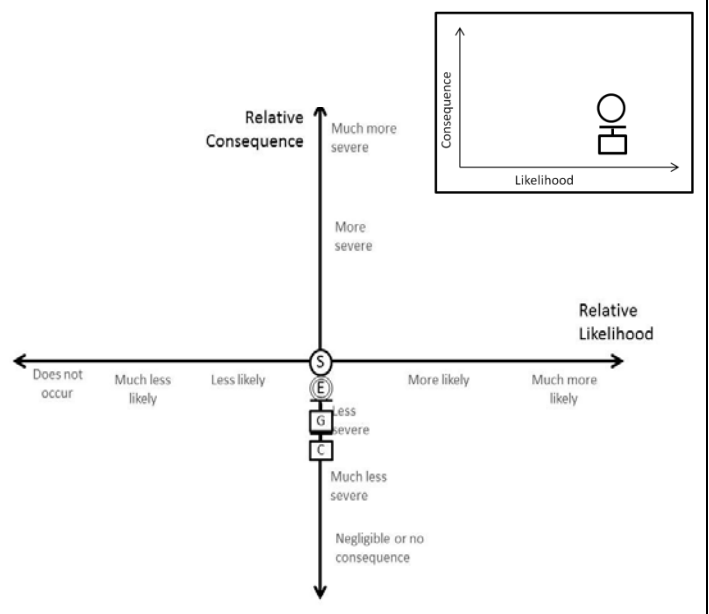
Severe Weather

Includes:

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

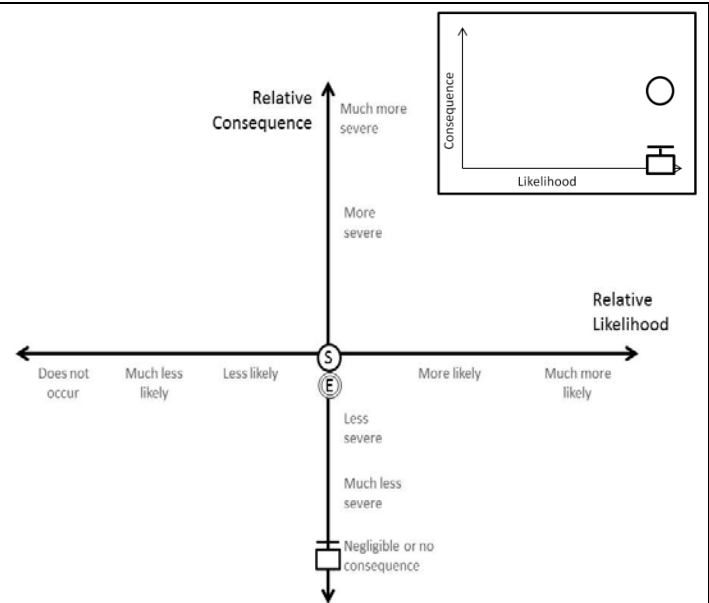
Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	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 (S)	Enhanced Surface (E)	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:

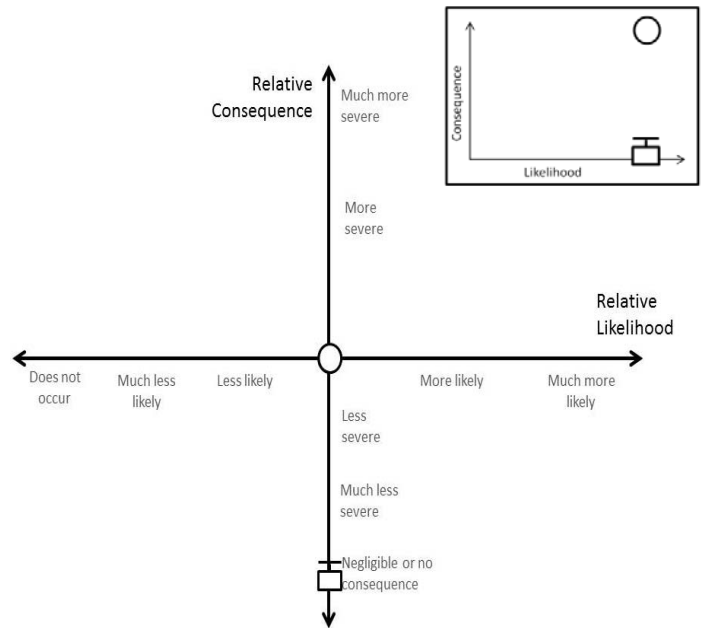
- The possible future re-occurrence of continental glaciation leading to the creation and movement of a thick ice sheet across the site
- Glaciation cycle is uncertain; assumes next glaciation in the timeframe of 10,000 – 100,000 years
- Cannot assume institutional control

Excludes:

- Any short-term possibilities (less than 100 years)

Timeframe: >100 years

Status Quo S	Enhanced Surface E	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:

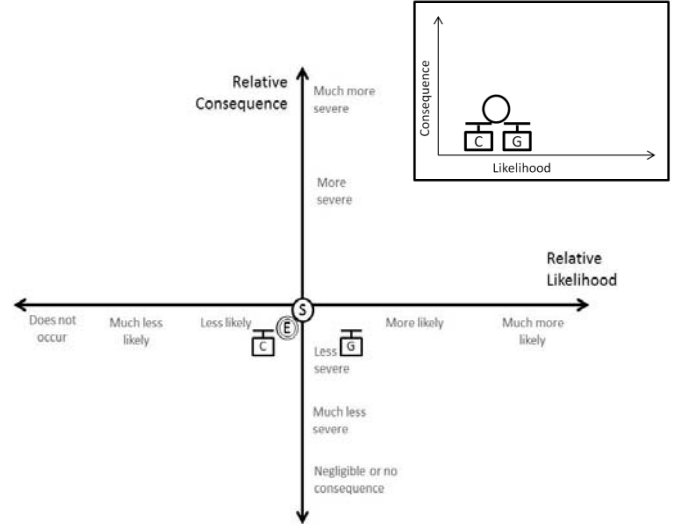
- All intentional acts regardless of motivation
- Theft, mischief, politically motivated acts
- Assumes presence of institutional controls in perpetuity

Excludes:

- Accidental intrusion

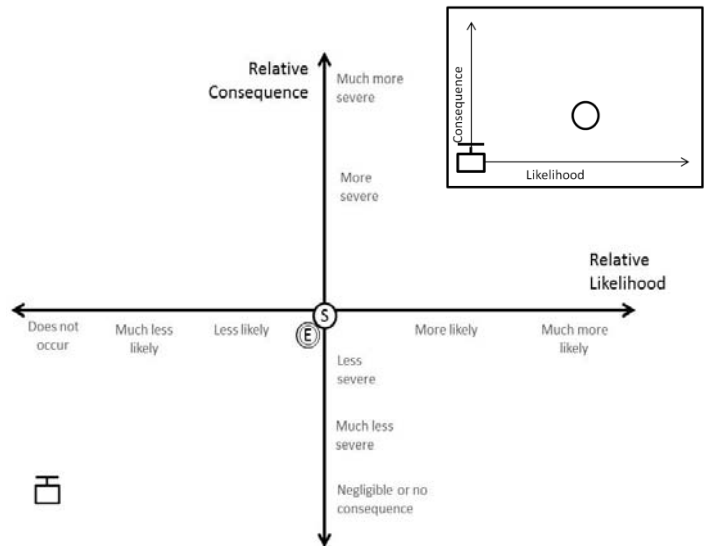
Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	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 (S)	Enhanced Surface (E)	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:

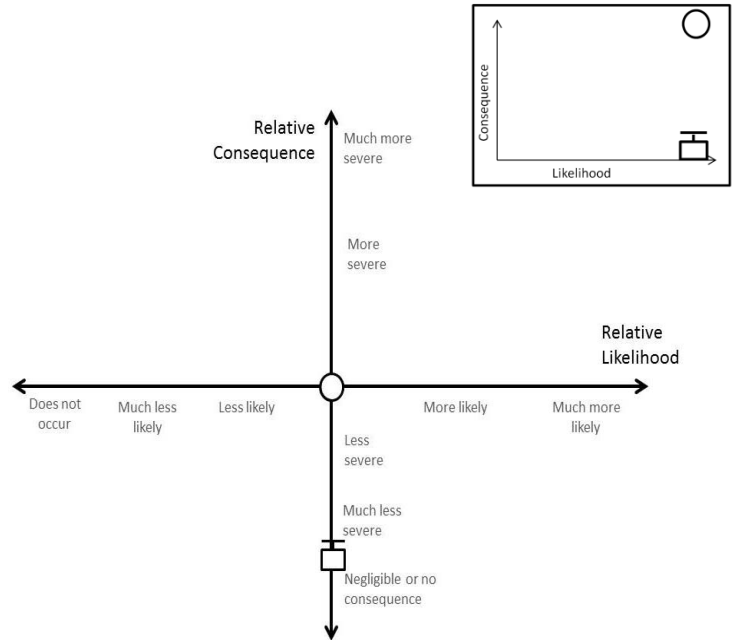
- Only relevant after 100 years
- Very high probability of occurrence at least once after 100 years and up to 100,000 years
- No changes in surface storage options over that same timeframe

Includes:

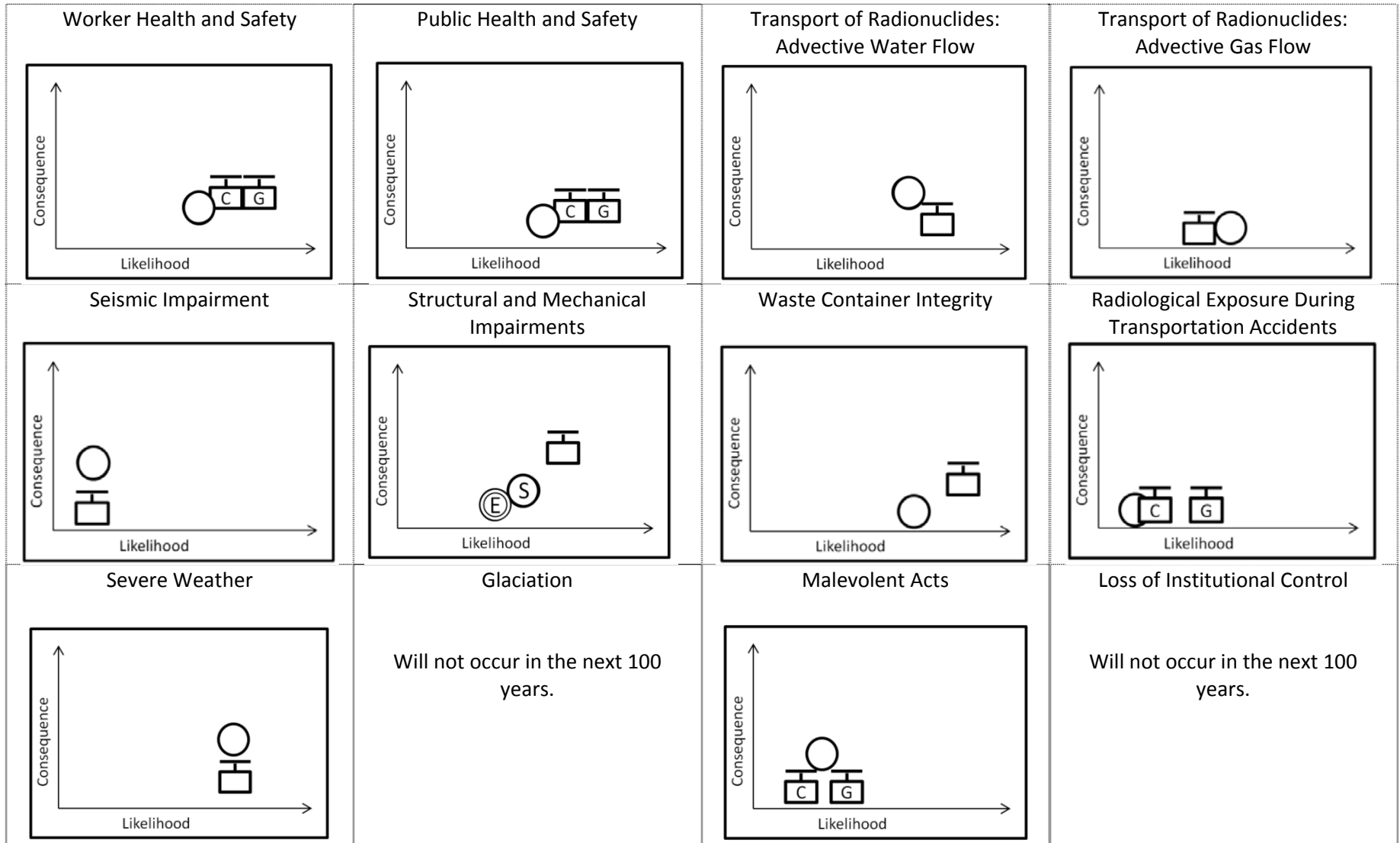
- All pathways of harm (natural, operational, accidental, malevolent) that rely on continuous presence of institutional control

Timeframe: >100 years

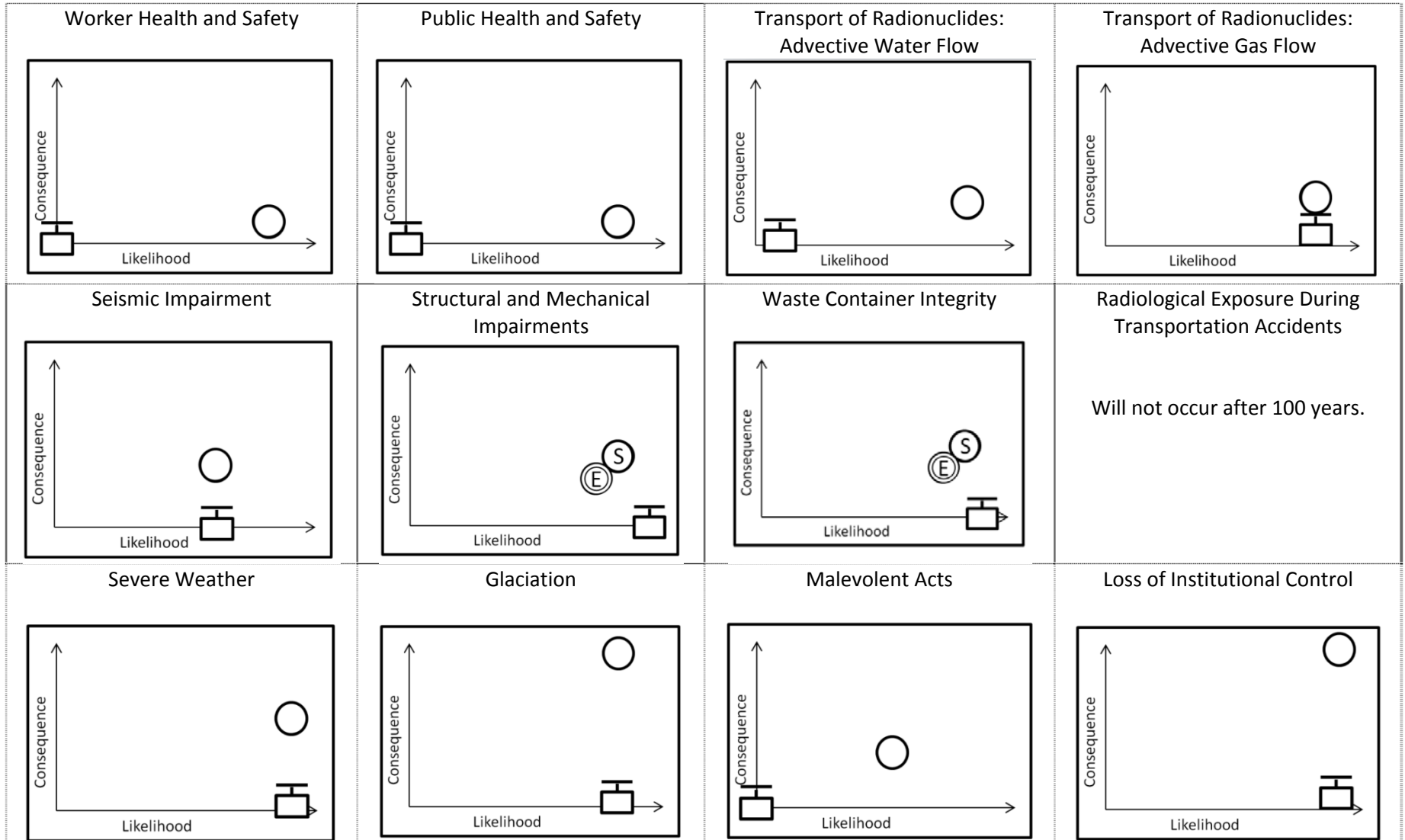
Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	=RISK	↓↓↓RISK	↓↓↓RISK
	Over the long term with loss of institutional control the surface options are essentially identical.	DGR is closed; very low probability of accidental intrusion remains, with limited consequences due to 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



Timeframe: >100 years



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.

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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
<ul style="list-style-type: none"> • Normal operations and selected accidents, malfunctions and malevolent acts → • Severe weather events, particularly under climate change scenarios → • Worker Health and Safety: construction, operation, and decommissioning → • Public Health and Safety: construction, operation, decommissioning and post-closure → • Risks to Safety Case: <ul style="list-style-type: none"> ○ advective water flow around and through the facility → ○ gas generation → ○ physical disruption <ul style="list-style-type: none"> ▪ 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): <ul style="list-style-type: none"> ▪ seepage } → ▪ release rates } → ▪ microbial activity } → ○ transport of released radionuclides <ul style="list-style-type: none"> ▪ sources } → ▪ travel times to nearest receptor (radionuclides and other constituents of concern e.g. metals) <ul style="list-style-type: none"> • near-field and far-field risks (including Lake Huron) ○ air emissions <ul style="list-style-type: none"> ▪ 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 <ul style="list-style-type: none"> ▪ passive and active → 	<ul style="list-style-type: none"> • Worker Health and Safety, Public Health and Safety, Malevolent Acts • Severe Weather, Glaciation • Worker Health and Safety • Public Health and Safety • Transport of Released Radionuclides: Advective Water Flow • Transport of Released Radionuclides: Advective Gas Flow • Seismic Impairment • Structural and Mechanical Impairments • Seismic Impairment • Waste Container Integrity • Transport of Released Radionuclides: Advective Water Flow • Transport of Released Radionuclides: Advective Gas Flow • Worker Health and Safety, Radiological Exposure During Transportation Accidents • Loss of Institutional Control

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 m³ (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.

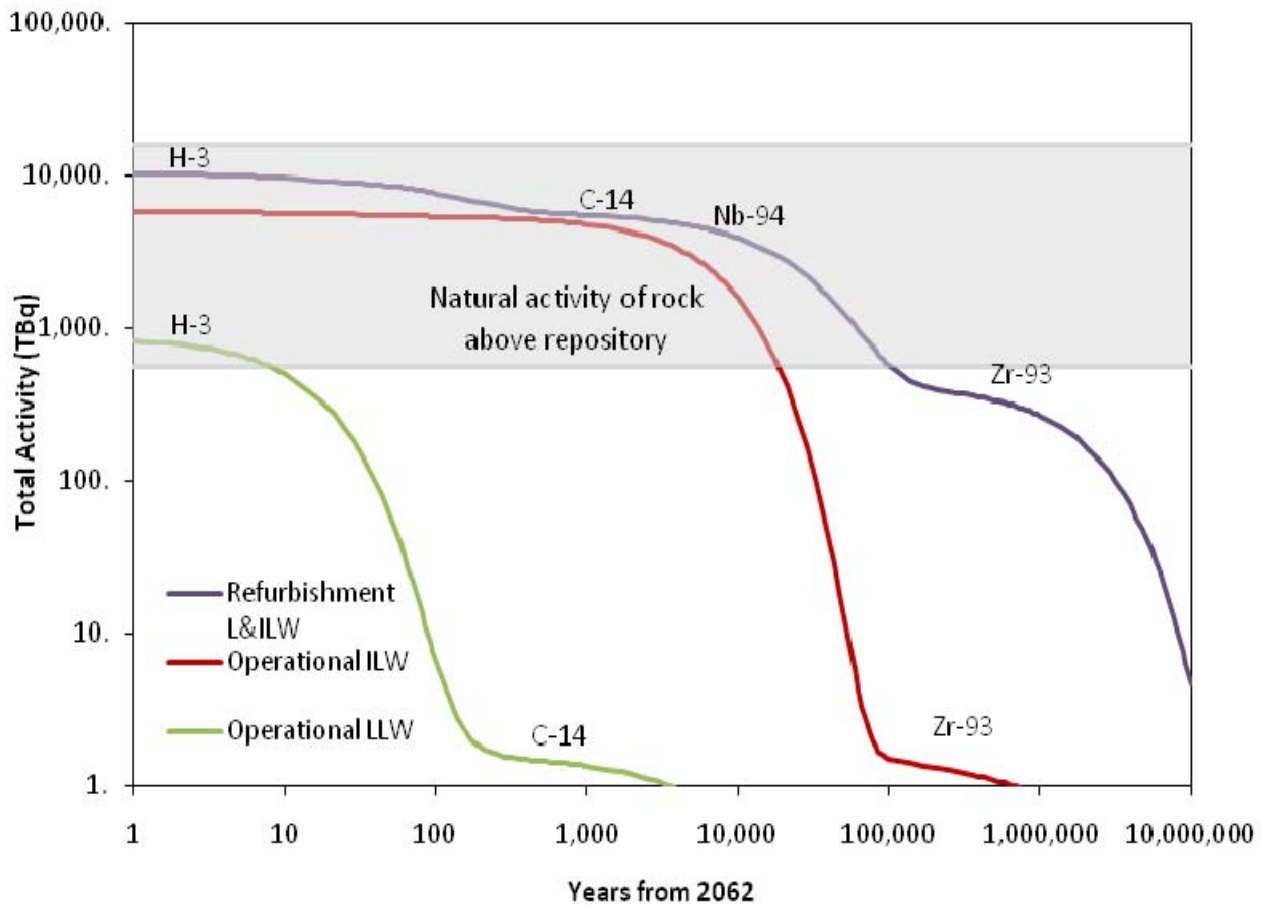


Figure 1.1: Reference inventory characteristics. Note that the shaded area represents the natural activity of the rock above the repository, with the range corresponding to a range of areas from repository footprint to Bruce site.

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 m³ of LLW and ILW each year from the Pickering, Darlington and Bruce nuclear stations. There is presently about 95,000 m³ 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).

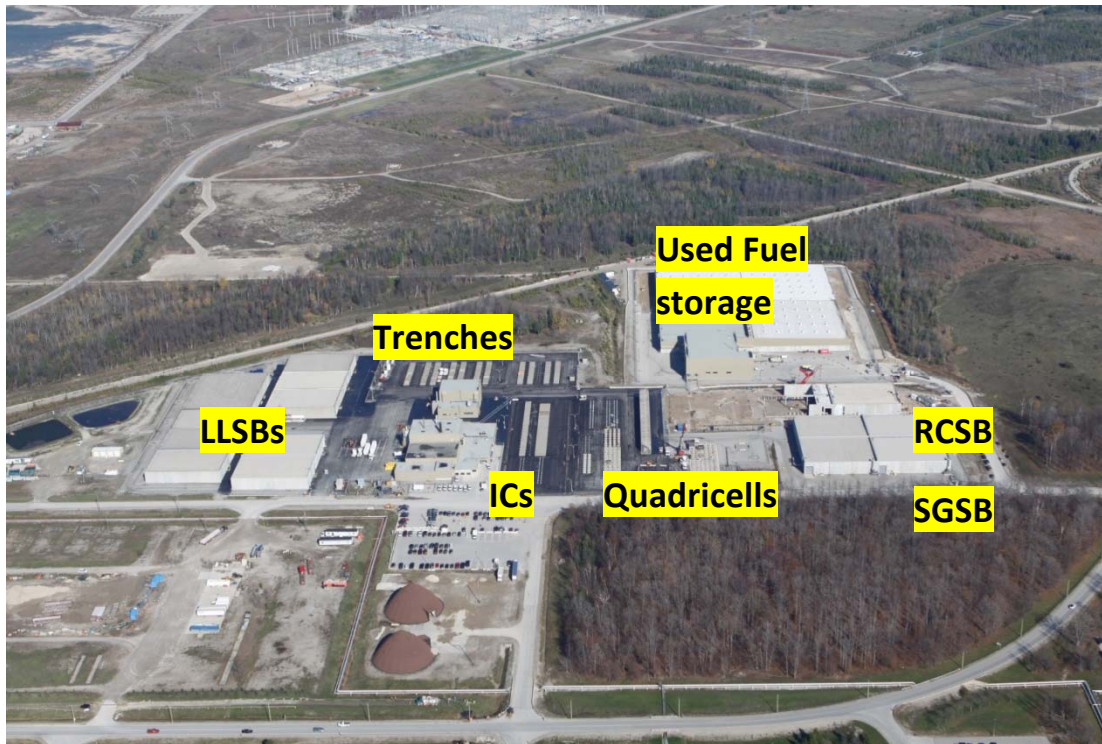


Figure 2.1: (a) Location of WWMF on the Bruce nuclear site. (b) Layout of facilities at WWMF.

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 m³ 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 $(32 \text{ buildings}) / (50 \text{ years}) = 0.64$ per year,
- constructing $(600 \text{ IC-18s}) / (50 \text{ years}) = 12$ 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.

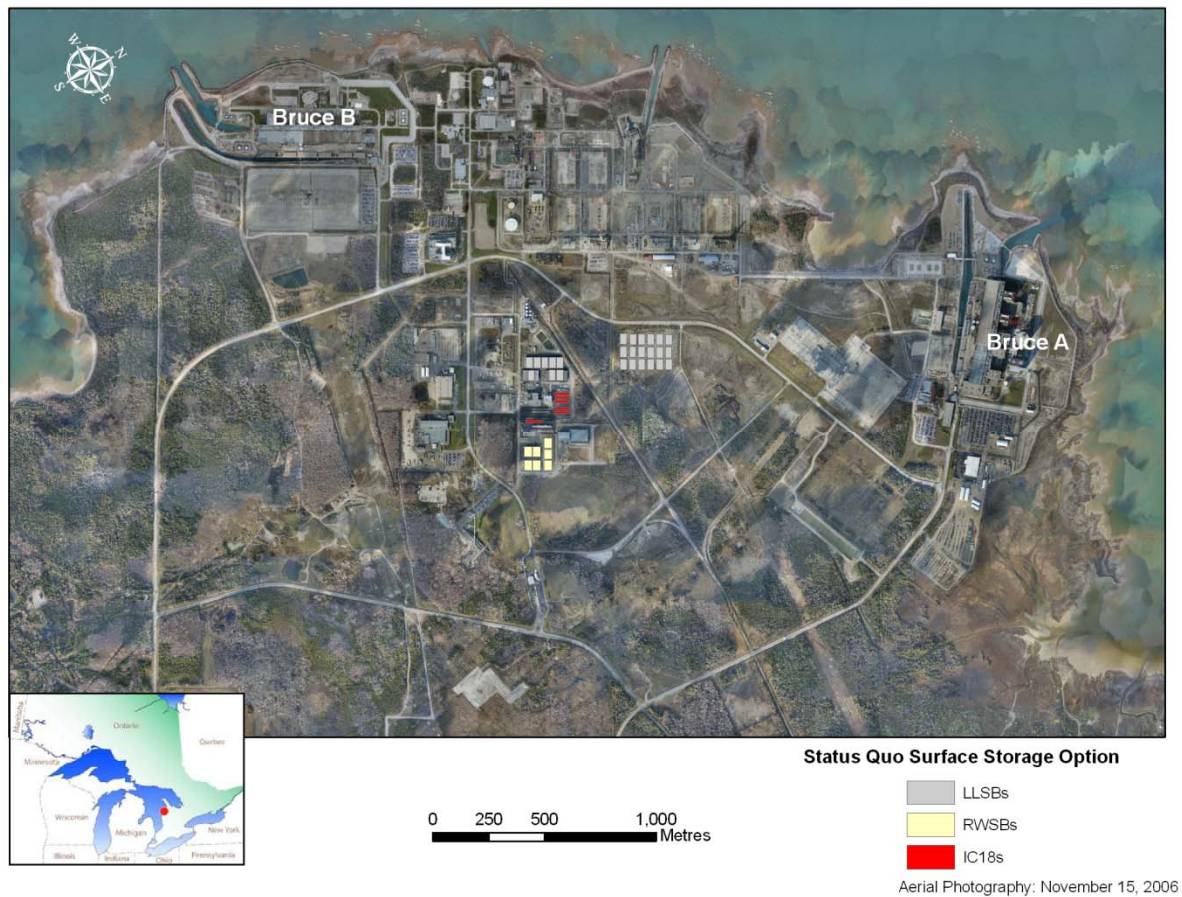


Figure 3.1: Illustrative layout of Status Quo option in 100 years, with all wastes transferred to LLSBs, IC18s and RWSEBs placed on current WWMF and proposed DGR site.

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 m³ 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 $(13+7 \text{ buildings})/(100 \text{ yrs}) = 0.2$ 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 $23,000/100 = 230/\text{yr}$
- transfer the ILW from old to new containers at a rate of $7,400/100 = 74/\text{yr}$.

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 Quo* 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 m³ of waste, has 40-cm thick concrete walls and a design life of 100 years.

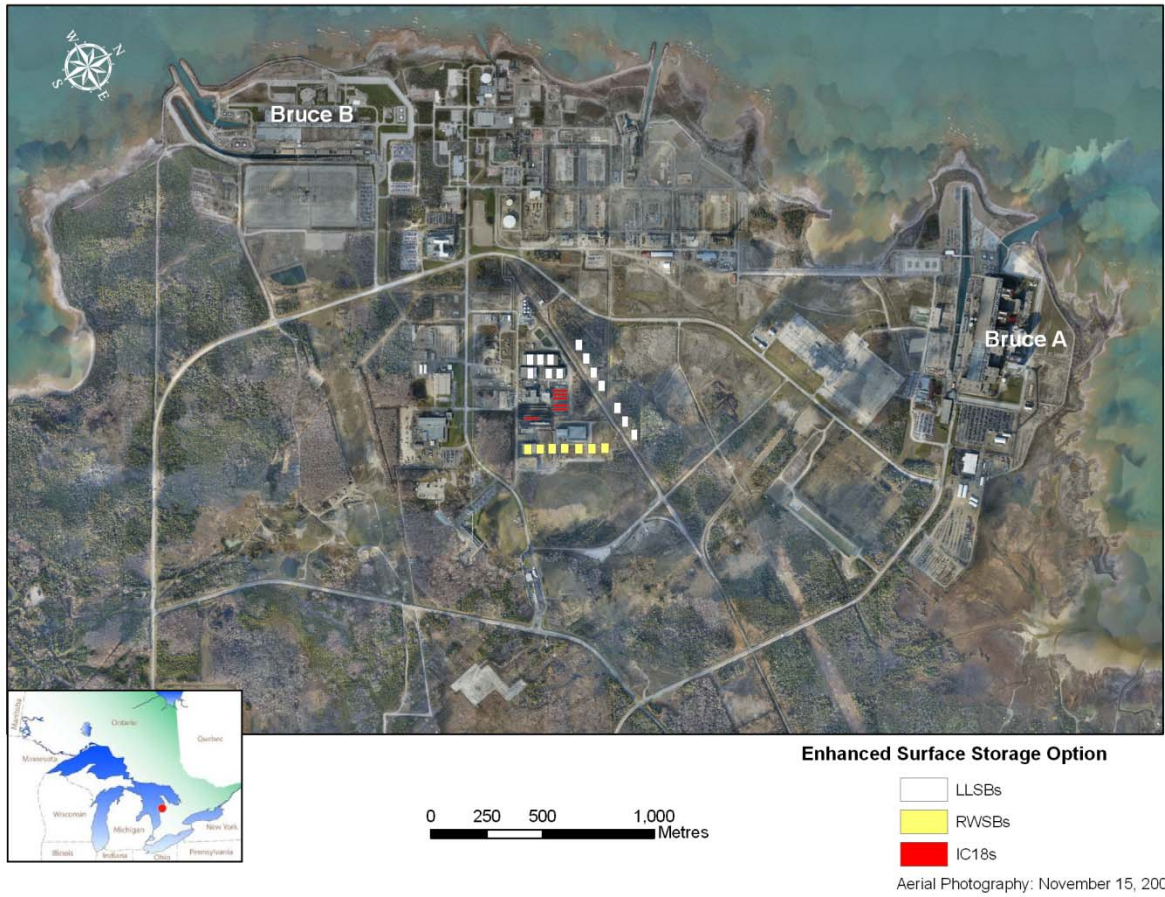


Figure 4.2: Illustrative layout of Enhanced Surface Storage option in 100 years, with all wastes transferred to LLSBs, IC18s and RWSBs placed on current WWMF and proposed DGR site. Structures are also spaced apart compared to Status Quo option.

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 m³ 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.

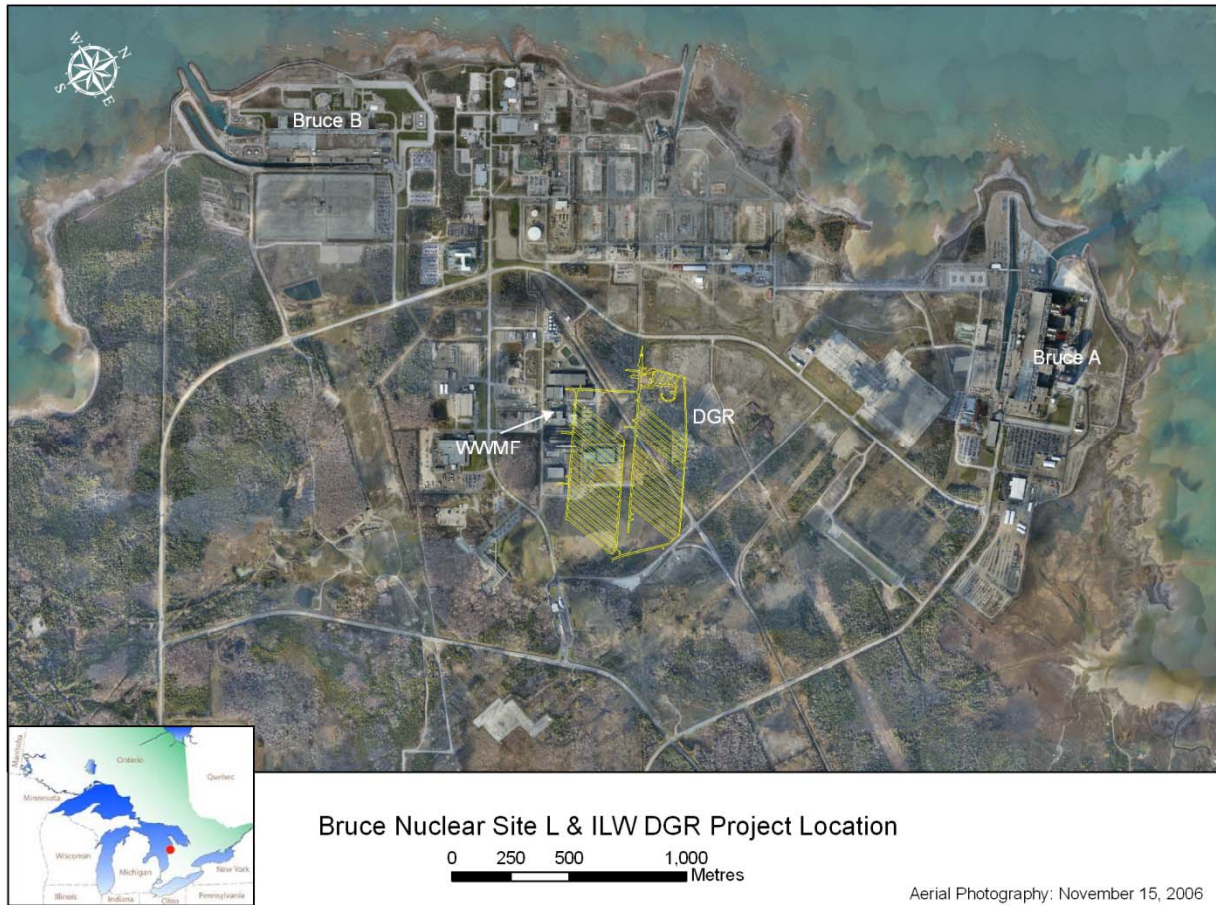


Figure 5.1: Illustration of footprint of DGR at Bruce nuclear site.

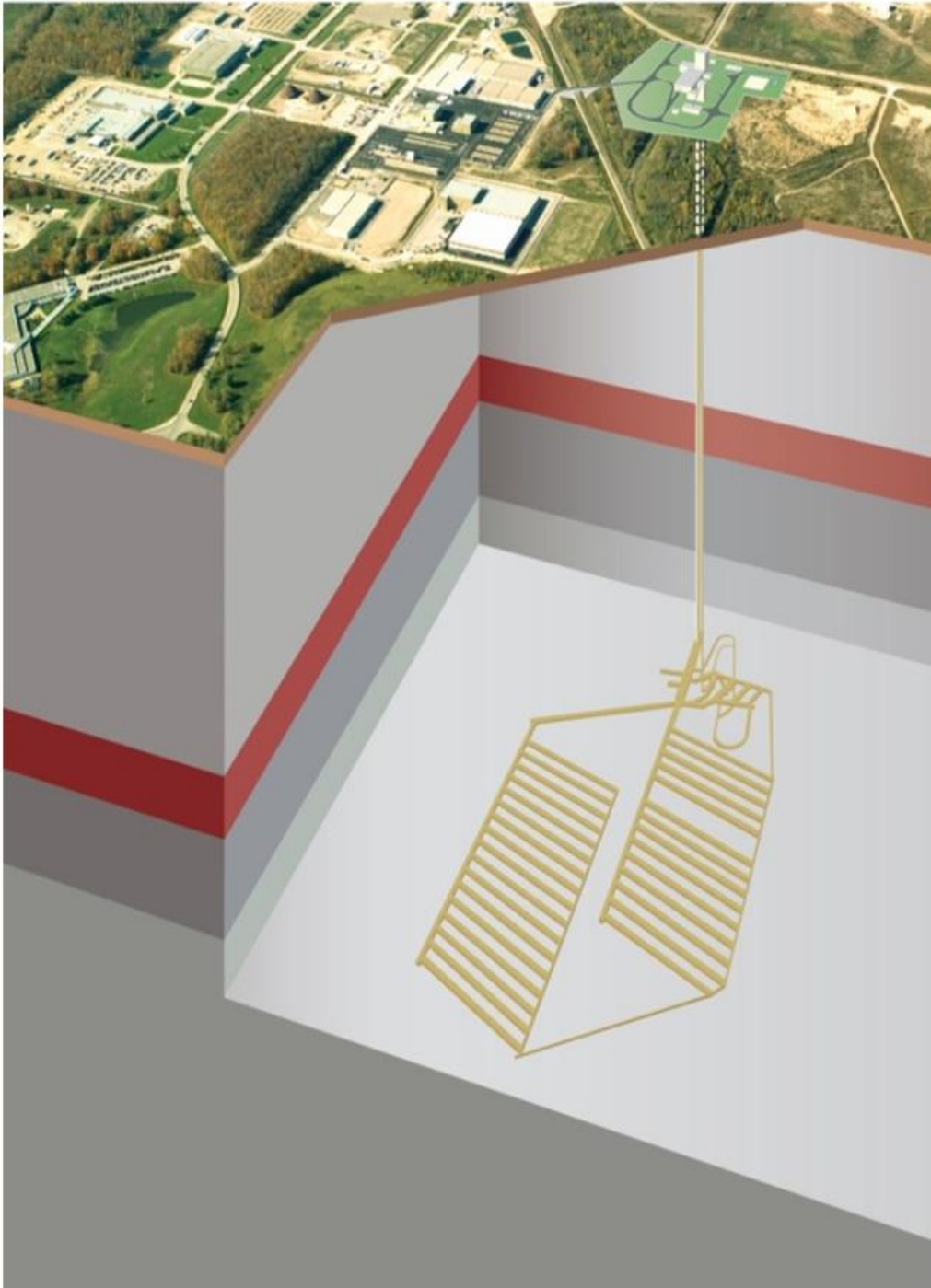


Figure 5.2: Perspective view of DGR at Bruce site.

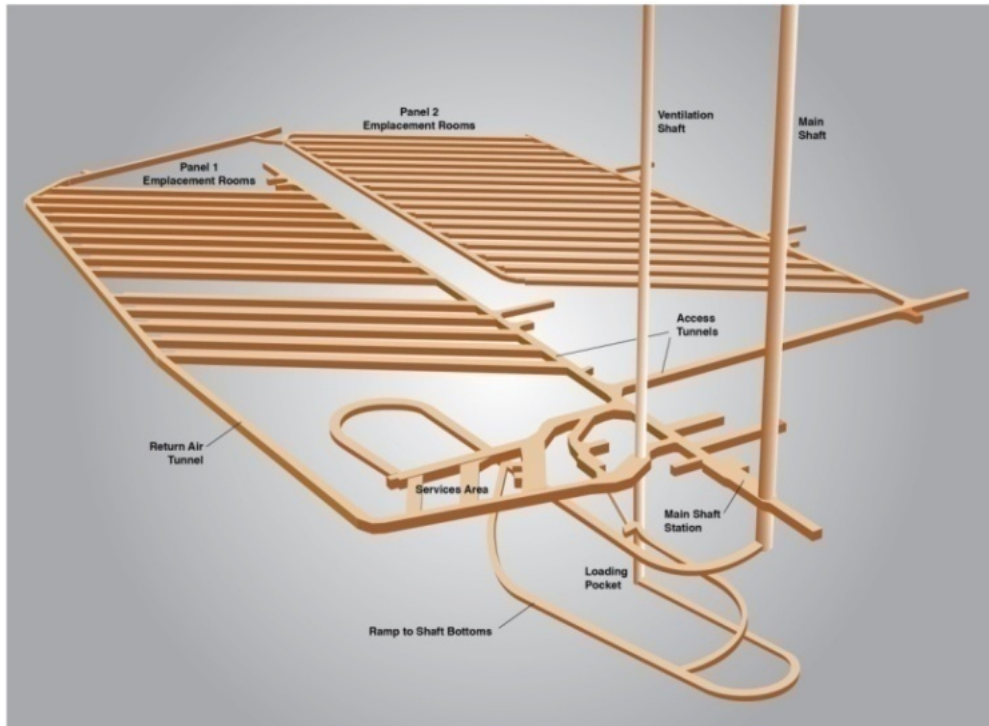


Figure 5.3: Illustration of (a) underground layout and (b) emplacement of LLW packages. Wastes are emplaced in 31 rooms in 2 panels. Rooms are 250 m long, 7 m x 8.5 m wide.

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.

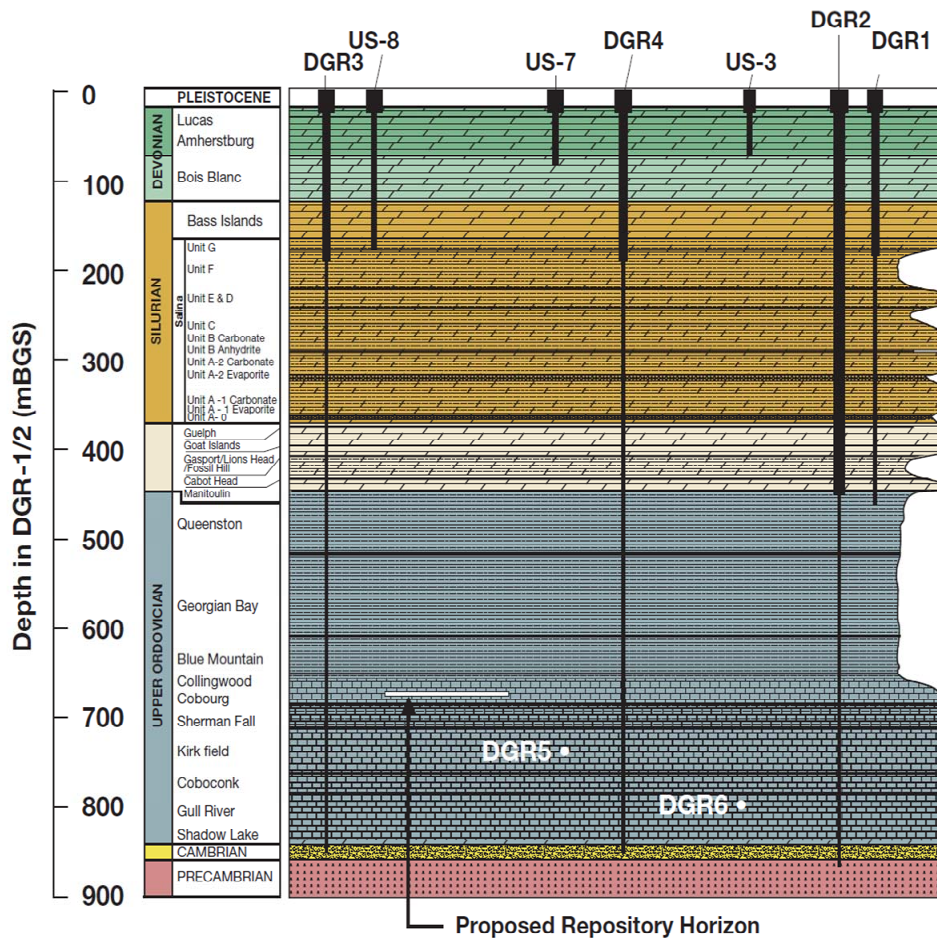
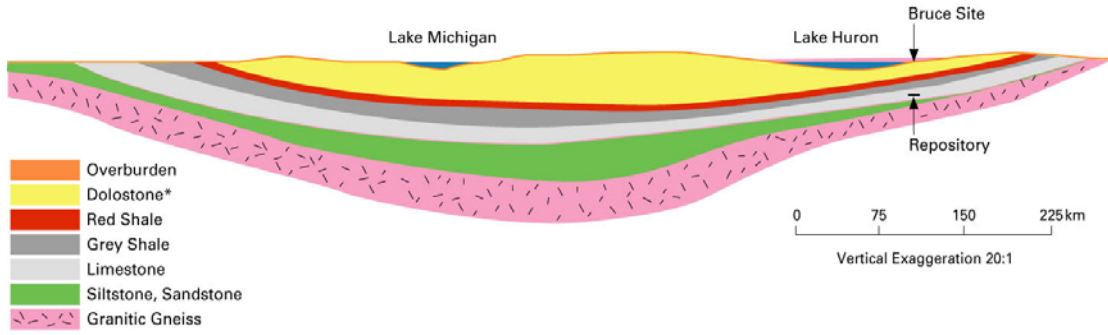


Figure 5.4: Rock formations beneath the Bruce nuclear site at the (a) Michigan Basin scale, and (b) DGR site. Repository would be located in the Cobourg Formation at about 680 m depth.

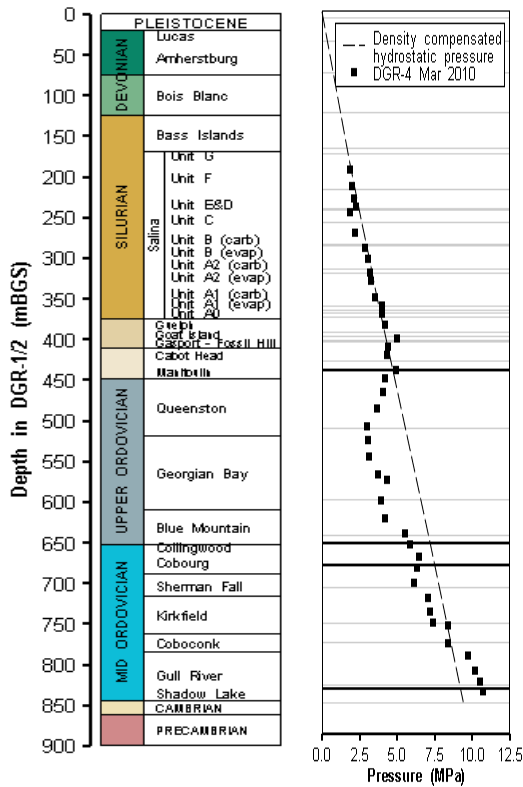
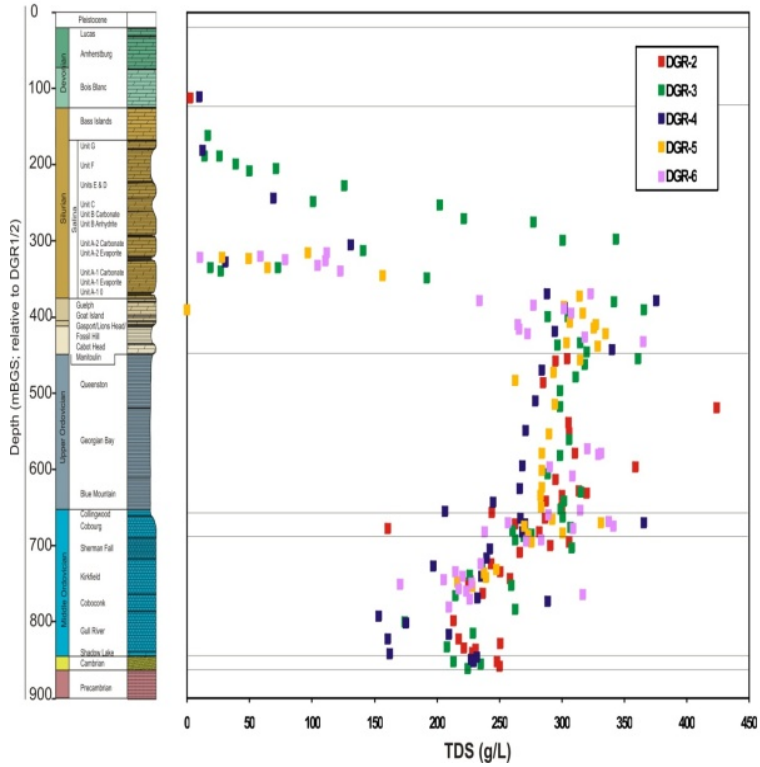


Figure 5.5: Properties of the rock formations beneath the Bruce nuclear site: (a) salinity profile; (b) hydraulic pressure profile. These profiles are indicative of low-permeability conditions at depth.

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 6×10^5 m³ of rock excavated, about 2×10^8 kg of concrete, about 3×10^6 kg of steel, and about 7×10^7 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 m³ 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.

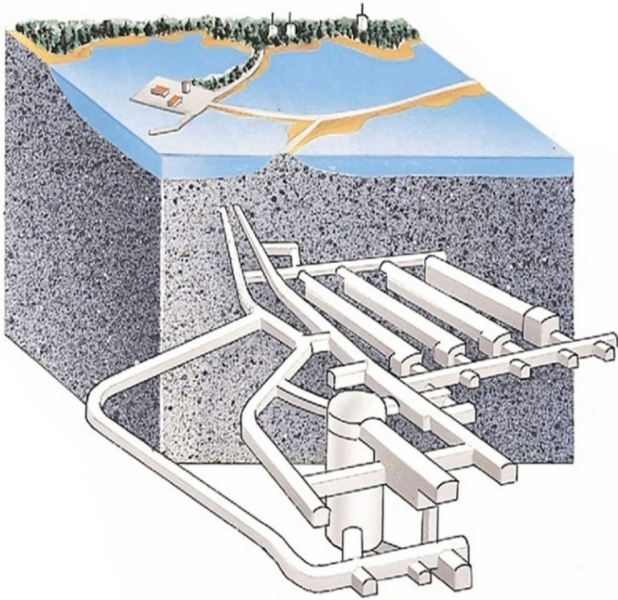
6.3 Location: Unspecified Canadian Shield site. For context, the nearest edge of the Canadian Shield is about 200 km by road from WWMF, while the Canadian Shield at the Manitoba/Ontario border is about 2000 km distant.

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.

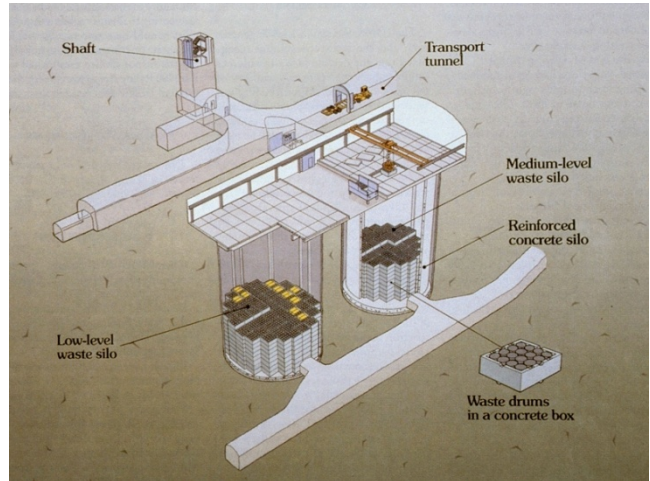
This option requires additional offsite transport compared to all of the other options. The amount of additional transportation depends on the granite site location. The current distance from the stations to WWMF is about 300 km by public roads from Pickering and Darlington stations, and about 1 km on 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.

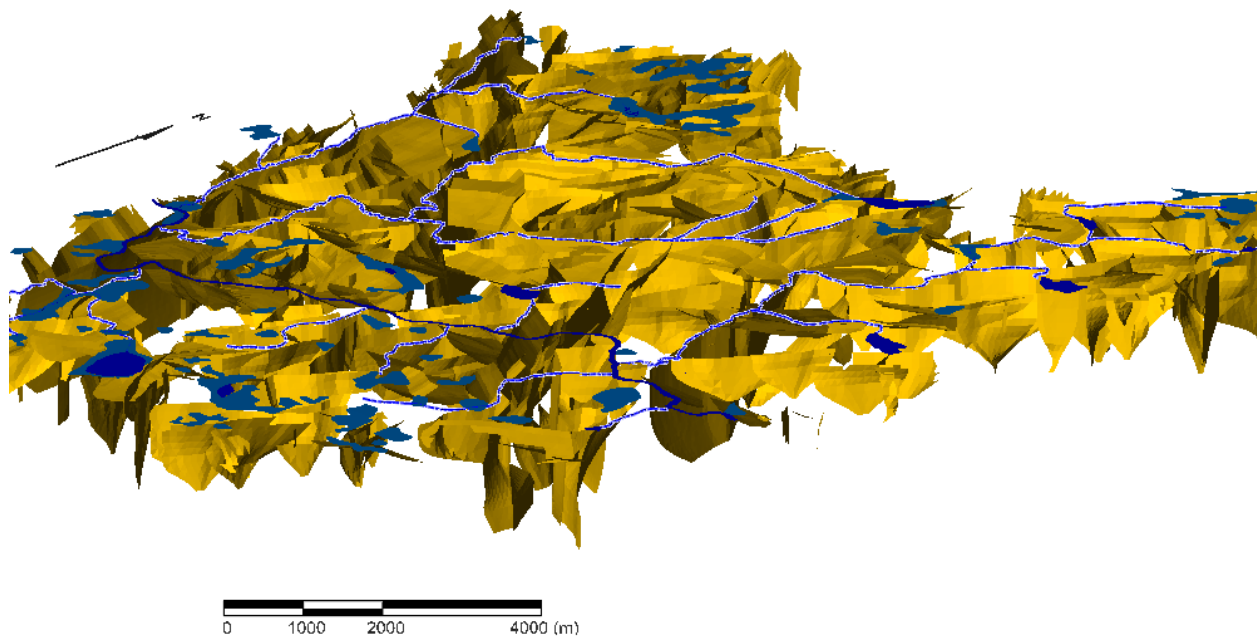
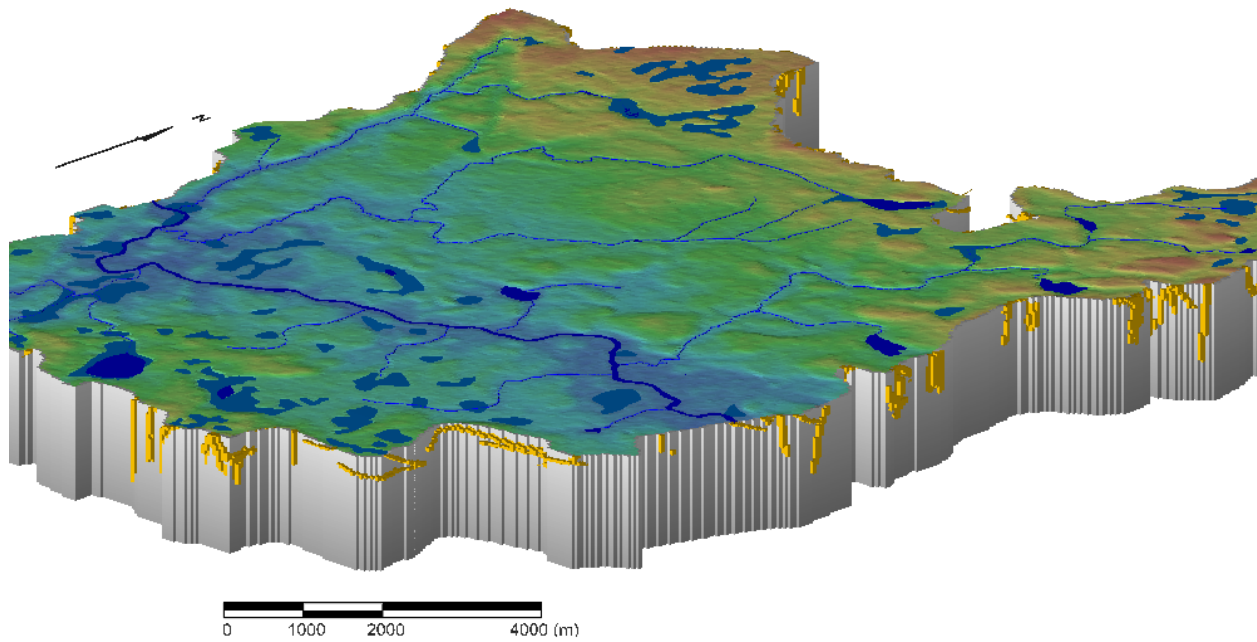


Figure 6.2: (a) Topography for hypothetical area in Canadian Shield. (b) Fracture network for hypothetical area of Canadian Shield.

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.

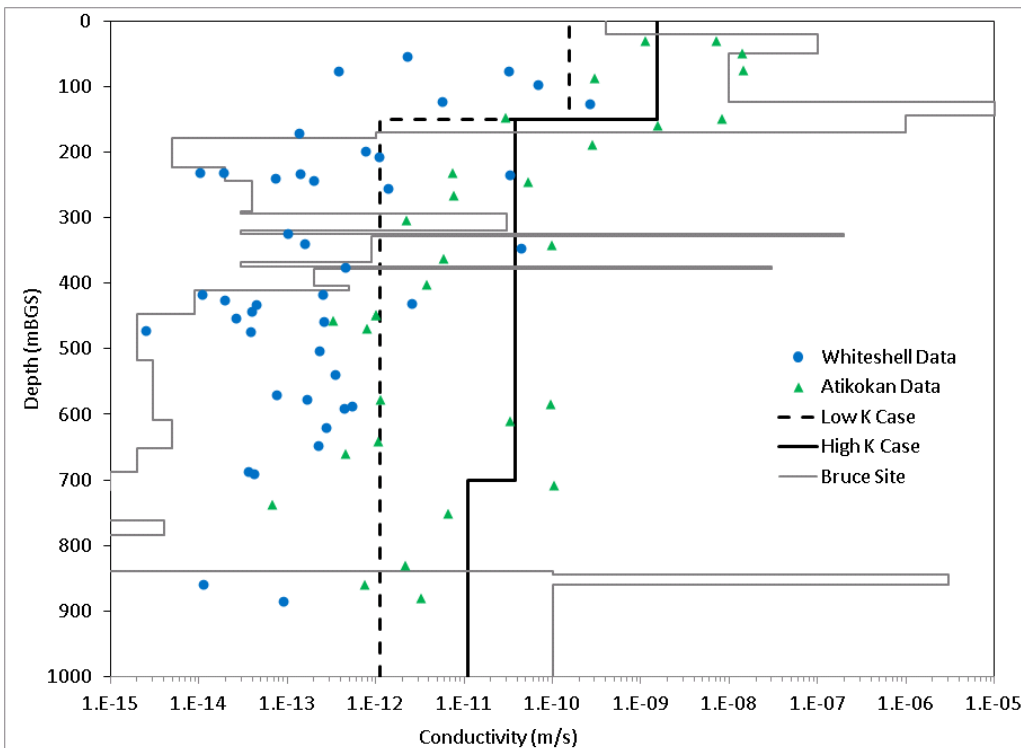
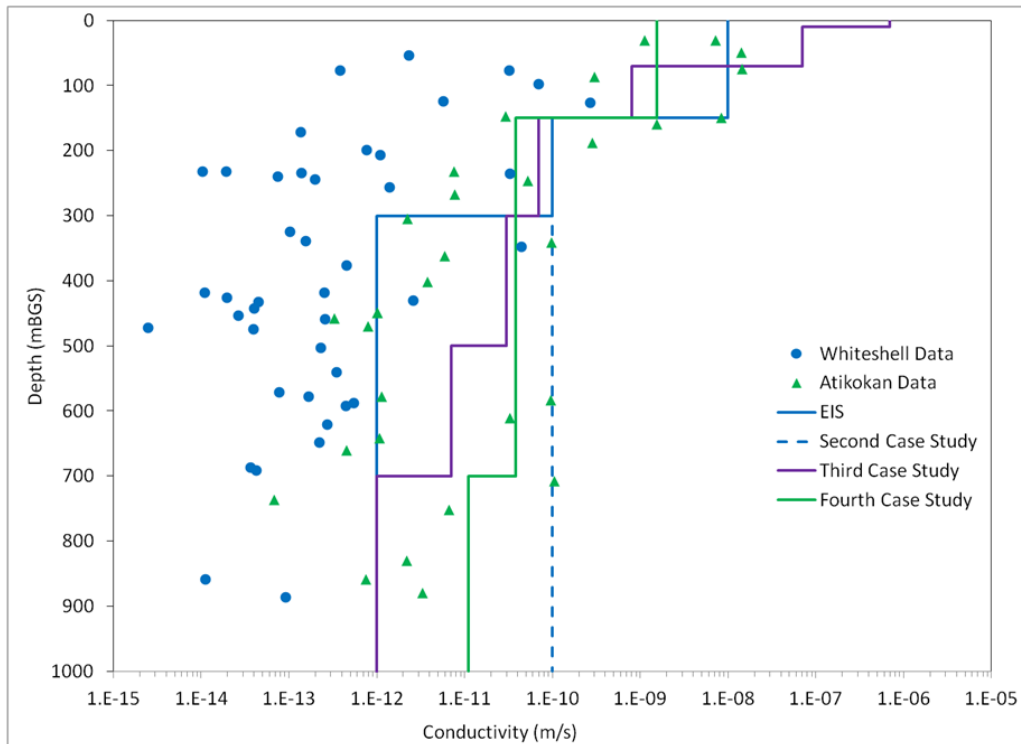
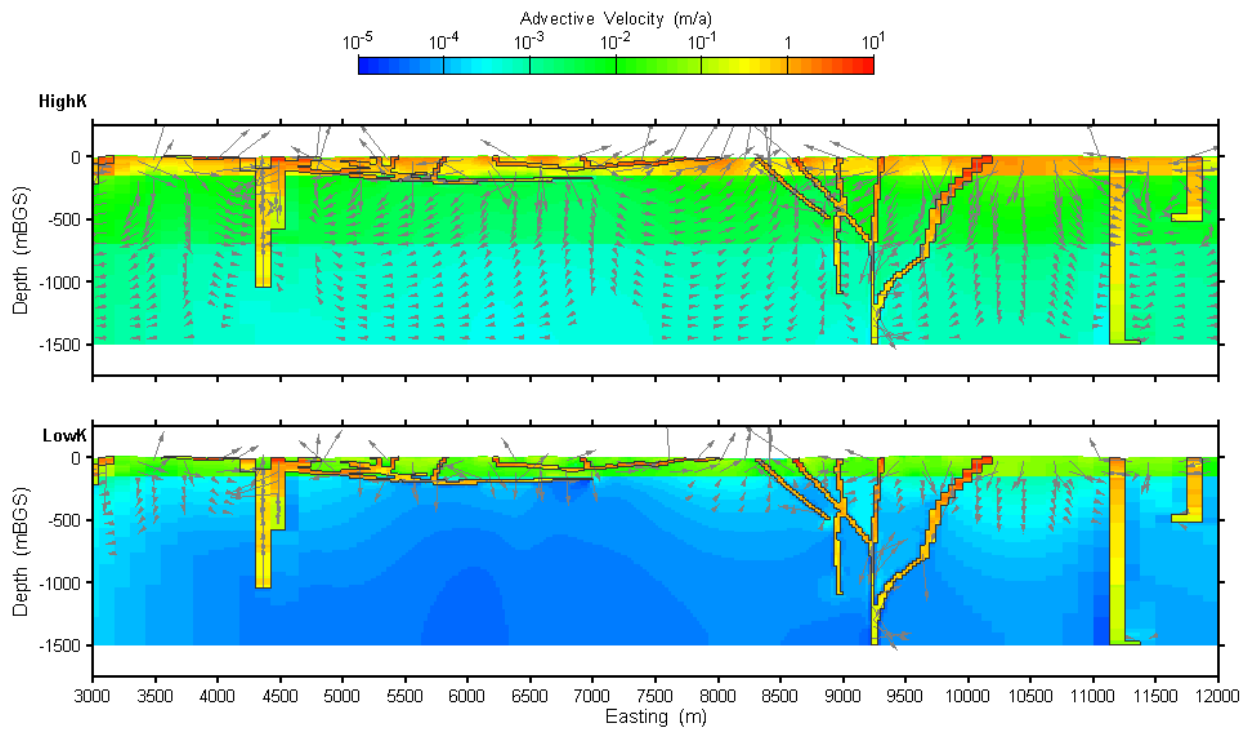
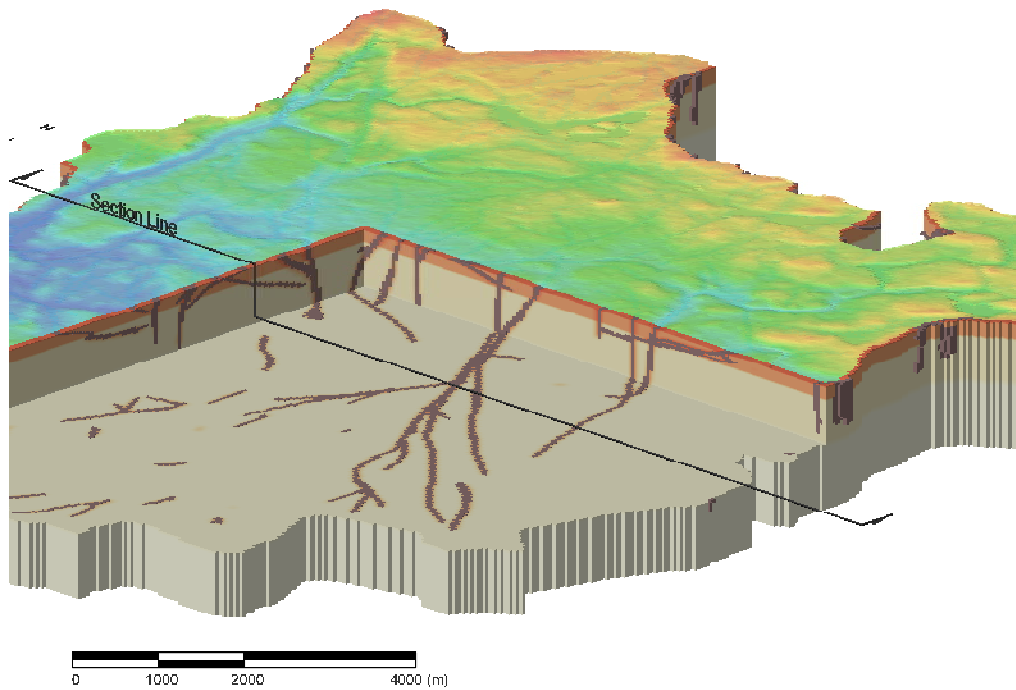


Figure 6.3: (a) Granite rock data at two sites and rock mass hydraulic conductivities assumed in various Canadian used fuel repository case studies. (b) Comparison of granite rock data with hydraulic conductivity at Bruce site. The reference repository depth is 680 m.



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 km², and annual average water throughputs of around 0.02-0.04 m³/s. The larger South River along the bottom of the model has a catchment area of around 2000 km² and an annual average water flow of 23 m³/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 m³/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 m³/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.

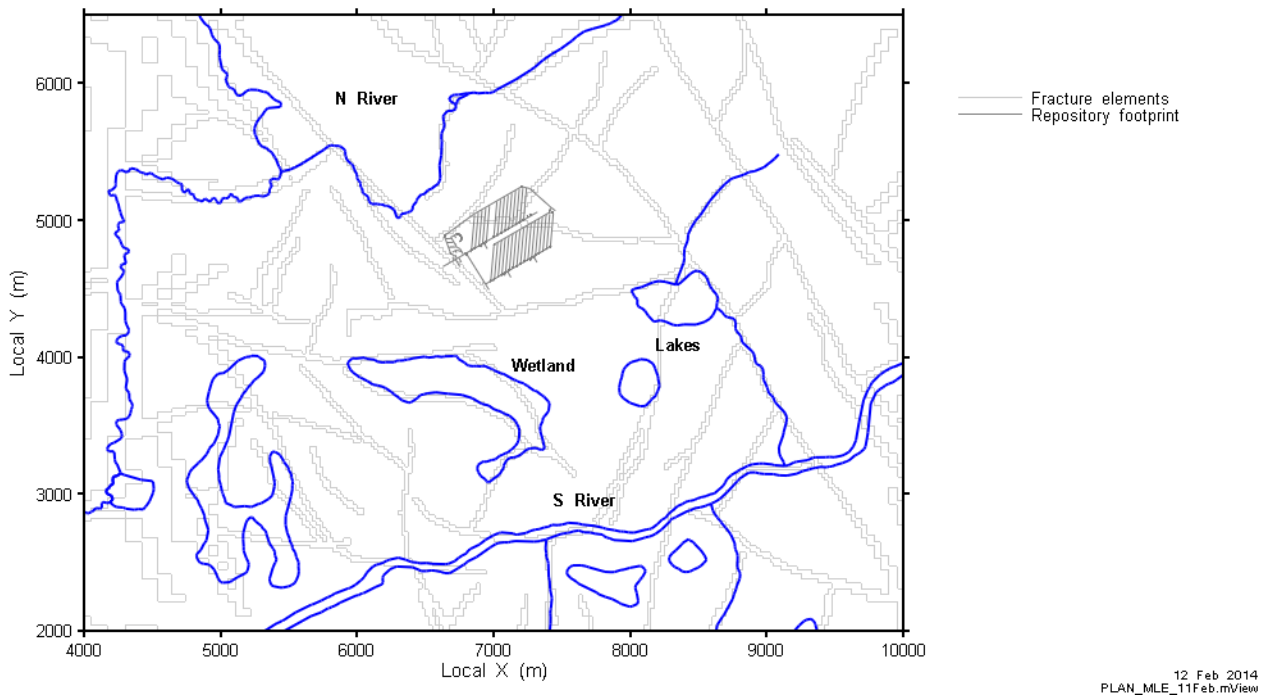
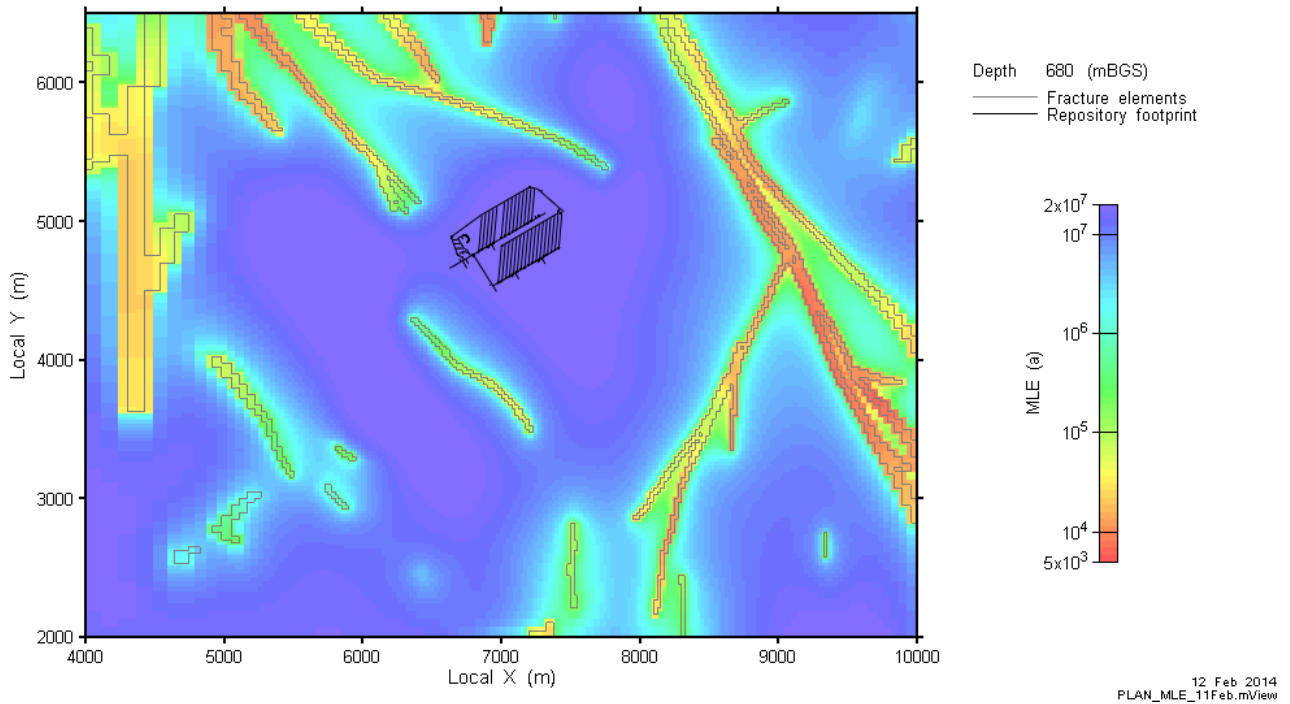


Figure 6.5: Illustrative repository location at 680-m depth at hypothetical site. (a) Major fracture locations at 680-m depth, and Mean Life Expectancy for Low K case of hydraulic conductivity. (b) Surface fracture locations and surface water features.

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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- Quintessa. 2003. Preliminary Safety Assessment of Concepts for a Permanent Waste Repository at the Western Waste Management Facility Bruce Site. Quintessa Ltd. Report for Municipality of Kincardine and Ontario Power Generation. Quintessa report QRS-1127B-1 v1.0. Henley, UK.
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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*.

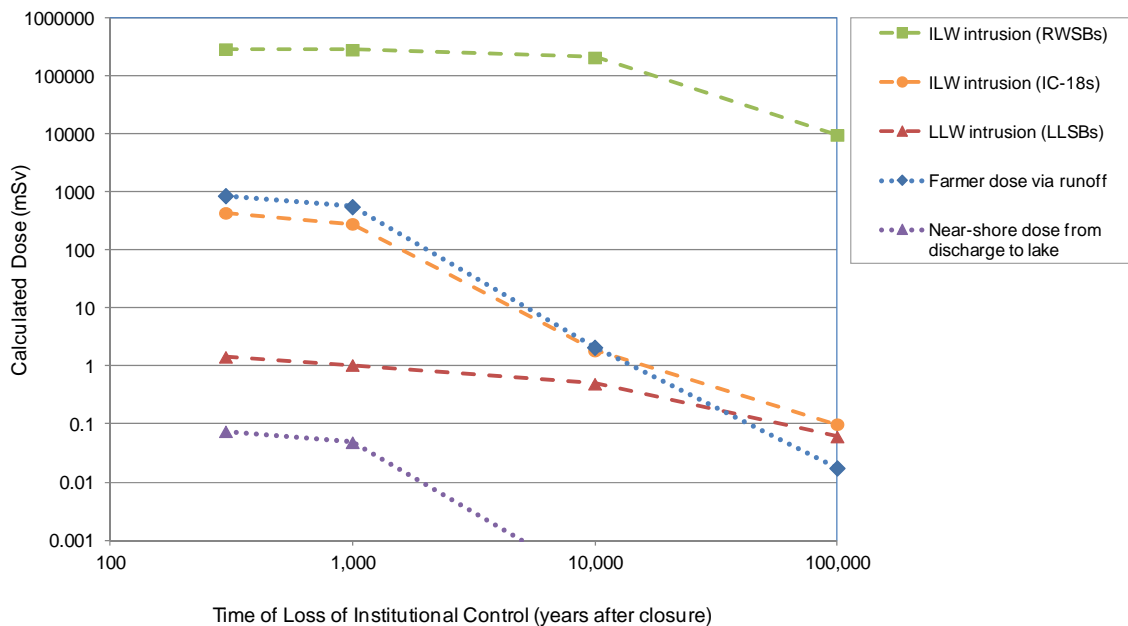


Figure A.1: Calculated Doses for Human Intrusion in the Enhanced Surface Storage Option via Groundwater and Intrusion Pathways, for Loss of Stewardship at Different Times

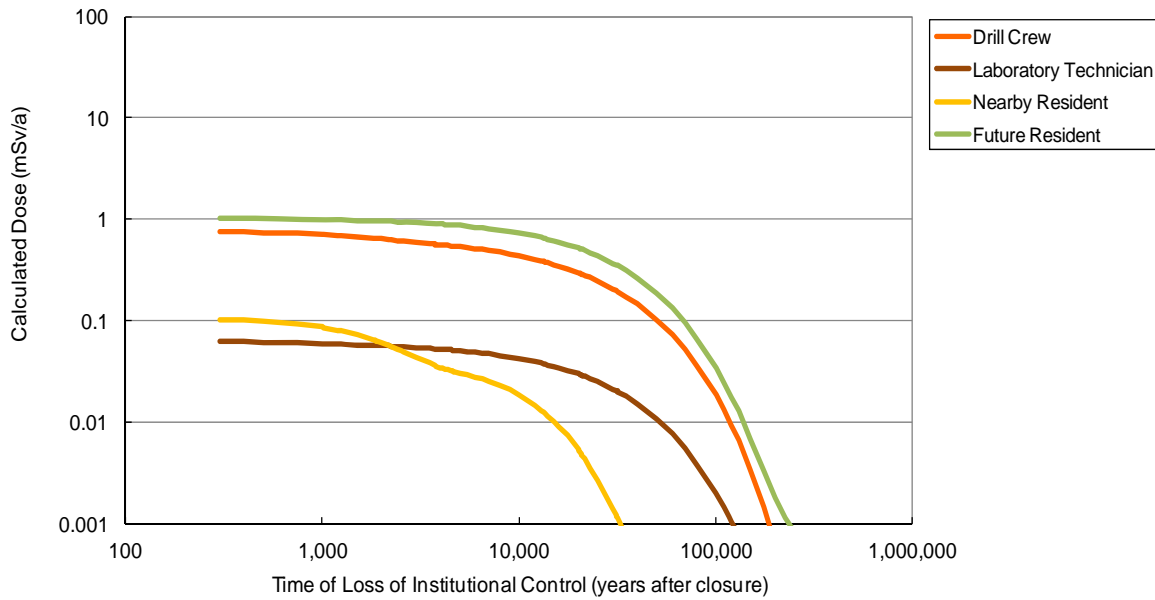


Figure A.2: Calculated Doses for Human Intrusion in the Bruce Site DGR Option for a Borehole Drilled to the Repository Horizon, for Loss of Institutional Control at Different Times (adapted from Figure 8-36, OPG 2011b)

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 CO₂ sequestration, hydraulic fracturing, oil and gas well integrity, steam injection for heavy oil production, biosolids injection, and thermohydraulic 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”:

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Institut de Radioprotection et de Sûreté Nucléaire (ISRN), *Radioactive Waste Management*. 2013: www.isrn.fr

International Atomic Energy Agency, *Disposal Approaches for Long Lived Low and Intermediate Level Radioactive Waste*. IAEA Nuclear Energy Series, No. NW-T-1.20 (2009): <http://www-pub.iaea.org/books/IAEABooks/8184/Disposal-Approaches-for-Long-Lived-Low-and-Intermediate-Level-Radioactive-Waste> .

OECD, “Radioactive Waste Management Programmes in OECD/NEA Member Countries”:
<https://www.oecd-nea.org/rwm/profiles/>

SKB International, *International Perspective on Repositories for Low Level Waste* (December 2011):
<http://www.skb.se/upload/publications/pdf/R-11-16.pdf>

World Nuclear Organization, global overview of nuclear waste policies and facilities:
<http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Appendices/Radioactive-Waste-Management-Appendix-3--National-Policies/>

OECD, Nuclear Energy Agency, classification of radioactive waste: <https://www.oecd-nea.org/press/press-kits/radioactive-waste.html>.

International Atomic Energy Agency (IAEA), *Classification of Radioactive Waste*: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1419_web.pdf

Canada:

Canadian Environmental Assessment Agency (2009), *Guidelines for the Preparation of the Environmental Impact Statement for the Deep Geologic Repository for Low- and Intermediate-Level Radioactive Wastes*: <http://www.ceaa-acee.gc.ca/050/documents/31039/31039E.pdf>

Canadian Environmental Assessment Agency (2014), *Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste, Environmental Assessment*:
<http://www.ceaa.gc.ca/050/details-eng.cfm?evaluation=17520>

Ontario Power Generation, *OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Environmental Impact Statement: Main Report, Volume 1*:
http://www.ceaa.gc.ca/050/documents_staticpost/17520/49818/vol1.pdf

Ontario Power Generation, *OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Environmental Impact Statement Summary*:
<http://www.nwmo.ca/uploads/DGR%20PDF/EIS/Environmental-Impact-Statement---Summary.pdf>

Golder Associates, *Final Report on Independent Assessment of Long-Term Management Options for Low And Intermediate Level Wastes at OPG's Western Waste Management Facility*. Submitted to: Municipality of Kincardine and Ontario Power Generation (February 2004).

QUINTESSA, *Preliminary Safety Assessment Of Concepts For A Permanent Waste Repository At The Western Waste Management Facility Bruce Site: Summary Report*. Submitted to: Municipality of Kincardine and Ontario Power Generation, Nuclear Waste Management Division (March 2003).

Nuclear Waste Management Organization, *Adaptive Phased Management: Used Fuel Repository Conceptual Design and Postclosure Safety Assessment in Crystalline Rock*. Pre-Project Report, December 2012: http://www.nwmo.ca/uploads/File/NWMO-TR-2012-16_4CS-Pre-project-Report_FinalforWebsite.pdf

Nuclear Waste Management Organization, *Assessing the Options: NWMO Assessment Team Report*. June 2004: http://www.nwmo.ca/uploads_managed/MediaFiles/1092_9-1assessingtheoptions_nwmoass.pdf

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:

http://www.enresa.es/activities_and_projects/low_and_intermediate_wastes

<http://www.csn.es/index.php/es/fuel-cycle-facilities/el-cabril>: