PMD 13-P1.10

File / dossier : 8.01.07
Date: 2013-07-23
Edocs: 4177276

Written Submission from

Natural Resources Canada

In the Matter of

Ontario Power Generation Inc.

Proposed Environmental Impact Statement for OPG's Deep Geological Repository (DGR) Project for Low and Intermediate Level Waste

Joint Review Panel

September 16 to October 12, 2013

Mémoire de

Ressources naturelles Canada

À l'égard de

Ontario Power Generation Inc.

Étude proposée pour l'énoncé des incidences environnementales pour l'Installation de stockage de déchets radioactifs à faible et moyenne activité dans des couches géologiques profondes

Commission d'examen conjoint

16 septembre au 12 octobre 2013

Canada

NATURAL RESOURCES CANADA'S SUBMISSION TO THE JOINT REVIEW PANEL DEEP GEOLOGIC REPOSITORY FOR LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE PROJECT

Public Hearing

July 23, 2013

Table of Contents

1 CONTEXT FOR NRCAN'S PARTICIPATION IN THE FEDERAL JOINT REVIEW PANEL FOR THE DEEP GEOLOGIC REPOSITORY PROJECT

1.1 NRCAN'S ROLE IN THE ENVIRONMENTAL ASSESSMENT

Natural Resources Canada (NRCan) is participating in the Joint Review Panel's (JRP) environmental assessment of the Ontario Power Generation's DGR Project as a Federal Authority (FA) providing, as requested by the JRP, specialist and expert information and knowledge within the meaning of s. 20 of the *Canadian Environmental Assessment Act, 2012* (CEAA). NRCan does not have any regulatory or approval role for the Project.

This submission responds to the June 18, 2013 (CEAR #1198) letter from the Joint Review Panel (JRP) for Ontario Power Generation's (the Proponent) Deep Geologic Repository for Low and Intermediate Level Radioactive Waste Project (DGR) (the Project), requiring NRCan to present conclusions regarding the potential effects of the Project within its areas of responsibility and expertise, with specific reference to the following areas:

- Hydrogeology/groundwater within the thin, permeable formations in the intermediate and deep groundwater systems;
- Near surface groundwater regime including the overburden groundwater/surface water interactions and overburden groundwater modeling;
- Seismicity including the seismic hazard assessment;
- Geology, specifically the stratigraphy and sedimentology of the sandstone and shale bedrock geology;
- Hydrogeochemistry including groundwater chemistry, fracture studies and the interpretation of the age of fractures; and,
- Geochemical characterization of waste rock and the waste rock management plan.

1.2 NRCAN'S MANDATE

NRCan seeks to enhance the responsible development and use of Canada's natural resources and the competitiveness of Canada's natural resources products. We are an established leader in science and technology in the fields of energy, forests, and minerals and metals and use our expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass.

Within NRCan several sectors have been involved in the review of the DGR, providing science and policy advice:

- The Earth Sciences Sector (ESS) is the Government of Canada's principal earth sciences agency, providing Canadians with reliable geomatics and geosciences advice and knowledge. The ESS supports the environmental, social and economic priorities of the federal government by focusing its science and technology programs

on innovative projects that improve the quality of life of Canadians. The ESS plays a pivotal role in the collection and dissemination of public-good earth sciences information of major importance to Canada's energy, mining and forestry sectors, among others.

- The Minerals and Metals Sector promotes the sustainable development of Canada's minerals and metals resources industry by integrating economic, social and environmental objectives. It provides policy advice, science and technology, as well as commodity and statistical information in support of decision making. It is also the federal government's primary source of expertise on explosives regulations and technology. The CanmetMINING Branch develops and advances new mining technologies and processes to advance the economic competitiveness and environmental responsibility of Canada's mining sector. CanmetMINING's innovative work includes: clean water; environmental management; energy efficiency; Northern mineral development; critical and strategic minerals processing; mining extraction innovation; and, radioactive waste management.

- The Energy Sector is the lead on energy policy for the Government of Canada. It engages in policy work, provides knowledge, delivers programs and works with other federal departments and agencies to promote the sustainable development and integrated management of Canada's energy resources. The Electricity Resources Branch develops federal policy in the area of electrical and nuclear energy, uranium and radioactive waste, and delivers programs that cleanup radioactive waste. It provides advice and recommendations on domestic and international issues concerning the nuclear fuel cycle. In the area of radioactive waste, the Sector is responsible for Canada's Radioactive Waste Policy (1996) and, in the area of radioactive waste particularly, administers Canada's Radioactive Waste Policy Framework (1996) and oversees programs concerning historic and legacy nuclear wastes. It is also responsible for the provision of policy advice on the following nuclear-related legislation: *the Nuclear Safety and Control Act*, *the Nuclear Liability Act*, *the Nuclear Fuel Waste Act*, and *the Nuclear Energy Act*.

1.3 NRCAN'S PARTICIPATION IN THE JOINT REVIEW PANEL'S ENVIRONMENTAL ASSESSMENT

NRCan has been participating in review of information and technical reports related to DGR since 2007, providing comments and geoscience expertise to the Canadian Nuclear Safety Commission in their review of the technical studies (*e.g*. Descriptive Geosphere Site Model, Interim Geosynthesis Report) for the DGR project.

OPG submitted their Environmental Impact Statement for the DGR project on April 18, 2011 (CEAR #298).

In its letter of February 3, 2012 (CEAR #338) the JRP asked NRCan to indicate whether the Environmental Impact Statement and associated documents provided by the Proponent sufficiently addressed the requirements of the guidelines issued by the federal

government to the proponent on January 26, 2009 (CEAR #150). The JRP required the advice of Natural Resources Canada in relation to: "*the credibility, defensibility, clarity, completeness, reliability and appropriateness of the proponent's information, methodology and conclusions*" as they relate to NRCan's mandate and areas of expertise. Following the receipt of this letter, NRCan delivered an overview presentation to the JRP on NRCan's mandate and areas of expertise during the JRP Orientation Session for the DGR project on February 21, 2012 (CEAR #344).

In NRCan's letter of March 23, 2012 (CEAR #352) and overview presentation to the JRP on the department's mandate and areas of expertise during the JRP Orientation Session, a list and description of the expertise it had identified for the DGR project was provided. This list included: geology, hydrogeology and hydrogeochemistry, glacial cycles, seismic hazards. It also included policy expertise in relation to radioactive waste.

NRCan's May 31, 2012 (CEAR #517) submission to the JRP considered the following subjects: hydrogeology, seismic hazards, glacial cycles, geology, and hydrogeochemistry. At the time, NRCan recommended that the JRP consider twelve information requests which addressed information related to the thin, permeable formations in the intermediate and deep groundwater systems at the proposed DGR site, the seismic hazard assessment report, long term climate change and the potential for glacial erosion, stratigraphy and sedimentology of the sandstone and shale bedrock geology and groundwater chemistry and solute transport at the DGR site. These information requests were included in JRP information request Package #4 submitted to OPG on July 3, 2012 (CEAR # 642) and JRP Package #5 submitted to OPG on October 24, 2012 (CEAR #728).

In the department's November 27, 2012 (CEAR #822) submission to the JRP, NRCan presented its review of the proponent's (September 6 and August 27, 2012) responses to comments related to hydrogeology and proposed two additional information requests. These information requests were included in JRP information request Package #8 submitted to OPG on December 20, 2013.

Subsequent to this, on March 27, 2013 (CEAR #938), NRCan submitted its review of the proponent's response to NRCan information requests related to hydrogeochemistry, seismicity, geology (stratigraphy and sedimentology) that were included in JRP information request Package #5.

In February 2013, NRCan participated in discussions with Environment Canada and the Canadian Nuclear Safety Commission regarding the geochemical characterization of waste rock and the potential for acid generation. NRCan provided comments to Environment Canada in its analysis of whether the proponent had adequately characterized the waste rock.

March 8, 2013 (CEAR #918) and April 22, 2013 (CEAR #970) the JRP requested that NRCan review a number of additional information requests in areas related to: glaciology, hydrogeology, hydrogeochemistry, geology (sedimentation and stratigraphy), acid rock/drainage, metal leaching and waste rock management. A number of these

information requests were outside the original scope of the department's review. In its review of these, the scope of NRCan's review was expanded to include the near surface groundwater regime including the overburden groundwater/surface water interactions and overburden groundwater modeling and the geochemical characterization of waste rock and the waste rock management plan.

NRCan submitted its final information request review on May 24, 2013 (CEAR #1120). In addition to the review of responses to JRP information requests related to NRCan dispositions, this review included departmental views on the additional information requests the JRP requested NRCan review. For those related to areas of expertise the department had available, NRCan found the information presented by the proponent to be sufficient. NRCan had no further information requests at the time, and considered the department's participation in JRP's public review period on the adequacy of the EIS to be complete.

NRCan's letter of July 12, 2013 (CEAR #1232) included a description of expertise the department identified and has made available for the public hearings:

- Hydrogeology/groundwater within the thin, permeable formations in the intermediate and deep groundwater systems at the proposed DGR site.
- Near surface groundwater regime including the overburden groundwater/surface water interactions and overburden groundwater modeling. This expertise does not extend to the groundwater/surface water interactions with the storm water management pond and the wetland.
- Seismic hazards.
- Stratigraphy and sedimentology of the sandstone and shale bedrock geology, which includes hydrocarbon potential, cap rock seals and their strength, faults and fractures and fluid migration in the permeable sandstone. It does not include resource evaluation, adequacy of geomechanical modeling and rock characterization, diffusion dominance in the repository and its cap rock, as well as natural tracer modeling in these sequences.
- Groundwater chemistry, fracture studies and the interpretation of the age of fractures.
- Geochemical characterization of the waste rock and the waste rock management plan.

The sections below include a summary of the department's technical review, as well as a description of the scope of review and specific expertise NRCan has provided to the JRP for the DGR project.

2 NRCAN'S TECHNICAL REVIEW OF THE EIS

The information presented in this submission is a summary of the technical review conducted by NRCan staff of the documents provided by the Proponent. The conclusions reached by staff reflect the professional opinions of the reviewers, based on the information provided to NRCan through the Joint Review Panel process. The department

has not undertaken additional studies or research to generate new information or to independently validate those data presented by the proponent.

2.1 HYDROGEOLOGY/GROUNDWATER WITHIN THE THIN, PERMEABLE FORMATIONS IN THE INTERMEDIATE AND DEEP GROUNDWATER SYSTEMS

For natural evolution scenarios of the Deep Geological Repository, groundwater is the only pathway for released radionuclides to migrate to the biosphere and potentially cause adverse environmental or human health effects. Dissolved radionuclides may migrate relatively rapidly within flowing groundwater (advective transport) or they may migrate very slowly in stagnant groundwater through a process known as chemical diffusion (diffusive transport). Advective transport can only occur in rock formations that are relatively permeable. Diffusive transport is important only in rocks having a very low permeability. Computer models are used to predict the migration of radionuclides from the repository through these two processes. NRCan's technical comments focused on the proponent's model representation of advective transport because this mechanism of radionuclide transport has the greatest potential to drive radionuclide migration beyond the boundaries of the repository.

2.1.1 Review approach and scope

The scope of NRCan's review was limited to hydrogeological matters including groundwater flow, groundwater chemistry and solute transport. NRCan's comments are intended to promote a better understanding of the fate of radionuclides migrating beyond the boundaries of the DGR site in the intermediate and deep groundwater systems.

2.1.2 Results of the review

The information requests submitted by NRCan concerned the thin, permeable formations in the intermediate and deep groundwater systems at the proposed DGR site. Specifically, NRCan recommended to the JRP that the proponent be requested to:

1) Refine the vertical discretization of the numerical hydrogeologic model so as to represent the thin permeable layers of the Salina, Upper Carbonate and Guelph formations (thickness, hydraulic parameter values) in order to better represent the horizontal advective solute transport that would be expected;

2) Revise the hydraulic parameters used to represent the Cambrian sandstone overlying the Shadow Lake layer in the numerical hydrogeologic model in order to reflect a continuous basal permeable unit across the model domain;

3) Revise the boundary conditions of the regional hydrogeologic model to reproduce hydraulic gradients and porewater velocities observed in the thin permeable units (e.g., Salina, Upper Carbonate, Guelph and Shadow Lake Formations);

4) Consider a more appropriate conceptual model of solute transport at the Bruce site that would feature a more representative geological environment (specifically the horizontal advective-dispersive transport along high-conductivity layers with diffusive vertical transport into adjacent low-conductivity "matrix" formations); and,

5) Lower the base of the 3D Simplified hydrogeologic model to the top of the Precambrian in order to assess lateral advective radionuclide transport in the Cambrian unit.

The significance of the comments for environmental and post-closure safety assessments stemmed from the potential role of thin, permeable, layers as preferential pathways for relatively rapid horizontal migration of radionuclides away from the repository site.

The JRP provided information requests on these topics to the proponent in information request Package #4 submitted to OPG on July 3, 2012. The proponent's response to these information requests was included in its August 27 and September 6, 2012 (CEAR # 704, 725) submission to the panel. While the proponent had provided some additional information in their responses, NRCan was of the view that the proponent had not adequately responded to, or had only partially responded to, information requests related to the representation of thin permeable layers in the intermediate and deep groundwater systems and the ability of the numerical modeling to reproduce hydraulic gradients and porewater velocities observed in these units.

In NRCan's disposition of the proponents response (November 27, 2012), NRCan reiterated its view that the Salina A1 Upper Carbonate unit and the Guelph, Cambrian/Shadow Lake Formations are thin, permeable layers that represent potential preferential pathways for relatively rapid horizontal advective radionuclide transport away from the repository site. We further stated that in order to investigate the fate of radionuclides migrating laterally beyond the boundaries of the DGR, and various near-field scenarios, the regional and embedded groundwater flow and transport models must faithfully represent hydrogeological observations from these units. In order to address these points, NRCan proposed two additional information requests to the JRP:

1. (a) The proponent should develop a modified version of the FRAC3DVS-OPG regional groundwater flow and solute transport model, and its embedded site-scale sub-model that incorporated: (i) a refined vertical discretization of the permeable layers of the Salina, Upper Carbonate and Guelph Formations to ensure explicit representation of their thicknesses and hydraulic properties as reported in the Descriptive Geosphere Site Model (DGSM) report (NWMO DGR-TR-2011-24); (ii) revised hydraulic parameters for the Shadow Lake Formation in order to reflect a continuous basal permeable unit across the model domain; and, (iii) revised boundary conditions to ensure that observed hydraulic gradients and porewater velocities, both updip[1] (Guelph, Cambrian) and down-dip (Salina A1 Upper Carbonate), are reproduced at the site.

[1] Updip - located up the slope of a dipping plane or surface.

(b) The proponent use the modified regional groundwater flow and solute transport model to investigate performance metrics for scenarios involving long-distance updip migration of radionuclides in the Guelph and basal clastic unit, and report results.

(c) The proponent use the modified embedded site-scale groundwater flow and solute transport sub-model to investigate tracer migration for scenarios including that of hypothetical discrete fracture zones hydraulically connected to the Cambrian/Shadow Lake Formations, and report results.

2. The proponent should incorporate the Cambrian unit in the 3DS model and report on Performance Safety Assessment modeling that investigates near-field radionuclide migration in the presence of horizontal hydraulic gradients in the Salina A1 Upper Carbonate, Guelph and Cambrian Formations, as observed at the site.

The panel submitted these information requests as part of JRP information request package #8 on December 20, 2013 (CEAR #844). The proponent responded to these information requests on March 15, 2013 (CEAR #915). Further to OPG's response, NRCan met with representatives from the Nuclear Waste Management Organization (NWMO) on May 7, 2013 to discuss the responses and seek clarifications. These discussions were captured in meeting minutes that were submitted, by NRCan, to the panel on May 23, 2013 (CEAR # 1120).

Horizontal advective solute transport in the Niagaran and Cambrian units

In response to the information request submitted by the JRP, the proponent undertook additional groundwater flow and solute transport modeling. The model was refined by increasing the layers represented from 39 layers to 100+ layers to ensure an explicit representation of layer thicknesses and hydraulic properties of the thin permeable layers of the Salina, Upper Carbonate and Guelph Formations as presented in the DGSM report (NWMO DGR-TR-2011-24). With this layer refinement, the velocity at which a radionuclide would be carried by groundwater (advective transport) increased from 0.031 to 0.16 m/a in unit 4A and from 0.0074 to 0.036 m/a in unit 4B. These revised seepage velocities more closely approximate corresponding DGSM values of 0.77 and 0.04 m/a in units 4A and 4B, respectively. Additionally, by subdividing the Niagaran unit so as to represent the permeable Guelph Formation (4.1m) and the very low-permeability Goat Island, Gasport and Lion's Head Formations, added 30.1 m of diffusive transport distance between the repository and the permeable layer where lateral advective transport dominates. As a result, the Mean Life Expectancy (MLE)[2] performance criterion increased from 164 to 202 Ma, which means it should take longer for radionuclides to migrate through the Niagaran unit.

[2] Mean Life Expectancy in the context of the DGSM for the DGR refers to the average time for particles at the location of the proposed DGR to reach the boundary of the base-case regional scale groundwater system.

The proponent did not perform any additional investigations related to a potential permeable basal unit in the Shadow Lake Formation beyond the updip limit of the Cambrian. The proponent considers that an existing sensitivity analysis in which the hydraulic conductivity of the upper Precambrian was increased to 1E-08 m/s adequately addresses this issue.

Also, the proponent made no changes to the regional groundwater flow model that would ensure that the magnitude and direction of hydraulic gradients and advective velocities in thin permeable units actually replicate observations from site characterization. It is the proponent's conclusion that the requested changes would not materially impact MLE at the repository horizon given the dominance of diffusive transport in the groundwater system.

Finally, the proponent has concluded that an assessment of modified groundwater flow and mass transport using the more refined model would indicate no material change to the DGR Safety Case.

Horizontal advective solute transport in the Cambrian Formation

While the proponent only partially addressed NRCan's concerns with respect to the regional groundwater flow and transport model (refer to summary above), the proponent has carried out additional Postclosure Safety Assessment groundwater flow and radionuclide transport modeling. The 3D Simplified model (3DS) model was extended vertically to include the permeable Cambrian unit and a portion of the upper Precambrian. Through the application of suitable lateral boundary conditions, horizontal hydraulic gradients and advective groundwater fluxes, as described in the DGSM, were implemented in the Cambrian, Guelph and upper A1 Carbonate permeable units. Model results for a Cl-36 radionuclide tracer show horizontal dispersion plumes in these units. In particular, the new modeling shows a very low concentration plume of the radionuclide Chlorine-36 moving away from Lake Huron, in the Cambrian sandstone layer. A peak Chlorine-36 concentration of approximately $1x\ 10^{-13}$ g/m³ is expected to occur in Cambrian, east of the repository, after 1 million years. Based on this supplementary analysis that incorporates horizontal radionuclide migration in the Cambrian sandstone, NRCan considers the proponent's response sufficient.

2.1.3 Conclusions and Recommendations

NRCan's information requests, which concerned the refinement of the regional and site specific groundwater models, were intended to promote a better understanding of the fate of radionuclides migrating beyond the boundaries of the DGR site in thin permeable units of the intermediate and deep groundwater systems. However they do not call into question the seven fundamental geoscience hypotheses or attributes that support the suitability of the Bruce site.

NRCan appreciates the limited additional modeling results submitted by the proponent. They highlight the importance of accurately resolving thin permeable units where advective mass transport is dominant, regardless of whether the consequences for the

Performance Safety Case are positive or negative. NRCan considers that all of its technical comments have been resolved satisfactorily.

2.2 SHALLOW GROUNDWATER

2.2.1 Review approach and scope

At the request of the JRP, NRCan reviewed information related to the near surface groundwater regime including the overburden groundwater/surface water interactions and overburden groundwater modeling. This included reviewing several third party information requests including EIS-01-01, EIS-03-55, EIS-03-57, EIS-03-96, EIS-08-391, and EIS-08-392. This review did not extend to the groundwater/surface water interactions with the storm water management pond and the wetland.

Accordingly, NRCan reviewed the proponent's response to EIS-01-01, EIS-03-55, EIS-03-57, EIS-03-96, EIS-08-391, and EIS-08-392 to the extent that they fall under NRCan's area of expertise in hydrogeology.

2.2.2 Results of the review

The JRP requested that NRCan review a number of responses to information requests related to shallow groundwater, specifically:

- Impacts of excavation and associated dewatering on groundwater flow patterns, seepage rates and surface water/groundwater interactions;
- Impacts of the dewatering of the waste rock management area (WRMA) on the marsh at the North end of the project site and the swamp at the southeast corner of the project area;
- Impacts of the WRMA and the stormwater management pond (SWMP) on the elevation of the groundwater table and local groundwater regime; and,
- The potential for tritium in the SWMP through groundwater migration.

NRCan reviewed the information provided by the proponent and was generally satisfied. It is NRCan's view that the responses provided by the proponent with respect to impacts of dewatering and the potential for Tritium plume migration leading to contamination of water in the SWMP are sufficient with one caveat. With respect to the impacts of the excavation and associated dewatering on the shallow groundwater, NRCan notes the value used to represent the hydraulic conductivity of the upper Bass Islands Formation in the groundwater model (refer to Table 1 of Sykes (2012a)) uses a hydraulic conductivity of 2×10^{-8} m/s, which is four orders of magnitude lower than the hydraulic conductivity of the Bass Islands Formation listed in the Descriptive Geosphere Site Model (DGSM) report which is 1×10^{-4} m/s. No explanation was provided for the discrepancy. However, Sections 3.8.3.1 (p.52) and 3.11.1 (p. 98) of the DGSM report describe the regional Silurian-Devonian unconformity and the associated enhanced weathering, dissolution and permeability in the upper parts of the underlying Bass Islands Formation, which would

point to a higher hydraulic conductivity for the Bass Formation. Despite this, the proponent concludes that the most important phase for shaft dewatering occurs before the concrete liner is constructed in the shallow bedrock zone (Lucas Formation).

2.2.3 Conclusions and Recommendations

In NRCan's opinion, in addition to the Lucas Formation, the upper 20 m of the Bass Islands Formation also represents a critical phase for shaft excavation where proper grouting may be essential to stem groundwater inflows.

Nonetheless, with respect to the Tritium plume, NRCan's view is that shaft inflows at the depth of the Bass Islands Formation (circa 124 m) are unlikely to cause perturbations to the shallow groundwater flow system that could affect migration patterns of the Tritium plume in the overburden and uppermost Lucas Formation.

Recommendation: NRCan recommends that the proponent be required to continue to collect baseline data on shallow groundwater flows and Tritium plume migration prior to and during construction in order to refine the groundwater model.

Recommendation: NRCan recommends that the proponent be required to confirm that grouting will be required to stem groundwater inflows from the upper 20 m of the Bass Islands Formation, and to develop mitigation measures accordingly, as appropriate.

2.3 SEISMIC HAZARDS

The damage potential of an earthquake is determined by how the ground moves and how the structures within the affected region are constructed. Expected ground motion can be calculated on the basis of probability, and the expected ground motions are referred to as the seismic hazard.

In Canada, the evaluation of regional seismic hazard for the purposes of the National Building Code of Canada (NBCC) is the responsibility of the Geological Survey of Canada of NRCan. The seismic hazard maps prepared by the Geological Survey are derived from statistical analysis of past earthquakes and from advancing knowledge of Canada's tectonic and geological structure.

The seismic hazard maps and earthquake load guidelines included in the NBCC are used to design and construct buildings to be as earthquake proof as practicable. The provisions of the building code are intended as a minimum standard. They are meant to prevent structural collapse during major earthquakes and thereby to protect human life. The provisions may not, however, prevent serious damage to individual structures.

2.3.1 Review approach and scope

NRCan's reviewer considered the seismic hazard analysis, specifically whether the EIS and associated licensing documents appropriately described and assessed the probability of contemporary earthquake shaking hazard, longer-term seismic hazard, earthquake-generated tsunami hazard, and faulting hazard.

In addition, NRCan compared the information and earthquake source models and hazard results prepared by AMEC to the model sources and hazard results for the area that NRCan prepared for NBCC2005 (Adams and Halchuk GSC Open File 4459) and those being prepared for NBCC2015.

2.3.2 Results of the review

The seismicity rate is low in the vicinity of the planned repository (DGR-TR-2011-20). Although the rate of small nearby earthquakes is low, rare large earthquakes pose a hazard to the repository, particularly because of its intended long life. The best way to assess and quantify the hazard is through a probabilistic seismic hazard assessment (PSHA). The Proponent engaged AMEC Geomatrix to perform a PSHA (NWMO DGR-TR-2011-20). The PSHA (March 2011) is based on the 2009 seismic hazard assessment performed for the "Darlington New Build" project. NRCan has assessed the AMEC report in the light of its experience with PSHA for the NBCC and had two information requests in relation to the seismic hazard report:

- NRCan requested that the Proponent provide the 24+ Plates referred to in the Seismic Hazard Assessment (*e.g.*, section 3.2.1). These figures display maps of the seismic source zones used, and are important for assessing the model used to produce the seismic hazard values against which the stability of the DGR is assessed.

- NRCan requested that the proponent provide the fractile seismic hazard values plotted on figure 5.1 and later in a table. The fractiles represent the spread of the uncertainty in the seismic hazard values and give context to the reliability of the seismic hazard values.

These information requests were included in JRP information request package #5. The Proponent provided the requested plates and fractile seismic hazard values (CEAR #777). NRCan's review found the proponent's responses to be satisfactory, and considered the information requests resolved.

2.3.3 Conclusions and Recommendations

NRCan's review assessed the probability of contemporary earthquake shaking hazard, longer-term seismic hazard, earthquake-generated tsunami hazard, and faulting hazard. NRCan's conclusions and recommendations for each hazard are detailed below:

Contemporary Earthquake Shaking Hazard

NRCan is of the view that the proponent has adequately characterized the contemporary earthquake shaking hazard and agrees that the seismicity rate is low in the vicinity of the planned repository. Although the rate of small nearby earthquakes is low, rare large earthquakes pose a hazard to the repository, particularly because of its intended long life.

There are two areas where the AMEC report may be unconservative:

- The maximum magnitude earthquake to be expected – these are smaller than values NRCan or USGS would use.
- How the earthquake rates are smoothed in space – NRCan prefers uniform smoothing, not kernel smoothing, particularly for assessing the hazard for such a long-life facility.

NRCan accepts that different practitioners may choose different input parameters and weight them in different ways, leading to different estimates. Where estimates differ, it is important to consider the uncertainty in each, as the difference may not be significant given the uncertainty.

In its PSHA, AMEC compared its results to NRCan's 2005 NBCC results and indicated good agreement (other than in the choice of ground motion prediction equations), but in fact AMEC was comparing NRCan median values with AMEC mean values, and the NRCan mean values were higher than AMEC realized (considerably higher for 1 second values). This aside, NRCan's view is that AMEC performed a thorough assessment of uncertainty and so give not just mean hazard, but the uncertainty on the mean hazard.

NRCan is completing a new seismic hazard model for NBCC2015. As it must be a nation-wide model, it is far simpler than AMEC's. It gives hazard results for the proposed repository site similar to AMEC's and the agreement is well within the uncertainty bounds of each estimate.

On the basis of that agreement, NRCan judges the AMEC report a satisfactory basis for safe design of the repository against contemporary earthquake shaking.

As a result of the effects of the Tohoku earthquake in Fukushima on the Fukushima nuclear power plant, there has been continued emphasis in nuclear safety on beyond design events (i.e. considering beyond design "what if" scenarios). It is considered that the design level (such as that based on the seismic hazard results for the probability used) will provide an adequate level of safety, but there is also the recognition that events larger than the design are possible (even though the probability of these occurring is extremely low). The current nuclear power plant philosophy is that designs should be robust in the sense that failure modes should be considered and mitigations suggested so that a small or moderate exceedence of the design level does not lead to "catastrophic" failure (for the DGR, this would be a large release of radioactivity into the environment). In some cases the "cost" of providing mitigation may be trivial, and good practice suggests it should be

incorporated into the design. For example, if the back-up power systems at Fukushima had been raised on plinths above the tsunami flooding level, there would have been no loss of on-site power and the nuclear disaster might not have happened. In other cases the "cost" may be assessed as disproportionate to the benefit, and the mitigation may not be implemented. With this in mind, NRCan recommends:

Recommendation: Extra conservatism on the mean shaking levels should be considered during detailed design because of the low maximum magnitudes adopted and because of the kernel smoothing approach in the PHSA.

Recommendation: Detailed design considerations should consider mitigation strategies or plans for conditions of "beyond-design" ground motions.

Longer-term seismic hazard

Both NRCan and AMEC's seismic hazard assessment present "snapshot" estimates of the seismic hazard assuming representative of the present day environment. However the repository will have a very long design life and it is expected that the stress regime will change with the next glaciation (Phase 1 Long Term Cavern Stability Fig. 40 2008 draft version). For example, Norway, Sweden, and Finland have a comparable glacial history to southern Ontario. Their record of past earthquakes has been better studied and the current interpretation of the record suggests that earthquake activity is suppressed during a glaciation and released in a pulse during deglaciation. As such, NRCan concludes that during the next deglaciation there will be a higher chance of strong earthquake shaking than indicated by the contemporary seismic hazard assessment.

Earthquake-generated Tsunami hazard

The generation of large tsunamis (height of greater than 2 m) would require very large earthquakes (magnitude of about 6½ or larger on the moment magnitude scale) to displace the lake bottom. Based on the PSHA conducted for the DGR site, the rates of such earthquakes occurring are extremely low. As such, the rates of earthquake-generated tsunamis are also very low at the site.

NRCan is satisfied that the earthquake-generated tsunami hazard is negligible and notes that the project design includes 7 m of freeboard[3], which NRCan considers a useful mitigating factor for beyond-design flooding.

Faulting Hazard

The strongest argument that the proponent has presented related to faulting hazards is that future faulting is unlikely to affect the integrity of the vault during its intended lifespan because it has not happened in the past 100+ million years.

[3] Freeboard in this context would mean the height of the operations areas above the design-basis 500-year Lake Huron water level (predicted to be 178.6 masl)

NRCan agrees with the proponent that the lack of faulting near the repository site and the low porewater pressure in the repository rock are a good indication that there have been no nearby large (surface-rupturing) earthquakes. The rate of large earthquakes estimated by the contemporary seismic hazard assessment is very low, and the chance of one occurring within 1 km of the repository appears to be considerably less than 1 in a million.

2.4 GLACIOLOGY: LONG TERM CLIMATE CHANGE AND THE POTENTIAL FOR GLACIAL EROSION

2.4.1 Review approach and scope

NRCan's expert who was providing expertise in long term climate change and the potential for glacial erosion is no longer with NRCan and the department no longer has staff with similar expertise. However, the following provides a summary of NRCan's review, which considered the proponent's long term climate change analysis, specifically whether the EIS and associated licensing documents described plausible glaciation cycles that may occur over the life of the Project and assessed the potential glacial erosion for various glaciation scenarios.

2.4.2 Results of the review

NRCan's review found that the Proponent's submission was generally in accordance with the Guidelines for the preparation of the EIS.

Using the "Glacier Systems Model" the proponent plotted a balanced range of possible and plausible multiple glaciation cycles, which was presented in the document entitled: Long Term Climate Change (NWMO DGRTR- 2011-14). Additionally, the proponent's model and approach have been tied into the international network of models EISMINT-2. NRCan also found the conclusions in the Glacial Erosion Assessment (NWMO DGR-TR-2011-18) to be reasonable.

NRCan did not have any information requests with respect to glaciology.

2.5 GEOLOGY: STRATIGRAPHY AND SEDIMENTOLOGY OF THE SANDSTONE AND SHALE BEDROCK GEOLOGY

2.5.1 Review approach and scope

NRCan's reviewer considered whether the proponent had adequately characterized the stratigraphy and sedimentology of the sandstone and shale bedrock geology for the purposes of the EIS and associated licensing documents.

2.5.2 Results of the review

The information requests submitted by NRCan covered several aspects related to the information the proponent provided on the stratigraphy and sedimentology of the sandstone and shale bedrock geology in the region of the DGR including:

1. Hydrocarbon Potential: provide a quantitative assessment of the potential for hydrocarbons in the vicinity of the DGR project, including a description of the risks/uncertainties of future hydrocarbon exploration, possible consequent disruptions to the DGR, and mitigation strategies to ensure the integrity of the DGR.

2. Fluid Migration: discuss the possible presence of permeable sandstone facies in the Shadow Lake Formation, its possible hydrologic continuity with the underlying permeable Cambrian sandstones and the resulting potential migration path of contaminated groundwater updip toward the crest of the Algonquin Arch and the shallow groundwater zone.

3. Faults and Fractures: (a) provide a rationale as to why it was not possible to conduct a 3-D seismic survey of the area to obtain further detail on the faults and fractures in the regional study area and the project site, and information on the strength of the calcite seals and their ability to re-open under pressure. (b) include an analysis of the un-mapped near vertical faults, the risk of them re-activating and the mitigation measures that would be applied to minimize effects. (c) discuss whether the extensive cavern excavation required to build DGR could encounter faults or even re-activate faults due to alteration/release of natural pressures, including a discussion of risks and uncertainties. (d) discuss the risks and uncertainties associated with the potential for hot fluids to move through possible deep-rooted faults and fractures which might cut the Ordovician section, including a description of any mitigation measures that are proposed to ensure the integrity of the DGR.

4. Cap-Rock Seal: discuss how the Collingwood Formation and lack of homogeneity of the upper Ordovician sequence may impact the regional seal capability and the risk of possible seal breaching or contamination by updip migration.

The JRP provided information requests on these topics to the proponent in information request Package #5. The proponent's response to these information requests was included in its October 24 and November 7, 2013 (CEAR # 776, 793) submissions to the panel. NRCan found the additional information provided by the proponent to be sufficient. However, NRCan proposed one follow up information request related to the potential for fluid migration and had a general comment in relation to the response prepared for the information request related to hydrocarbon potential.

Fluid Migration:

While NRCan was satisfied with the proponent's discussion of the risks associated with some of the potential scenarios for contaminated groundwater migration, NRCan was of the view that the proponent should also discuss the possible hydraulic conductivity and long-distance groundwater migration in the subsurface along strike to the northeast toward the surface in Georgian Bay, through the Shadow Lake and Cambrian sandstones.

This information request was covered in information requests included with JRP information request package #8 (EIS-08-382). The proponent provided a response to this follow up information request on February 28, 2013 (CEAR #902). NRCan's review found the information to sufficient and had no additional information requests to propose.

Hydrocarbon Potential:

(1) With respect to the information request on hydrocarbon potential at the DGR site, the proponent did not provide a quantitative assessment. Instead, the Proponent provided further information on the hydrocarbon exploration and economic feasibility in today's terms. NRCan's information request related to hydrocarbons was meant to elicit more confidence in the long-term integrity (or risks) to the DGR with respect to future economic drivers/conditions. A key part of the response was "*it is anticipated that institutional controls will be put in place as part of the Licence to Abandon granted by the Canadian Nuclear Safety Commission that would involve land zoning restrictions that would prevent the authorization of deep drilling near the DGR site*". Based on the proponent's explanation, it is NRCan's understanding that such enforcement by CNSC will be in place for many future generations; as such NRCan is satisfied with OPG's response.

2.5.3 Conclusions and Recommendations

NRCan is satisfied with the information provided by the proponent in relation to the stratigraphy and sedimentology of the sandstone and shale bedrock in the region of the DGR. The proponent has gathered an adequate understanding of the geologic environment in order to describe the risks and plan mitigation measures to address these risks. However, some information gaps remain. For example, the proponent has not provided or referred to an actual quantitative, or even qualitative, assessment of the hydrocarbon potential of the Cambrian and Ordovician strata present in the greater DGR region. While NRCan agrees with the proponent that in today's economic climate, the hydrocarbon potential is "low", this does not address the current trend and long-term potential (*i.e.* that many of the resources being exploited today were also not considered economically feasible even just a few years ago).

There is still a possibility that decades in the future, knowledge of land zoning restrictions may have been forgotten or lost, and deep drilling might accidentally proceed into the DGR (if the economic feasibility of the potentially small hydrocarbon deposits which may be present might be worthwhile for exploration).

Recommendation: NRCan recommends that the panel consider what additional mitigation measures or institutional controls might be put in place to ensure restricted access to the DGR site for the long-term.

2.6 HYDROGEOCHEMISTRY: GROUNDWATER CHEMISTRY, FRACTURE STUDIES AND THE INTERPRETATION OF THE AGE OF FRACTURES

2.6.1 Review approach and scope

The scope of NRCan's review covered hydrogeological matters including, groundwater chemistry and solute transport as they relate to the formation and interpretation of fracture systems. NRCan's reviewer considered whether the proponent had adequately characterized the fractures and appropriately interpreted the age of fractures systems in the region of the DGR.

2.6.2 Results of the review

The information request submitted by NRCan was in relation to the interpretation of age of fracture systems in the regional study area. In its technical review NRCan highlighted several inconsistencies in the proponent's information and concluded that the evidence provided did not support the proponent's conclusion that "all joint and vein sets share common orientations, which suggests that the jointing and veining events were contemporaneous and formed under conditions of elevated pore fluid pressure in the presence of an abundant source of carbonate rich brines" and "the main fracture sets developed during compaction, dewatering and diagenesis of the Lucas and underlying formations". NRCan made reference to research papers which conclude that the fracture orientations are consistent with those in southern Manitoba carbonates of similar age (Chen et al., 2011) and in much younger Tertiary rocks in southern Alberta (Grasby et al., 2008). NRCan further noted that these fracture systems have been shown to be parallel to the modern regional stress field (Bell and Grasby 2012), which supports the potential for much younger fracture dates.

Furthermore, NRCan questioned the proponent's assumption that initial dewatering would be the only point in the basin history where high pore pressures would develop to enable fluid transport. NRCan's view is that basin fluid pressures can evolve or elevate through their history, outside of initial dewatering through events such as: maximum burial[4] or petroleum generation. In addition NRCan noted that recent glaciation is also known to cause very high overpressures in underlying sedimentary basins, a point that was supported by information in the EIS, DGR-TR-2011-15, Regional Geology, sec 3.1.4, page 20.

[4] Maximum burial – refers to higher pressures and temperatures at the lower reaches of sedimentary basins.

As such, NRCan proposed that the JRP request additional evidence to support the proponent's conclusion. The JRP provided an information request on this topic to the proponent in information request Package #2 (CEAR #438), in which it asked the proponent to provide additional information to support the timing of fracturing and mineral infilling in the study area and identify any plans for absolute age determinations of fracture minerals.

The proponent's response to this information request was included in its June 1, 2012 (CEAR #523) submission to the panel. NRCan found the additional information provided by the proponent to be sufficient.

2.6.3 Conclusions and Recommendations

NRCan is satisfied that the proponent has provided sufficient information to support their conclusions regarding the history of fracture formation and fluid movement in the basin. The proponent has gathered an adequate understanding of the hydrogeologic environment in order to describe the risks and plan mitigation measures to address these risks.

2.7 Geochemical Characterization of Waste Rock and Waste Rock Management Plan

Drainage waters from sulphidic geologic materials can contain elevated concentrations of metals and other elements at any pH, which can lead to adverse environmental effects if not properly predicted, measured and mitigated (MEND 2009). While many factors (e.g., environmental conditions, climate, hydrology and hydrogeology) contribute to drainage chemistry, a key factor of determining whether drainage will contain contaminants is characterizing the mineralogy and geochemistry of the geologic materials being excavated and stored as waste or used as a construction material at a site.

The prediction of drainage chemistry may require site specific measurement or estimation of physical properties and processes such as, but not limited to, the following:

- Concentrations of soluble elements, acidity and alkalinity and resulting pore water pH.
- Minerals in which potentially deleterious elements and potential acidity and neutralization occur and the extent to which these will be exposed by excavation, deposition and weathering.
- Physical and geochemical conditions under which weathering and leaching will occur.

The objective in predicting drainage chemistry is to make sure adequate measures are in place to prevent significant adverse environmental impacts. These predictions should be made for all excavated, exposed and otherwise disturbed geologic materials containing sulphide minerals, even at trace concentrations. Determining successful mitigation

measures depends on an accurate prediction of future drainage chemistry, which is a technical subject involving a large number of methods, properties and processes.

2.7.1 Review approach and scope

In February 2013, because of its expertise in the predictions of drainage chemistry for mine wastes and mine waste management, NRCan was asked to participate in discussions with Environment Canada and the Canadian Nuclear Safety Commission regarding the geochemical characterization of waste rock and the potential for acid generation and metal leaching from the rock that would be excavated in order to develop the DGR. In this regard, NRCan provided comments to Environment Canada in its analysis of whether the proponent had adequately characterized the waste rock. Following this, in its letter dated March 8, 2013(CEAR #918), the JRP requested that NRCan review third party information requests related to acid rock/drainage, metal leaching and waste rock management. Specifically the JRP requested that NRCan review the proponent's response to information request EIS-04-159. In its sufficiency review of this information request, NRCan also considered the response to the related EIS-04-160 as well as responses to information request EIS-08-394 and EIS-10-489, which were follow-up to EIS-04-159.

2.7.2 Results of the review

The information requests submitted by the panel were in relation to the geochemical characterization of waste rock and the proposed plan for the management of excavated rock from the DGR site. Specifically, the JRP requested that the proponent conduct kinetic leach tests on existing samples of core rock that exhibited signs of mineralization and based on the results of the tests, carry out drainage predictions to estimate contaminant loadings (total dissolved solids, metal concentrations and pH in the drainage water) from waste rock to surface water and shallow groundwater and prepare a waste rock management program that verifies the predictions of the EA for waste rock characterization and leachate quality. Further to these information requests, the JRP requested that the proponent provide: (a) an estimate of volume of rock potentially requiring management based on all contaminants of potential concern (COPCs) identified in the shake flask tests, (b) a rationale for comparing leach test concentrations to surface water quality objectives rather than predictions from the problematic material, which would matter in the design of the stormwater management pond and (c) a discussion on whether waste rock from carbonate rock strata (e.g., Salina Group, Guelph Formation, etc.) may also require special management due to salinity, and possibly associated metals, that may be released from these rocks.

In its response to the first information request, the proponent provided a rationale for why kinetic tests would not provide useful data or results in the specific situation of the DGR. The proponent referred to the guidance provided in the *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials* (MEND Report 1.20.1, 2009). The proponent also included a reference to a report prepared by Golder - *Results of*

Geochemical Testing of Rock Samples from the Deep Geologic Repository (Golder 2011). NRCan was satisfied with the response to this information request.

With respect to the information requests and responses provided in relation to the Waste Rock Management Program, NRCan was satisfied with the response provided by the proponent however NRCan's agreed with the guidance provided in the JRP information requests (EIS-04-160 and EIS-10-489).

2.7.3 Conclusions and Recommendations

NRCan reviewed the *Results of Geochemical Testing of Rock Samples from the Deep Geologic Repository* (Golder 2011) report and found the approach and results to be reasonable. The assessment of the acid generating potentials of the rocks to be excavated is sound. Because the waste rock pile will be comprised essentially of limestone (Coburg-Lower Member), the Acid-Base Accounting and net acid generating test results are to be expected because the excavated rock will include low levels of sulfide minerals based on sulfide sulfur and large quantities of limestone (*i.e.* a carbonate-based rock made essentially of calcite and dolomite minerals) which has high neutralizing potentials.

However, while the proponent's approach for predicting acidic drainage is appropriate, uncertainty in the results remain due to the compositional variability of the rock formations, sampled along a limited number of drill holes. NRCan further notes that metal(loid) leaching can occur at neutral and slightly elevated pH, especially for arsenic. These points are especially important when considering the development of the Waste Rock Management Program for the DGR site.

The proposed guidance outlined in the information requests for the Waste Rock Management Plan has merit, as do some aspects of the proponent's proposed Waste Rock Management Program. The proponent has committed to undertake additional geochemical characterization to verify the predictions related to the potential for acid generation, elemental content and metal leaching potential. It is NRCan's view that the results of continued tests will help inform the design of the Waste Rock Management area. For example, should results identify rock with a higher potential for acid generation or metal leaching, this rock could be (a) be excluded from any rock being used for construction purposes and (b) strategically placed within the waste rock pile, surrounded by rock with a high neutralization potential.

Given the uncertainty surrounding the geochemical characterization of the excavated rock and the predictions for drainage chemistry, NRCan has included a recommendation for the JRP's consideration.

Recommendation: NRCan recommends that the proponent be required to continue to refine the results of the geochemical characterization program prior to and during the development phase of the DGR. This could include conducting additional shake flask tests, kinetic tests and field cell tests on the excavated material.

3 SUMMARY OF RECOMMENDATIONS

NRCan appreciates the opportunity to provide this Submission to the Joint Review Panel in advance of the Public Hearings. The following provides a summary of NRCan's recommendations for the JRP's consideration:

SHALLOW GROUNDWATER

Recommendation: NRCan recommends that the proponent be required to continue to collect baseline data on shallow groundwater flows prior to and during construction in order to refine the groundwater model.

Recommendation: NRCan recommends that the proponent be required to confirm that grouting will be required to stem groundwater inflows from the upper 20 m of the Bass Islands Formation, and based on the result develop mitigation measures (grout) to stem groundwater inflows .

SEISMIC HAZARDS: CONTEMPORARY EARTHQUAKE SHAKING HAZARD

Recommendation: Extra conservatism on the mean shaking levels should be considered during detailed design because of the low maximum magnitudes adopted and because of the kernel smoothing approach in the PHSA.

Recommendation: Detailed design considerations should consider mitigation strategies or plans for conditions of "beyond-design" ground motions.

GEOLOGY: STRATIGRAPHY AND SEDIMENTOLOGY OF THE SANDSTONE AND SHALE BEDROCK GEOLOGY

Recommendation: NRCan recommends that the panel consider what additional mitigation measures or institutional controls might be put in place to ensure restricted access to the DGR site for the long-term.

GEOCHEMICAL CHARACTERIZATION OF WASTE ROCK AND WASTE ROCK MANAGEMENT PLAN

Recommendation: NRCan recommends that the proponent be required to continue to refine the results of the geochemical characterization program prior to and during the development phase of the DGR. This could include conducting additional shake flask tests, kinetic tests and field cell tests on the excavated material.

DOCUMENTS REVIEWED AND REFERENCES

Section 1.1 NRCan's Role in the Environmental Assessment

- CEAR # 1198. Letter from the Joint Review Panel to Natural Resources Canada concerning the Department's participation in the Deep Geologic Repository (DGR) Public Hearing Process (CEARIS Doc #1174 and #1175). June 18, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/90278E.pdf)

Section 1.2 NRCan's Participation in the Joint Review Panel's Environmental Assessment

References for this section include:

- CEAR # 298. Environmental Impact Statement for a Deep Geologic Repository for Low and Intermediate Level Waste (http://www.ceaa-acee.gc.ca/050/document-eng.cfm?document=49818)

- CEAR # 334 Letter regarding the Participation of Natural Resources Canada in the Public Review and Comment Period and Initial Panel Orientation Session (http://www.ceaa-acee.gc.ca/050/documents/54201/54201E.pdf)

- CEAR #150 Guidelines for the Preparation of the Environmental Impact Statement (Final Version) (http://www.ceaa-acee.gc.ca/050/documents/39323/39323E.pdf)

- CEAR# 344 Presentation of NRCan's mandate as it applies to the project, presented to the Joint Review Panel during the Panel Orientation Session (http://www.ceaa-acee.gc.ca/050/documents/54626/54626E.pdf)

- CEAR# 352 Natural Resources Canada Areas of Expertise in relation to DGR – March 23, 2012 (http://www.ceaa-acee.gc.ca/050/documents/55435/55435E.pdf)

- CEAR# 517 Natural Resources Canada's Proposed Information Requests - Submission to the Joint Review Panel. May 29, 2012 (http://www.ceaa-acee.gc.ca/050/documents/56769/56769E.pdf)

- CEAR #642. Joint Review Panel to Ontario Power Generation - Information Request Package #4. July 23, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/80510E.pdf)

- CEAR #728. Joint Review Panel to Ontario Power Generation - Information Request Package #5. September 12, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/81381E.pdf)

- CEAR # 822 Natural Resources Canada's Disposition of OPGs Response to Panel IRs derived from NRCan IRs on hydrogeology for the Deep Geologic Repository (DGR) project. November 27, 2012 (http://www.ceaa-acee.gc.ca/050/documents/p17520/83793E.pdf)

- CEAR #915. Ontario Power Generation's Responses to the Joint Review Panel's Information Request Package #8 - EIS-08-325, 330, 333, 334, 335, 353, 354, 358, 359, 360, 361, 362, 368, 371, 379, 385, 386, 387, 388, 389, 390, 396 and 397 and an Updated Tracking Table for all OPG Submissions to date. March 15, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/87019E.pdf)

- CEAR # 938 Natural Resources Canada Sufficiency Review of Responses to Information Requests EIS-02-38, EIS-05-161, EIS-05-162, EIS-05-163, EIS-05-164 and EIS-05-166 (http://www.ceaa-acee.gc.ca/050/documents/p17520/87786E.pdf)

- CEAR # 918 Request from the Joint Review Panel to Natural Resources Canada (http://www.ceaa-acee.gc.ca/050/documents/p17520/87022E.pdf)

- CEAR # 970 Request from the Joint Review Panel to Natural Resources Canada (http://www.ceaa-acee.gc.ca/050/documents/p17520/88532E.pdf)

- CEAR # 1120 Natural Resources Canada Sufficiency Review of Information Requests related to glaciology, hydrogeology, hydrogeochemistry, geology (sedimentation and stratigraphy), acid rock/drainage, metal leaching and waste rock management (http://www.ceaa-acee.gc.ca/050/documents/p17520/89561E.pdf)

- CEAR # 1232. Natural Resources Canada Response to the Joint Review Panel's Letter concerning its Participation in the DGR Public Hearing Process (CEARIS doc #1198). July 12, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/91111E.pdf)

Section 2.1: Hydrogeology/Groundwater within the thin, permeable formations in the intermediate and deep groundwater systems

Documents reviewed included:

- NWMO DGR-TR-2011-15, Regional Geology – Southern Ontario, report prepared by AECOM Canada Ltd. and Itasca Consulting Inc., March 2011.

- NWMO DGR-TR-2011-12, Regional Hydrogeochemistry – Southern Ontario, report prepared by Hobbs, M.Y., Frape, S.K., Shouakar-Stash, O., Kennell, L.R., March 2011.

- NWMO DGR-TR-2011-23, Analogue Study of Shale Cap Rock Barrier Integrity, report prepared by Engelder, T., March 2011.

- NWMO DGR-TR-2011-21, Excavation Damaged Zone Assessment, report prepared by Fracture Systems Ltd., March 2011.
- NWMO DGR-TR-2011-24, Descriptive Geosphere Site Model, report prepared by Intera Engineering Ltd., March 2011.
- NWMO DGR-TR-2011-16, Hydrogeologic Modelling, report prepared by Sykes, J.F., Normani, S.D., Yin, Y., March 2011.
- NWMO DGR-TR-2011-11, Geosynthesis, report prepared by Nuclear Waste Management Organization (NWMO), March 2011.
- NWMO DGR-TR-2011-03, Geology Technical Support Documents, report prepared by Golder Associates Ltd., March 2011.
- NWMO DGR-TR-2011-29, Postclosure Safety Assessment: Features, Events and Processes, report prepared by Quintessa Ltd., SENES Consultants Ltd. and Geofirma Engineering Ltd., March 2011.
- NWMO DGR-TR-2011-28, Postclosure Safety Assessment: System and its Evolution, report prepared by Quintessa Ltd., March 2011.
- NWMO DGR-TR-2011-30, Postclosure Safety Assessment: Groundwater Modelling, report prepared by Geofirma Engineering Ltd., March 2011.
- NWMO DGR-TR-2011-26, Postclosure Safety Assessment: Analysis of the Normal Evolution Scenario, report prepared by Quintessa Ltd., March 2011.
- NWMO DGR-TR-2011-25, Postclosure Safety Assessment, report prepared by Quintessa Ltd., Geofirma Engineering Ltd. and SENES Consultants Ltd., March 2011.
- CEAR # 725. September 6, 2012. Ontario Power Generation, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to a Sub-set of Package #4 Information Requests, letter with attachment from Albert Sweetnam to Dr. Stella Swanson. (http://www.ceaa-acee.gc.ca/050/documents/p17520/81371E.pdf)
- CEAR # 704. August 27, 2012. Ontario Power Generation, Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Responses to a Sub-set of Package #4 Information Requests, letter with attachment from Albert Sweetnam to Dr. Stella Swanson. (http://www.ceaa-acee.gc.ca/050/documents/p17520/80955E.pdf)

- CEAR #844. Joint Review Panel to Ontario Power Generation - Information Request Package #8. December 20, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/84257E.pdf)

- CEAR # 1049. May 13, 2013. Ontario Power Generation, Consolidated Responses to JRP Information Requests for Deep Geologic Repository Project for Low and Intermediate Level Waste. Pages 1291-1295 and 1295-1303.

Section 2.2: Shallow Groundwater

Documents reviewed included:

- CEAR # 1049. March 9, 2013. Ontario Power Generation, Consolidated Responses to JRP Information Requests for Deep Geologic Repository Project for Low and Intermediate Level Waste

- February 14, 2012. Sykes, J.F. 2012a. Analysis of the Impact on the WWMF of Groundwater Withdrawal Associated with the Construction of the DGR Shafts. NWMO Technical Memorandum DGR-TM-03400. Toronto, Canada.

- August 21, 2013. Sykes, J.F. 2012b. OPG DGR Analysis of Shallow Groundwater Impacts. NWMO Technical Memorandum DGR-TM-03400 (P). Toronto, Canada.

Section 2.3: Seismic Hazards

Documents Reviewed included:

- NWMO DGR-TR-2011-20: Probabilistic Seismic hazard assessment (PSHA). Prepared by: AMEC Geomatrix, Inc. March 2011.

- CEAR #777. Ontario Power Generation to the Joint Review Panel - Enclosure #1 - OPG Submission of Supplemental material for IR Package #5 - EIS-05-161 Response - Seismic Hazard Assessment Plates. November 5, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/83315E.pdf)

- Conceptual Design Report; OPG's Deep Geologic Repository for Low & Intermediate Level Waste Supporting Technical Report, May 2008, prepared by Hatch Limited, OPG 00216-REP-03902-00004-R01

- Phase I Regional Hydrochemistry, Southern Ontario; OPG's Deep Geologic Repository for Low & Intermediate Level Waste Supporting Technical Report, November 30th 2008, prepared by Hobbs, M.Y., Frape, S.K., Shouakar-Stash, O., Kennell, L.R., OPG 00216-REP-01300-00006-R00

- Phase I Regional Geology, Southern Ontario; OPG's Deep Geologic Repository for Low & Intermediate Level Waste Supporting Technical Report, November 30th 2008, prepared by Gartner Lee Limited, OPG 00216-REP-01300-00007-R00

- Phase I Regional Hydrogeologic Modelling; OPG's Deep Geologic Repository for Low & Intermediate Level Waste Supporting Technical Report, November 30th 2008, prepared by Sykes, J.F., Sykes, E.A., Normani, S.D., Yin, Y., Park, Y.-J., OPG 00216-REP-01300-00009-R00

- Phase I Geosynthesis; OPG's Deep Geologic Repository for Low & Intermediate Level Waste Supporting Technical Report, November 30th 2008, prepared by Gartner Lee Limited, OPG 00216-REP-01300-00010-R00

- Phase 1 Long-term Cavern Stability, OPG November 30, 2008 version

References for this section included:

- GSC – Open File 4459: Fourth generation seismic hazard maps of Canada: values for over 650 Canadian localities intended for the 2005 National Building Code of Canada, 2003

Section 2.4: Glaciology - long term climate change and the potential for glacial erosion

Documents reviewed included:

- NWMO DGR-TR-2011-14: Long Term Climate Change. Prepared by: W.R. Peltier. March 2011.

- NWMO DGR-TR-2011-18: Glacial Erosion Assessment. Prepared by: Berard Hallet. March 2011.

Section 2.5: *Geology: stratigraphy and sedimentology of the sandstone and shale bedrock geology*

Documents reviewed included:

- NWMO DGR-TR-2011-03 Geology Technical Support Document. Report prepared by Golder Associates Ltd., March 2011.

- NWMO DGR-TR-2011-011 Geosynthesis, report prepared by Nuclear Waste Management Organization (NWMO), March 2011.

- NWMO DGR-TR-2011-015 Regional Geology - Southern Ontario. Report prepared by AECOM Canada Ltd. and Itasca Consulting Inc., March 2011.

- NWMO DGR-TR-2011-022 Karst Assessment. Prepared by S.R.H. Worthington. March 2011.

- NWMO DGR-TR-2011-023 Analogue study of shale cap rock barrier integrity. Report prepared by Engelder, T., March 2011.

- NWMO DGR-TR-2011-024 Descriptive geosphere site model. Report prepared by Intera Engineering Ltd., March 2011.

- NWMO DGR-TR-2011-042 Three-dimensional geological framework model. Prepared by: Itasca Consulting Canada, Inc., and AECOM Canada Ltd. March 2011.

- NWMO DGR-TR-2011-043 Outcrop fracture mapping. Report prepared by: A. Cruden, March 2011

- CEAR #902. Ontario Power Generation's Responses to the Joint Review Panel's Information Request Package #8 - EIS -08-313, 314, 316, 320, 321, 322, 323, 327, 328, 331, 336, 340, 345, 351, 355, 356, 357, 367, 368, 370, 380, 382, 394, 398, and 400. February 28, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/86593E.pdf)

- CEAR # 793. Ontario Power Generation's Responses to the Joint Review Panel's Information Request Package #5 – EIS 05-162, 164-5, 167, 171-173,178-9, 185-6, 189, 193, 195, 199, 203, 205-6, 208-9, 211, 214, 216, 222, and 228. November 7, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/83429E.pdf)

- CEAR #776. Ontario Power Generation's Responses to the Joint Review Panel's Information Request Package #5 - EIS 05-161, 163, 166, 168-170, 174-177, 180-184, 187, 188, 190-192, 194, 196-198, 200-202, 204, 207, 210, 212, 213, 215, 217-221, 223-227 and 229. October 24, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/83291E.pdf)

Section 2.6 *Hydrogeochemistry: groundwater chemistry, fracture studies and the interpretation of the age of fractures*

Documents reviewed included:

- NWMO DGR-TR-2011-43, Outcrop Fracture Mapping, report prepared by: A. Cruden, March 2011

- NWMO DGR-TR-2011-15, Regional Geology – Southern Ontario, report prepared by AECOM Canada Ltd. and Itasca Consulting Inc., March 2011.

- NWMO DGR-TR-2011-12, Regional Hydrogeochemistry – Southern Ontario, report prepared by Hobbs, M.Y., Frape, S.K., Shouakar-Stash, O., Kennell, L.R., March 2011.

- NWMO DGR-TR-2011-11, Geosynthesis, report prepared by Nuclear Waste Management Organization (NWMO), March 2011.

References for this section included:

- Bell, S. and Grasby, S.E. (2012) The Stress Regime of the Western Canadian Sedimentary Basin. Geofluids, 12, 150-165.

- Chen, Z., Grasby, S.E., and Osadetz, K.G. (2011) Geological controls on regional transmissivity anisotropy. Geofluids, 11, 228-241.

- Grasby, S.E., Chen, Z., Hamblin, A.P., Wozniak, P.R.J., and Sweet, A. (2008) Regional characterization of the Paskapoo Bedrock aquifer system, southern Alberta. Canadian Journal of Earth Sciences, 45, 1501-1516.

- CEAR # 438. Information Request Package #2 (From Joint Review Panel to Ontario Power Generation). May 2, 2012. (http://www.ceaa-acee.gc.ca/050/documents/55966/55966E.pdf)

- CEAR # 523. Ontario Power Generation Response to the Joint Review Panel Information Request Package 2 (From Ontario Power Generation to Joint Review Panel). June 1, 2012. (http://www.ceaa-acee.gc.ca/050/documents/56805/56805E.pdf)

Section 2.7: Geochemical Characterization of Waste Rock and Waste Rock Management Plan

Documents reviewed included:

- GOLDER. 2011. Results of Geochemical Testing of Rock Samples from the Deep Geologic Repository (DGR). Golder Associates Ltd. Technical Memorandum from C.McRae to D.Barker (NWMO). (included in CEAA Registry Doc# 523)

- CEAR #523. Ontario Power Generation Response to the Joint Review Panel Information Request Package 2 (From Ontario Power Generation to Joint Review Panel). June 1, 2012.

- CEAR #759. Ontario Power Generation's Response to the Joint Review Panel's Information Request Package #4 - EIS 04-101, 109, 112, 114, 115, 119, 123, 124, 135, 143, 145, 149, 150, 151. 153. 154, 158, 159 and 160. September 28, 2012. (http://www.ceaa-acee.gc.ca/050/documents/p17520/81979E.pdf)

- CEAR #902. Ontario Power Generation's Responses to the Joint Review Panel's Information Request Package #8 - EIS -08-313, 314, 316, 320, 321, 322, 323, 327, 328, 331, 336, 340, 345, 351, 355, 356, 357, 367, 368, 370, 380, 382, 394, 398, and 400. February 28, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/86593E.pdf)

- CEAR #990. Ontario Power Generation Submission to the Joint Review Panel of Responses to the First Sub-set of Package #10 Information Requests. April 30, 2013. (http://www.ceaa-acee.gc.ca/050/documents/p17520/88772E.pdf)

References for this section included:

- MEND. 2009. Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials. MEND Report 1.20.1. Mining Environment Neutral Drainage Program, Natural Resources Canada.

- CEAR # 918 Request from the Joint Review Panel to Natural Resources Canada (http://www.ceaa-acee.gc.ca/050/documents/p17520/87022E.pdf)