2024 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG)

December 2024

By NWMO Adaptive Phased Management Geoscientific Review Group

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Remarks by GRG Chair

The Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG) again followed NWMO's geoscientific initiatives to provide advice, and to undertake a thorough review of technical and scientific documents. The GRG was established by NWMO in 2012 and, over the years, has consisted of between five and six members. Brief biographies are included at the end of this report. This year, the GRG did not undertake a field trip but was able to attend an in-person review meeting in Toronto. This greatly helped the GRG to connect with the Geoscience Site Assessment team and to discuss matters in more detail than is possible during virtual meetings. The in-person meeting included an interactive workshop format to stimulate interdisciplinary discussion and debate.

This annual report comes at a key milestone for NWMO, namely the recent announcement that Wabigoon Lake Ojibway Nation (WLON) and the Township of Ignace were selected as the host communities for the future site for Canada's used nuclear fuel. The GRG has guided the Geoscience team to arrive at a well-justified technical story that supports the conclusion and choice of repository site.

This report presents an overview of the activities undertaken by the GRG since 2012 to support NWMO's geoscience team in leading site characterization for the site selection process, and summarizes the GRG's findings and conclusions for activities completed in 2024. The GRG was again informed by high-quality presentations at bi-monthly virtual meetings about progress at drill sites, and both data processing and interpretation work. During 2024, the GRG completed its review of the initial draft "Descriptive Geoscientific Site Model (DGSM)" report for the South Bruce Site, and, for the WLON-Ignace (Revell) Site, a new version of a Discrete Fracture Network (DFN) model and the first sub-regional hydrogeological model. The GRG also provided key guidance and expertise for the development of the first one-dimensional stress model for the Revell Site. These represent significant technical milestones to support the reduction of uncertainty in site understanding, a key focus of the GRG.

Good progress has been made over the years with high quality work produced by the Geoscience Site Assessment team. At the early desktop and preliminary assessment stages of the site assessment process, the approaches adopted by the NWMO followed or exceeded best international geoscientific practice. More recently, the GRG was pleased to see good progress in the production of draft data interpretation reports and related modelling of the potential repository sites. The GRG also considers that the interaction between the Geoscience and Safety Assessment teams has been much improved with closer integration between them and between different disciplines. The GRG continues to point out that NWMO will need support from specialized independent experts to address outstanding issues. The GRG continued to express the opinion that a geoscientific site understanding report should be completed for the site not selected for detailed characterization, as it will accentuate the valuable data set collected to date in the investigation program.

The GRG shares the opinion of the NWMO, as expressed in the "Confidence in Safety" draft reports released to the public at the beginning of 2024, that both the Revell and South Bruce sites would be suitable from a technical perspective to host a repository. The GRG is of the view that remaining knowledge gaps and geoscientific uncertainties for the Revell Site can be overcome by future work programs, including ongoing site characterization and engineering design. This future work is essential to eliminate these uncertainties, and further increase the confidence and ongoing suitability of the selected site.

On behalf of all GRG members, I wish to express our appreciation for the professional work by the NWMO team and for the diligent response to review feedback provided by the GRG.

Peter K. Kaiser, Ph.D, P.Eng., F.EIC, F.CAE

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1 Introduction

The Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG) was established by the NWMO in 2012. It was formed to provide independent review, comments and advice on geoscientific preliminary assessments being conducted as part of NWMO's evaluations to identify a single suitable deep geological repository site for Canada's used nuclear fuel in an informed and willing host community. The selection of a single site was announced by the NWMO in November 2024 with Wabigoon Lake Ojibway Nation (WLON) and the Township of Ignace moving forward as the host communities for the future site for Canada's deep geological repository for used nuclear fuel. The GRG warmly congratulates the NWMO, and acknowledges the hard work of the Geoscience team in support of reaching this milestone decision.

During the process to arrive at this decision, the GRG reviewed all geoscientific site characterization work and provided critical comments on the approach, methods and criteria used, the interpretation of data, and reporting of findings. It assessed and advised on the adequacy of proposed preliminary field investigations and drilling programs, to advance understanding of the geology and increase confidence in the potential suitability of the various siting areas being considered by NWMO. Increasingly, the GRG has been providing feedback on draft data interpretation reports resulting from the site characterization program and related modelling of the potential repository sites.

Ten yearly GRG reports have been issued since December 2013, except in 2015, and these are publicly available on NWMO's website (APM-GRG 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023). This report provides a summary of the geoscientific site characterization activities and the GRG's activities between 2012 and 2023 leading up to the site selection milestone. It also provides a more detailed summary of the GRG's findings and conclusions for activities completed in 2024.

2 Objectives of geoscientific preliminary assessments

The suitability of communities was assessed using a staged approach including 'Initial Screenings' and 'Preliminary Assessments' to be followed by 'Detailed Site Characterization' at the single selected site. The assessments considered both technical and community well-being factors (NWMO 2010).

The overall preliminary assessment was conducted through a series of technical, socio-economic and cultural studies conducted in two phases over several years. Technical studies involved geoscience, engineering, transportation, environment and safety. The objective of the geoscientific suitability preliminary assessment was to assess whether candidate areas had the potential to meet NWMO's site evaluation factors (geoscientific suitability). The two phases included:

- Phase 1 - Desktop studies: These studies were undertaken for all communities electing to be the focus of a preliminary assessment. This phase involved an evaluation of available geoscientific information, and a set of key geoscientific characteristics and factors that could be realistically assessed at the desktop phase of the preliminary assessment. Desktop studies for 21 communities were completed. One community left the site selection process prior to the initiation of desktop studies.
- Phase 2 - Preliminary field investigations: These were undertaken to further assess the potential suitability of a subset of communities selected by the NWMO. Depending on

the geological setting, Phase 2 field investigations included high resolution airborne surveys, geological mapping, seismic surveys and initial borehole drilling.

The subset of communities advanced to Phase 2 preliminary assessment were selected based on the findings from the desktop study during Phase 1. It is important to note that the mandate of the GRG is entirely focussed on the approach, methods, criteria and findings associated with the geoscientific suitability assessments. The GRG is not involved in matters pertaining to transportation, physical and social environment, and is not consulted when narrowing down the number of communities.

The 22 communities that were involved in the NWMO's site selection process are shown in Figure 1. From 2020 and onward, four communities hosting two sites have remained in Phase 2 of the site selection process, comprising the Wabigoon Lake Ojibway Nation (WLON)-Ignace area in northwestern Ontario (Revell Site), underlain by crystalline rock, and the Saugeen Ojibway Nation (SON)-South Bruce area in southern Ontario (South Bruce Site), underlain by sedimentary rock. As of late November 2024, Wabigoon Lake Ojibway Nation (WLON) and the Township of Ignace were selected by NWMO as the preferred host communities for the future site for Canada's deep geological repository for used nuclear fuel.

Figure 1: Communities that expressed interest in NWMO's site selection process

3 Geoscientific site characterization and GRG activities: 2012-2023

The process to select a site for Canada's plan to safely manage used nuclear fuel long-term started in 2010, with a total of 22 communities across Saskatchewan and Ontario proactively expressing interest by 2012 (Figure 1). The GRG provided support and guidance for the planning and undertaking of initial desktop studies, and for the planning and undertaking of Phase 2 preliminary field investigations for the communities remaining in the process.

Throughout the guidance and review process from 2012 onward, the GRG made various contributions to geoscientific and editorial aspects in technical documents, and presented all suggestions, questions and comments in disposition tables, which were subsequently addressed by the NWMO. The GRG considers that the NWMO has provided and continues to provide high-quality responses to all points raised by the GRG in a timely, transparent and professional manner. The GRG remains impressed by the professional work undertaken by the Geoscience Site Assessment team and continues to look forward to contributing to a successful resolution of outstanding challenges.

3.1 Initial desktop studies and generic work plans for Phase 2 studies

Between 2012 and 2016, the GRG systematically reviewed the approach, methods and criteria being used by NWMO to conduct the initial desktop geoscientific assessments for the communities under consideration. The GRG also identified critical uncertainties that were relevant for the purpose of selecting a subset of communities suitable for further geoscientific characterization during Phase 2.

The GRG reviewed the findings of the desktop studies and concluded that the resulting geoscientific assessments, despite the obvious remnant uncertainties, were sound and formed a reliable basis for the identification of potentially suitable siting areas in each community. Overall, the GRG considered that a high standard had been achieved by NWMO's Geoscience team at this early desktop stage of the site assessment process. Based on the experience of the GRG members, the adopted approaches followed or exceeded best international geoscientific practice.

By 2014, while continuing to support the geoscientific desktop assessments, the GRG was also tasked with reviewing generic work plans for the approach and methods used by the NWMO to plan and conduct initial Phase 2 field activities in the communities underlain by crystalline rock. These included the acquisition and interpretation of airborne geophysical surveys, lineament interpretation using the newly acquired high resolution geophysical and remote sensing data, and the observation of general geological features in connection with a preliminary geological mapping campaign. The GRG was further tasked with reviewing the approach and methods used by the NWMO for assessing whether, based on initial field studies, a Phase 2 community contains smaller potentially suitable areas for further studies, beginning with detailed geological mapping, specifically focusing again on communities underlain by crystalline rock.

Between 2014 and 2016, the GRG provided guidance and feedback regarding the proposed types of field activities to be completed in the communities underlain by sedimentary rock, including seismic ground surveys and an initial framework approach for borehole drilling activity.

3.2 Phase 2 studies prior to borehole drilling and testing

NWMO initiated the first of the Phase 2 field activities in 2014 in communities underlain by crystalline rock, and these continued to be implemented even after the start of borehole drilling

and testing during 2017. To support these activities, the GRG reviewed detailed work plans, data, interpretation and reports for airborne geophysical surveys, lineament interpretations and geological mapping, as well as key findings and geoscience relative suitability assessments. In 2015-2016, the GRG also reviewed a framework document for borehole drilling and testing as well as the approach proposed by NWMO. Independent of the GRG, but with their support, NWMO selected preferred locations for initial boreholes with the involvement of people living in the communities in the WLON-Ignace area.

The GRG took the opportunity, during implementation of the Phase 2 activities in communities underlain by crystalline rock, to direct NWMO's attention towards specific geological features and products requiring additional attention in support of site selection and characterization. For example, they emphasized the need to evaluate the significance of mafic dykes in potentially suitable areas, and encouraged the initiation of updated, three-dimensional (3D) Geological and Discrete Fracture Network (DFN) modelling activities to support on-going site characterization.

During 2017, the GRG completed a review and provided feedback on all pre-borehole drilling activities for the remaining crystalline rock sites. In addition, focus switched to providing comment and advice on specific test plans for drilling the first deep borehole at the Revell Site in the WLON-Ignace area (IG_BH01), as well as providing guidance on the location, objectives and approaches for boreholes IG_BH02 and IG_BH03. The GRG visited the area of the first borehole at the Revell Site and was able to explore how the site characterization efforts documented in the various reports related to the site conditions. The GRG received and reviewed plans for Phase 2 initial borehole drilling and testing at the South Bruce sedimentary rock site considerably later during 2020 and 2021 and was able to visit this site during 2022. The GRG noted that both field visits greatly helped them to communicate with the Geoscience Site Assessment team, and to discuss matters in more detail than is possible during virtual meetings.

During the implementation of the Phase 2 activities leading up to borehole drilling, the GRG made many suggestions for process improvements. The GRG is pleased to report that the NWMO responded to all identified issues in a highly satisfactory manner. In the GRG members' opinion, the adopted approach continued to follow or exceed international practices in this early phase of assessment. It is evident to the GRG that NMWO's team had executed an extensive and very detailed field mapping effort in preparation for drilling activities.

3.3 Phase 2 borehole drilling, data analysis and modelling

Shortly after the start of drilling activity at the Revell Site during November 2017, the GRG reviewed plans for borehole geological-geophysical data integration and DFN modelling, encouraging consideration of how the latter should feed early into integrated workflow processes. It was evident to and welcomed by the GRG that the NMWO's Geoscience team had initiated work with single borehole data integration and interpretations in preparation for forthcoming 3D geoscientific modelling work at the Revell Site and surroundings. The GRG also discussed with NWMO the "Geoscientific Site Characterization Plan" (GSCP) for this site, providing guidance to improve the structure of the presentation of information in the plan and in future reporting of the technical information. Necessary changes were completed by the NWMO during 2019. The GRG was pleased that the revised GSCP reflected a more generic rather than simply a site-specific perspective, which was favourable at that stage in the process. Later, during 2021, the GRG reviewed the GSCP document for the South Bruce Site. In 2019, the GRG also reviewed an updated NWMO APM Project Glossary of Terms, and reviewed work plans for additional borehole drilling and testing, 3D geological model development, and a preliminary sub-regional groundwater system numerical simulation.

The GRG noted at an early stage after drilling started that challenging timelines lay ahead for NWMO. The GRG was pleased to see that NWMO had implemented during 2020 various organizational and model planning recommendations proposed in 2019 to meet these challenging timelines. The GRG feels that new resourcing has enabled the NWMO to execute some of the technical reporting tasks previously assigned to consultants, which has resulted in an improvement in the quality and consistency of documents.

Between 2020 and 2021, the GRG reviewed technical reports involving geoscientific data analyses, including sub-regional-scale DFN and groundwater models. The GRG continued to highlight the importance of data integration, emphasizing the need for a correct handling of hydraulic test data, including character and orientation of transmissive features, stress domaining, and reducing associated uncertainties related to subordinate rock types. The GRG also expressed concern regarding available hydrogeochemical data for the limited number of transmissive fractures and pore waters from the adjacent rock matrix in the bedrock at the Revell Site, and was pleased to see that NWMO modified the data acquisition procedures to help improve this database.

From 2021 to the present, the primary focus of the GRG's review and advisory work has dealt with continued site characterization studies, including modelling work and additional work or test plans at the Revell Site, and the first site characterization studies and some test plans at the South Bruce Site. The GRG reviewed the first 3D geological models for the Revell and South Bruce sites during 2021 and 2023, respectively, and, subsequently during 2022 and early 2023, the first, site-scale DFN model and the first attempt to integrate and interpret all the geoscientific data in a "Descriptive Geoscientific Site Model" (DGSM) at the Revell Site. In addition, an upgraded DFN model for the Revell Site and a partial draft DGSM for South Bruce were submitted for review by the GRG during November 2023. These two reports will be discussed further in Section 5. The GRG also welcomed the initial implementation of a site-scale DFN framework in the hydrogeological model for the Revell Site during 2023, which will also be addressed in Section 5.

The GRG had re-iterated concerns about tight timelines, delays in the delivery of material from external consultants, the handover of data to the Engineering and Safety Assessment teams, issues related to concept development and data integration, and the need for careful tracking of assumptions, uncertainties and limitations of the findings from different studies. At the in-person meetings in 2022 and 2023, the GRG inspired the development of break-out sessions with the aim of cross-disciplinary discussion and debate to identify key unresolved issues in each field of investigation.

3.4 Team interplay, confidence in safety and site understanding

The GRG feels that the interaction between the Geoscience Site Assessment and Safety Assessment teams has become much improved over the years, with closer integration between these teams and between different disciplines in the Geoscience team. The GRG was informed of, and supported, the recent restructuring to integrate the Geoscience Research and Development group into the Geoscience Site Assessment team.

The GRG shared the opinion of NWMO, expressed in their "Confidence in Safety" reports for the Revell and South Bruce sites, indicating that both sites would be suitable from a technical perspective for hosting a repository. These reports utilized firstly all results as of early 2022 and, subsequently in updated versions, as of late 2023 (NWMO 2023a, b). They were intended to serve public discussion around site selection. The GRG looks forward to providing advice on more detailed NWMO's plan for future years, including ongoing site characterization and

engineering design work, created to further increase confidence and demonstrate the suitability of the selected site.

The GRG is pleased to see progress in the development of site understanding at each site, reflected by the development of first draft DGSM reports. Geoscientific information about the South Bruce Site for detailed characterization should be preserved and made available to the public, as it represents a valuable data set. For the purpose of building public confidence, the GRG has expressed the opinion that geoscientific site understanding reports should be completed for both sites.

4 Geoscience site characterization activities in 2024

Throughout 2024, the NWMO continued to assess the suitability of the Revell and South Bruce sites, the two remaining potential locations for a deep geological repository, following the staged approach described above, and considering both technical and community well-being factors (NWMO 2010).

The Revell Site is underlain by Archean crystalline rock, and, by the end of 2024, the Geoscience Site Assessment team and their contractors had completed the drilling and testing, and most of the reporting of results, for six deep boreholes in the Revell batholith. The primary geoscientific field activities in this area during 2024 included ongoing purging, profiling and sampling of the instrumented deep and shallow groundwater monitoring wells, as well as maintenance and monitoring of the installed, nine-station micro-seismic monitoring network.

The South Bruce Site is underlain by Paleozoic sedimentary rocks, and by the end of 2024, the Geoscience Site Assessment team and their contractors had completed the drilling and testing, and most of the reporting of results for two deep boreholes at the site. The primary geoscientific activities in this area during 2024 included completing the installation and initiation of ongoing profiling and sampling of a shallow groundwater well network, as well as maintenance and monitoring of an installed, micro-seismic monitoring network.

5 GRG review activities in 2024

Review activities in 2024 were conducted by the five current GRG members described in brief biographies at the end of this report and shown in Figure 2. A sixth member, Anders Ström, was also active with the GRG until retiring from the group in April 2024 prior to the annual in-person meeting.

The review process followed the same approach as in previous years, involving virtual and in-person meetings, formal reviews of technical documents with completion of disposition tables, and direct correspondence between GRG and the NWMO Geoscience Site Assessment team. The GRG is satisfied with the adopted mode of communication, which allows the GRG to operate and follow progress effectively.

5.1 Meetings between the GRG and the NWMO Geoscience Site Assessment team

The GRG attended seven virtual meetings in 2024 to discuss specific technical/scientific issues, and to address questions and recommendations emerging from the reviews of technical documents. In addition, a four-day in-person meeting was held in Toronto in late April to early May. The GRG met with NWMO's Senior Management during this in-person meeting to allow the NWMO to inform the GRG of the overall program goals and approaches, and to discuss areas that the GRG considers requires further attention. In this manner, the GRG continued to fulfill

its advisory function on forthcoming work tasks. Furthermore, a virtual presentation to the NWMO's Project Oversight Committee of the Board of Directors was made in March 2024 summarizing the GRG's activities and findings during 2023, with a focus on confidence in the work carried out by the Geoscience Site Assessment team. This year Dr. M. Stephens on behalf of the GRG reported to the committee on March 26. The schedule and primary focus of these meetings are summarized in Table 1.

Figure 2. APM-GRG Members from left to right: Alexander (Sandy) Cruden, Sven Follin, Peter Kaiser (Chair), Andreas Gautschi, Michael Stephens.

Table 1: GRG meeting schedule for 2024

Meeting	Topic of Focus
January 24, 2024 (W) (W for web-meeting)	NWMO feedback on GRG comments from hydrogeological modelling report and discussion; GRG general feedback on V1 DFN report.
February 28, 2024 (W)	Revell Site geological model updates; NWMO feedback on GRG comments from V0 South Bruce DGSM report and discussion.
March 26, 2024 (W)	Meeting with NWMO Project Oversight Committee of the Board of Directors. Summary of GRG activities during 2023 and broader issues, with a focus on confidence in activities carried out by the Geoscience Site Assessment team.
April 16, 2024 (W)	NWMO feedback on GRG comments from V1 DFN report; agenda review for GRG in-person meeting Toronto.
April 30-May 3, 2024 (IP) (IP for in-person meeting)	In-depth discussion of several topics: Updated 3D geological model, amphibolite and geochronology updates, and DFN modelling for Revell Site; updated 3D seismic model for South Bruce Site; in-situ stress, rock mechanical and thermal property update for both sites; hydrogeology and hydrogeochemistry updates for both sites; detailed site characterization planning for both sites; Geosynthesis and ongoing work by Safety Assessment team. During this

	in-person meeting, various break-out sessions were held to stimulate discussion and engagement of all involved, and to identify key unresolved issues in each field of investigation.
May 1, 2024 (IP)	Meeting with Senior Management to discuss means to support and strengthen the Geoscience Site Assessment team for timely delivery of quality documents required for licensing.
July 18, 2024 (W)	Site selection process – update; NWMO feedback on GRG comments from IG_BH06 WP10 integration report; NWMO response to GRG comments on the methodology for in-situ stress model development plan and discussion.
September 11, 2024 (W)	Site selection process – update; in-situ stress model – update and discussion.
November 14, 2024 (W)	Hydrogeochemical model update; NWMO feedback on GRG comments concerning the alternative DFN model developed based on fractures from boreholes IG_BH01 to IG_BH03; preliminary workplan for a hydro-DFN model.
December 11, 2024 (W)	Next steps after site selection; NWMO feedback on GRG comments to Geosynthesis table of contents for Revell Site.

NWMO shared draft work or test plans and initial findings in technical documents as they became available to solicit review comments. Feedback from the GRG for consideration by the NWMO was shared during and after each meeting, and individual GRG members communicated directly by e-mail or during additional focused virtual meetings. For example, Dr. P. K. Kaiser contributed further discussion on the approach and presentation of key technical information in supporting the in-situ stress model development for the Revell Site; Dr. S. Follin provided initial technical feedback to support the development of a DFN workplan coupled to hydrogeological modelling (hydro-DFN); Dr. A. Gautschi provided feedback on an early version of the Geosynthesis Table of Contents; and Dr. M. Stephens discussed various aspects of the alternative DFN model report, which was presented to the GRG for information only.

These meetings and e-mail exchanges with the Geoscience Site Assessment team served to discuss the GRG's review comments and impressions on progress made. In particular, the in-person meeting provided an excellent opportunity to discuss various broader issues identified by the GRG to help enable the team to successfully complete their tasks in the deep geological repository program at NWMO. The revised workshop format with break-out sessions facilitated interdisciplinary exchanges and helped to form more comprehensive perspectives to guide interpretation of data and future work.

5.2 Specific studies reviewed by the GRG

In 2024, the GRG systematically reviewed approaches, methods and findings reported in nine technical documents on both sites. Two documents received in late 2023, and all documents received and reviewed prior to December 2024, are addressed here. The reviews of other documents are still in progress and will be addressed in next year's annual report. Several key aspects arising from the review work are summarized below.

The GRG appreciates the diligent use of disposition tables linked to the reviewed documents that facilitates tracking and, if necessary, a response to actions planned by or feedback received

from the NWMO. In several cases, disposition tables with written responses by the NWMO and final modified reports were also reviewed by the GRG.

5.2.1 Revell Site in the WLON-Ignace area

The GRG completed reviews of eight technical documents (Table 2) addressing various activities close to and around the Revell Site.

Table 2: Technical documents reviewed by the GRG from the Revell crystalline rock site in the WLON-Ignace area

Timing of receipt	Technical document
November 2023	Sub-regional scale integrated hydrogeological model for the Revell batholith and surrounding area.
November 2023	Version 1 Discrete Fracture Network (DFN) and subordinate rock model for the Revell Site.
April 2024	Evaluation of borehole failure at the Revell Site.
June 2024	WP10 – Geological-geophysical data integration report for borehole IG_BH06.
July 2024	WP10 – Rock Mass Classification for IG_BH04, IG_BH05, and IG_BH06. RMC-index.
Sept./October 2024	In-situ stress data model report; Stress modelling plan.
October 2024	Diffusion coefficient and porosity measurements for rock cores from boreholes IG_BH02, BH03, BH04, BH05 and BH06.
October 2024	Amphibolite characterization for the Revell Site.

The GRG received two milestone reports near the end of 2023, which were reviewed during early 2024. The first of these documents addressed a hydrogeological model for the Revell Site and surroundings, using partly and for the first time, site-specific data from boreholes IG_BH01, IG_BH02 and IG_BH03, and the established, 3D geological (version 1) and DFN (version 0) models for the site. Subsequently, the GRG received for review the version 1, site-scale DFN and subordinate rock model. This model updates the version 0 DFN model by using data from all six boreholes (IG_BH01 to IG_BH06) and ongoing work with the version 2.0 3D Geological Model for the Revell Site.

The GRG was pleased to see the first attempt to produce a hydrogeological model for the crystalline rock site at Revell using not only regional but also site-specific data. The GRG was concerned about insufficient interplay between the contractor, who had executed the hydrogeological modelling work (University of Waterloo), and the Geoscience Site Assessment team at NWMO, who had generated, for example, the site-scale geological and DFN models. In particular, there was insufficient communication to the University of Waterloo concerning the progress made at NWMO around how subordinate rock occurrences influence groundwater flow at the Revell Site. The GRG was disappointed that no hydromechanical approach was adopted in the understanding of groundwater flow at the site. This situation largely reflected the lack of availability of a site-specific, in-situ stress data model when the hydrogeological modelling work was completed, a situation that has recently been improved (see below). The GRG also recommended a broader discussion of alternative models to explain the origin of

salinity in deeper groundwaters in the crystalline rock at the Revell Site. Attention on alternative processes for groundwater salinity in deeper shield rocks needs to be discussed.

The version 1, site-scale DFN and subordinate rock model, based on data from six deep boreholes, provides a significant improvement relative to the version 0 DFN model presented to the GRG one year ago, based solely on data from the first three boreholes. The GRG requested the Geoscience Site Assessment team to document far more distinctly all the assumptions and, by consequence, uncertainties in each step in the process to produce the DFN model. One example concerns the assumptions around the relative time relationship between the four different fracture sets at the site. The GRG also recommended more care around the use of terminological jargon in future documents. As for the hydrogeological modelling report, the GRG was disappointed that no reference to the in-situ stress state at the site was included when fracture properties in different orientation sets were discussed. Consequently, the GRG has argued for the separate production of a hydro-DFN model suitable for use in the next stage of hydrogeological modelling. The GRG was pleased that NWMO listened to this important guidance and is now working to develop the first, site-specific hydro-DFN, planned for completion in early 2025.

An important step to help understand the in-situ stress state at the Revell Site was completed during 2024 in a study to identify borehole breakouts in all six deep boreholes at the site. These borehole breakouts are commonly associated with natural fractures and permitted an analysis of the local stress field. The GRG noted that rock inhomogeneity, not simply the occurrence of natural fractures, is a key factor steering the location of the breakouts, resulting in anomalies in rock stress or rock strength (or both) along the boreholes, as suggested by the authors.

Valuable data for the in-situ stress state along borehole IG_BH01 was collected by Diametrical (rock) Core Deformation Analysis (DCDA test method; see Li, 2021). This is an indirect stress determination method that has not yet found wide application and, at the Revell Site, was not verified by other techniques. However, the test results seem consistent with borehole fracture data interpretations and assisted greatly in developing the first 1D, in-situ stress model for the Revell Site.

The borehole breakouts and DCDA data confirm the existence of three stress domains with a much deeper transition zone compared to conditions encountered at the URL in Pinawa, Manitoba. The results suggest that the deep stress domain with higher in-situ stresses is reached at approximately 650 m in IG_BH01 close to the upper interface of the integrated rock unit IRU3. The proposed 1D, in-situ stress model provides a much-improved understanding of the likely stress state at the Revell Site, and important information for the Repository Engineering and Safety Assessment teams. The GRG recommends that, in the next investigation stage, a sound 3D stress model be developed by collection of further DCDA data (and eventually other stress determination tests), and by developing a 3D numerical stress model that accurately captures the measured stress profiles and the observed variability in stress orientation.

The GRG reviewed the sixth and final single-borehole geology-geophysics data integration report (WP10 for borehole IG_BH06) prior to selection of a site for more detailed investigations. The GRG noted that the structure of the IG_BH06 report follows that which was designed by NWMO in collaboration with GRG during preparation of the WP10 report for borehole IG_BH01, and that the findings are in good agreement with the lithological and structural features in similar compilations for previous boreholes. The draft version of the report contained several errors, not least around the orientation of structures, and an understanding of the interplay between rock structures and the orientation of the borehole. However, all GRG comments were adequately addressed in the final version of the report.

Another important step for the Geoscience Site Assessment team concerns completion of the rock mass classification (RMC-index) report based on the analysis and compilation of data collected along boreholes IG_BH04, IG_BH05 and IG_BH06. The GRG noted that this report follows the structure and technical approach in the equivalent report for boreholes IG_BH01, IG_BH02 and IG_BH03, following extensive review work by the GRG and discussions with NWMO during 2022.

Bearing in mind the need to evaluate radionuclide transport properties at the site, the GRG welcomes the presentation of the new diffusion coefficient and porosity measurements for rock cores at the site based on new through-diffusion experiments from borehole IG_BH02 to IG_BH06. In addition, older through-diffusion data from IG_BH01 exist, as well as data from chloride out-diffusion experiments from boreholes IG_BH01 to IG_BH03. The GRG noted that the experimental procedure and preparation of the so-called CR-10 reference experimental water for the new experiments are well described in detail. Furthermore, the description of the new samples is very well documented. However, the GRG noted a sampling bias whereby only core segments showing no or very minor tectonic disturbance have been analyzed. For this reason, the GRG advised some addition of text informing users of this bias to prevent a misinterpretation of the results of the diffusion experiments in the context of radionuclide transport.

Given its strong association with high fracture frequency intervals (HFFI's) and hydraulically conductive features, the GRG has previously expressed concerns around the level of geological and petrological understanding of the mafic, subordinate rock type classified informally as "amphibolite" during geological core logging. The GRG is pleased that the NWMO has addressed this issue and has reviewed a report carried out by Lakehead University documenting a detailed petrographic and geochemical analysis of samples of "amphibolite". As previously suggested by the GRG, the report concludes that these subordinate rocks at the Revell site are in fact metamorphosed lamprophyre dykes, a type of ultra-potassic intrusive igneous rock that is common across the Superior Province, inside which the Revell Site is situated. However, the GRG noted that the report requires substantial revision to improve the order of presentation, and the clarity of the findings and major conclusions.

The GRG also received four reports with the aim of informing the GRG of other activities or studies related to the Revell Site (Table 3). Formal review of these reports by the GRG was not requested. However, the alternative DFN modelling based on fracture data from boreholes IG_BH01 to IG_BH03 provoked a discussion between the GRG and the Geoscience Site Assessment team. This matter concerned the emergence of some differences between the modelling results presented and those attained in the version 0 DFN model for the Revell Site based on the same data set. NWMO has responded satisfactorily to the GRG concerning these differences. The GRG also pointed out that recognition of a fractal character for the fracture intensity-size distribution model in the alternative DFN helped NWMO with the development of the spatial generation of the fracture intensity-size distribution model in the updated version 1 DFN and subordinate rock model (see above). Now that the Revell Site is chosen at the preferred site, the GRG recommends a follow-up study with the alternative DFN model using data for all boreholes IG_BH01 to IG_BH06, and that this study is reviewed formally by the GRG.

Table 3: Additional technical documents from the Revell crystalline rock site in the WLON-Ignace area sent to the GRG solely for information purposes

Timing of receipt	Technical document
June 2024	Rb-Sr and Lu-Hf geochronology by LA-ICP-MS/MS.
July 2024	Alternative DFN model of the Revell Site based on fracture data from boreholes IG_BH01 to IG_BH03.
July 2024	A review of the major chemical and isotopic characteristics of groundwater in crystalline rocks of the Canadian Shield.
October 2024	Compilation of in-situ stress data from the AECL Underground Research Laboratory.

5.2.2 South Bruce Site in the SON-South Bruce area

The GRG reviewed the first draft of a "Descriptive Geoscientific Site Model (DGSM)" for the South Bruce Site (Table 4), potentially marking a significant milestone in site understanding. Unfortunately, the draft report was incomplete and contained several errors. For example, the identification and estimates in abundance of minerals in the different formations at the site are partly incorrect, and the GRG recommended that use of the QEMSCAN technique in this context should be avoided in future DGSM work. The GRG also identified the need for integration of the 3D geological model with the 3D seismic data to avoid separate presentation of these two important, complementary components for site understanding. Parts of the report addressing issues more directly relevant for users in engineering and safety analysis require significant revision. For example, the section on hydrogeology described the instrumentation used and the data acquired but failed to provide any evaluation of the development of under-pressures and even included some statistical errors in the data handling.

Table 4: Technical documents reviewed by the GRG from the South Bruce sedimentary rock site in the SON-South Bruce area

Timing of receipt	Technical document
November 2023	"Descriptive Geoscientific Site Model (DGSM)" Version 0 report.

The GRG also received two reports from NWMO with the aim to keep the GRG informed of other activities or studies around the South Bruce Site (Table 5). Formal review of these reports by the GRG was not requested.

Table 5: Additional technical documents from the South Bruce sedimentary rock site in the SON-South Bruce area sent to the GRG solely for information purposes

Timing of receipt	Technical document
May 2024	Regional geology update for Southern Ontario
July 2024	Reflection and love-wave imaging of a buried valley using Land-Streamer seismic data

6 Concluding remarks

This report summarizes the most important findings and conclusions of the GRG in connection with their work since its inception in 2012 and, in more detail, during 2024. For more than a decade, the GRG has been impressed by the professional work undertaken by the Geoscience Site Assessment team and is looking forward to guiding future site characterization efforts for the Revell Site in the Wabigoon Lake Ojibway Nation (WLON)-Ignace area.

Following advice from the GRG to NWMO on the approach and methods to be used, many high-quality reports documenting results and interpretation were obtained and reviewed by the GRG. These reports have contributed to the view, expressed by the GRG, that both the Revell and South Bruce sites are suitable from a geoscientific perspective to host a repository. The role of the GRG will shift in the future to assist and guide the Geoscience team in developing tactical means to eliminate or significantly reduce remaining uncertainties such that a safe repository can be constructed and operated in the WLON-Ignace area. The GRG looks forward to this next chapter and the opportunity to continue working with the Geoscience team to further advance the geoscientific understanding of the Revell Site.

7 References

Documents available from www.nwmo.ca including annual reports by the GRG

- APM-GRG, 2013. 2012-2013 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2014. 2014 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2016. 2015-2016 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2017. 2017 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2018. 2018 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2019. 2019 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2020. 2020 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2021. 2021 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2022. 2022 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- APM-GRG, 2023. 2023 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG).
- Li Y, 2021. Determination of mining-induced stresses using diametrical rock core deformation measurements and finite element modelling. M.Sc. thesis, McGill University, Montreal, Canada, 105 p.
- NWMO, 2010. Moving Forward Together: Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel, Nuclear Waste Management Organization.

- NWMO, 2023a. Confidence in Safety – Revell Site. NWMO-TR-2023-07, Nuclear Waste Management Organization.
- NWMO, 2023b. Confidence in Safety – South Bruce Site. NWMO-TR-2023-08, Nuclear Waste Management Organization.

8 Brief biographies of the APM-GRG members

The APM-GRG was composed of five to six internationally recognized experts from Canada, Australia, Sweden and Switzerland. The five current members combine extensive multidisciplinary international experience in areas relevant to the siting of deep geological repositories in both crystalline rock and sedimentary rock formations. The tenure in the GRG is noted in brackets after each GRG member's name.

Dr. Peter Kaiser (2012-present)

Dr. Peter Kaiser, Chairman of the APM-GRG, is Professor Emeritus of Mining Engineering at Laurentian University, former Chair for Rock Engineering and Ground Control, Director of the Rio Tinto Centre for Underground Mine Construction, Founding Director of the Centre for Excellence in Mining Innovation, and geomechanics consultant. His interests lie in geomechanics, underground excavation stability, mine design, mechanized excavation, and the applications of emerging technologies that increase mining safety and productivity. Dr. Kaiser is a Fellow of the Canadian Academy of Engineers and a Fellow of the Engineering Institute of Canada.

Dr. Sandy (Alexander) Cruden (2012-present)

Dr. Sandy (Alexander) Cruden is Professor of Tectonics and Geodynamics in the School of Earth, Atmosphere and Environment at Monash University (Australia). Dr. Cruden has more than 30 years of geoscience experience related to structural geology, analysis, and characterization in both crystalline and sedimentary rock settings. Dr. Cruden completed a fault reactivation analysis and structural characterization of southwestern Ontario as part of site characterization activities for Ontario Power Generation's proposed Low- and Intermediate-Level Waste Deep Geologic Repository at the Bruce site.

Dr. Sven Follin (2019-present)

Dr. Sven Follin is a retired geoscience consultant who has been actively involved in the Swedish site evaluation process for hosting a deep geological repository, including geoscientific feasibility studies and the detailed site characterization of the Forsmark site, which was selected by SKB (the Swedish Nuclear Fuel and Waste Management Company) as the site for the deep geological repository for spent nuclear fuel in Sweden. Focus has been on hydrogeological aspects using the Discrete Fracture Network (DFN) approach. He was also involved in SKB's subsequent safety assessment. In addition to working with site descriptive hydraulic DFN modelling for SKB, Dr. Follin has been actively involved in the hydraulic investigations and the structural-hydraulic DFN modelling of excavated damage zones (EDZ) around deposition tunnels at the Olkiluoto site, which was selected by Posiva (the Finnish Nuclear Fuel and Waste Management Company) as the site for the deep geological repository for spent nuclear fuel in Finland.

Dr. Andreas Gautschi (2012-present)

Dr. Andreas Gautschi was Chief Geoscientific Advisor at the Swiss National Cooperative for the Disposal of Radioactive Waste (Nagra). Since his retirement he works as an international geoscientific consultant and as geoscientific advisor for Nagra. Dr. Gautschi has more than 30 years of geoscience experience related to the planning, co-ordination, and implementation of site evaluation programs for deep geological repositories in both crystalline and sedimentary rocks, in close collaboration with Nagra's safety assessment group. He was a member of Posiva's **IN**ternational **A**dvisory **G**roup for the **O**nkalo (INAGO) deep geological repository during the first phase of site characterization on the Olkiluoto island, Finland. For many years

he had lectureships at Tübingen University and ETH Zurich on Deep Geological Disposal of Radioactive Waste.

Dr. Richard Smith (2012-2017)

Dr. Richard Smith is a Professor in the Department of Earth Sciences at Laurentian University, where he is the Industrial Research Chair of Exploration Geophysics. He has expertise in the application of geophysical methods generally and airborne methods specifically to investigate the geosphere at depth. Dr. Smith brings over 20 years of experience working in the exploration business. In 2015, he was asked by the Geological Society of London and the UK Department of Energy and Climate Change to be a member of the National Geological Screening Independent Review Panel.

Dr. Michael Stephens (2012-present)

Dr. Michael Stephens is a retired Senior State Geologist with the Geological Survey of Sweden in Uppsala. Dr. Stephens has been actively involved in the Swedish site evaluation process, including country-wide reconnaissance studies conducted in Sweden to identify potentially suitable regions for hosting a deep geological repository, geoscientific feasibility studies, and the detailed site characterization of the Forsmark site, which was selected by SKB as the site for the deep geological repository in Sweden. Focus has been on base geological aspects.

Mr. Anders Ström (2017-2024)

Mr. Anders Ström is Senior Program Manager of final disposal solutions for spent fuel at SKB (the Swedish Nuclear Fuel and Waste Management Company). Mr. Ström has been actively involved in SKB's siting program since the 1990s, among other things, in charge of the development of requirements on the crystalline rock for the spent fuel repository and criteria for site evaluation. During the site characterization project, he was Chief Project Manager for the multidisciplinary site descriptive modelling conducted for the two candidate sites at Forsmark and Laxemar-Simpevarp (Oskarshamn). He is now international coordinator of SKB and in charge of the close co-operation between SKB and Posiva, in Finland, for implementing robust disposal solutions according to the KBS-3 concept.