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CD#: 00216-CORR-00531-00220
Project ID: 10-60004

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

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

Dear Dr. Swanson:

Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-511

The purpose of this letter is to provide OPG's response to Information Request (IR) EIS-12-511 from IR Package #12 (Reference 1).

The Attachment contains the response to the IR as well as an updated copy of the Geoscience Verification Plan for the DGR Project, NWMO DGR-TR-2011-38-R001.

An updated Tracking Table showing how this submission links to various sections in the documents submitted on April 14, 2011 (References 2 and 3), will be submitted with the final response for IR Package #12, committed for submission by April 4, 2014, in Reference 4. The commitment to incorporate the results of the geoscientific activities into a revised DGR Safety Case in support of the Operating License application will be added to the updated DGR Project Consolidated Commitment Lists report originally submitted July 19, 2013 (Reference 5).

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

Sincerely,

Laurie Swami
Vice President, Nuclear Services
Ontario Power Generation

Attach.

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

References:

1. JRP letter from Dr. Stella Swanson to Laurie Swami, “Information Request Package #12 from the Joint Review Panel”, November 8, 2013, CD# 00216-CORR-00531-00215.

2. OPG letter from Albert Sweetnam to JRP Chair, “Submission of Information in Support of OPG’s Licence Application for a Deep Geologic Repository for Low and Intermediate Level Waste”, April 14, 2011, CD# 00216-CORR-00531-00090.

3. OPG letter from Albert Sweetnam to JRP Chair, “Submission of an Environmental Impact Statement for a Deep Geologic Repository for Low and Intermediate Level Waste”, April 14, 2011, CD# 00216-CORR-00531-00091.

4. OPG letter from Laurie Swami to Dr. Stella Swanson, “Deep Geologic Repository Project for Low and Intermediate Level Waste – Acknowledgment of Information Request (IR) Package #12”, December 4, 2013, CD# 00216-CORR-00531-00216.

5. OPG Letter from Allan Webster to Dr. Stella Swanson, “Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Commitments Report”, July 19, 2013, CD# 00216-CORR-00531-00197.

ATTACHMENT

Attachment to OPG letter, Ms. Laurie Swami to Dr. Stella Swanson, “Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-511”

January 30, 2014

CD#: 00216-CORR-00531-00220

OPG Response to Information Request EIS-12-511 from Joint Review Panel

OPG Response to Information Request EIS-12-511 from Joint Review Panel

IR#	EIS Guidelines Section	Information Request and Response
EIS 12-511	• Section 16, Follow-Up Program	***Information Request:*** ***Geoscientific Verification Plan*** *Provide an updated Geoscientific Verification Plan (GVP) that includes more details concerning specific methods, timing, and the sequencing of sampling as well as how Ontario Power Generation will develop triggers for changes to engineering design and benchmarks for verification of the safety case.* *Verification activities that are outlined in NWMO DGR-TR-2011-08 are generally defined and lack substantive detail as to the procedures that would be used, spatial locations of testing and timing of testing. An example deficiency is provided in the following paragraph, with more details being provided in the Context section of this IR request.* *A primary GVP activity that is critical to final repository siting design is in-situ overcoring stress measurement that would be used to verify regional scale stress magnitude and orientation assumptions. These assumptions will be utilized to direct repository layout design in order to minimize induced stresses about rooms and access drifts, thereby maintaining least excavation rock disturbance and damage. In the GVP, stress measurement activities are planned only to take place at the location of the shaft bottom and within the Cobourg Formation, and are indicated to occur only during the initial construction interval at the time of shaft sinking. It is not indicated whether such stress measurement activity will take place within the Main Shaft and the Ventilation Shaft, or at only one site. Inasmuch as stress conditions can vary spatially over short distances, limited site testing within only one shaft, or both shafts, at the depth of the Cobourg Formation may provide insufficient data to accurately confirm previous stress orientation and magnitude assumptions that were made based on regional scale approximations. It is also indicated in the GVP that no similar testing will be conducted to assess spatial variation of in-situ stress conditions (orientation and magnitude) over the full lateral extent of the repository horizon as drifts and rooms are developed. Justification for this lack of extensive stress monitoring activity, which is critical to room layout design and necessary for modeling performance verification, must be provided.* ***Context:*** *A Geoscientific Site Characterization Plan was initiated by OPG in 2006 to obtain regional data on relevant aspects of geology, geomechanics, hydrogeology, geochemistry and seismicity in order to provide evidence that the hosting rock mass environment would provide strong geosphere barrier-in-depth capability to provide safe, long-term containment and isolation of the L&ILW within the DGR. In its EIS submission, OPG provided a GVP in which procedures and plans for additional geoscientific study, to take place during construction and operations phases of the DGR, were outlined to provide support for engineering design decisions and the long-term safety case assumptions.* *Additional detail is required to provide assurance of the integrity and long-term stability of the site-specific geosphere and engineered barriers to safely contain and isolate L&ILW. To date, geoscientific information has been obtained either from*

IR#	EIS Guidelines Section	Information Request and Response
		regional studies (including seismic surveys) or from quantities of core material recovered from a total of eight boreholes, of which six were developed to the depth of the planned repository horizon. Accordingly, OPG has proposed a series of planned geoscientific investigations that would be conducted during vertical and lateral development, and operation, of the DGR to verify sub-surface geosphere conditions. *During shaft sinking and lateral development, one geoscientific activity to be conducted for additional information gathering will be geological mapping. In the described mapping process, “imaging” would be conducted and “rock mass characterization” will be used for geosphere data verification. The manner in which image mapping data will be used to infer geosphere properties, what properties will be determined, and the specific procedures and outputs of rock mass characterization, are not, however, defined. It is unclear how, for this activity, information gained will be used to address design decisions and safety case assumptions.* *Additionally, under the activity defined as in-situ geomechanical testing, upscaling of geomechanical properties of the rock at the repository level has been presented in Tables 2.1 and 2.3 of NWMO DGR-TR-201138. The procedures for field scale sample acquisition, sample testing and the rationale for determination of field scale versus previous laboratory-derived rock properties, at smaller scale, are not described in this document and thus provide little justification for such activity planning.* *The geosphere will be subject to considerable change as the construction process proceeds and development activity will influence the pre-existing geosphere environment. For this reason, verification activities that may be applied to measure geosphere environmental conditions and their influence on design aspects of the DGR over the long term should also be evaluated and described.* *The proponent, in its GVP submission, has also not provided sufficient detail to confirm that best operational practices and testing methods have been considered for information gathering. By way of example, consideration is given to, but no justification provided for, use of the United States Bureau of Mines (U.S.B.M.) deformation gauge overcore technology (used for biaxial stress condition measurement in multiple, orthogonal boreholes) versus use of triaxial gauge overcore technology (used for three-dimensional stress condition measurement in single boreholes) to assess in-situ stress conditions.* *Site characterization studies to date have relied on examination of only a limited number of core sample tests from a few boreholes, only one of which has been sited within the spatial boundary and depth of the proposed repository. Geomechanical characterization of actual repository site conditions is thus extremely limited and will require more extensive evaluation. Planning for verification work, in terms of core retrieval activities both along the shafts and within lateral development sites, the spacing and depth of boreholes within which core recovery will take place, the size of boreholes to be drilled, the number of samples to be recovered at each site, the types (and justification) of characterization tests, the number of each type of test and the application of information gained in verification of initial design assumptions, is not well described nor defined.*

IR#	EIS Guidelines Section	Information Request and Response
		The proponent, in its hearing submissions, has stated that detailed information concerning testing procedures, as partially described in the preceding paragraphs, would be submitted for licensing approval immediately prior to the start of the shaft construction phase of the proposed DGR project, should the project proceed.
		OPG Response: In March 2011 NWMO issued a Geoscientific Verification Plan (GVP) that outlined a framework for verification activities to be performed during the underground construction of the DGR (NWMO 2011a). The purpose of the GVP was to describe activities necessary to confirm site attributes contributing to the DGR Safety Case. The 2011 GVP has since been revised to include not only proposed activities within the shaft and lateral development related to verifying the DGR Safety Case, but also specific geotechnical field verification activities necessary to confirm repository design and assure safe underground excavation practices (NWMO 2014, enclosed). Tables 1 and 2 (attached) list revisions made to the GVP. As the detailed design of the DGR is progressed, the Geoscientific Verification Plan will be updated and reissued as necessary. As indicated in the CNSC’s draft Licence Condition Handbook, attached to PMD 13-P1.2, assuming the licence is issued, OPG will be required to provide written notification to the CNSC staff of any changes to the GVP. Any comments received from the CNSC about this revision of the plan (i.e. Rev 001) will be addressed in a future revision of this plan. The plan will ultimately be developed in sufficient detail to allow the development of technical specifications for procurement of equipment and for services to execute the plan. The scheduling of all proposed sub-surface activities will be coordinated with construction activities to ensure timely collection and assessment as required for underground excavation, verification of DGR design elements and verification of parameters used in the DGR Safety Case (see attached Table 3). It should be noted that while the revised GVP provides greater detail, particularly for real-time geotechnical data information needs during construction and the means for collection (e.g., rationale for selection of USBM method versus triaxial over-coring gauge), individual test plans would be created for each activity. The test plans would incorporate information and experience consistent with international best practice to assure data reliability. Further, the detailed test plans would stipulate confirmed design basis or ‘trigger’ values related to rock mass response for excavation safety, verification of the DGR engineered design and layout, and the safety case. Data gathered during implementation of the GVP would be used to reaffirm the geosphere conceptual model and understandings presented in the DGR Geosynthesis (NWMO 2011b) and update the DGR Safety Case to re-evaluate dose consequences and margins of safety. This information would be presented as part of the DGR Operating Licence application. As described above the revised GVP is comprised of two related sets of verification activities: 1) geotechnical verification, and 2) geoscience verification. The geotechnical verification activities support construction monitoring and design verification, whereas the geoscience verification activities are principally conducted to reaffirm the DGR Safety

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		Case. A brief description of how these activities would be undertaken and possible response to observed conditions inconsistent with assumptions or data used in either the engineering design or the analyses supporting the DGR Safety Case is provided under the following two headings. A final section describes issues related to the scheduling and timing of proposed activities. Geotechnical Verification The geotechnical verification activities involve field investigations and monitoring performed during the construction of the two shafts and the underground repository. The geotechnical verification activities are designed to provide real-time information as to the in situ behaviour of the rock formations relevant to: i) the observational methods for safe underground excavation practice and ii) verifying that behaviour is within expected and predefined trigger values. In the remote event that rock mass properties and/or behaviour fall outside trigger values, the repository design will be re-examined incorporating the new parameter values to assess influence, if any, on construction methods and/or the repository design. Table 4 (attached) summarizes the various geotechnical measurements that will be obtained during construction, as well as preliminary trigger values and associated mitigation actions if results fall materially outside of these values. The trigger values and mitigation activities will be further refined at a later date when the DGR design has progressed closer to ‘issue-for-construction’ status and contractor equipment and execution approach are defined. This information will be included in future test plans for the work identified in the GVP. Geoscience Verification The geoscience verification activities involve field investigations and monitoring activities during both shaft sinking and lateral development. These activities yield data for the purpose of verifying the assumptions and geoscience data used to support the DGR Safety Case. In particular data will be gathered to confirm that the host Cobourg Formation and the overlying rock formations will act as a long-term barrier to contain and isolate the low and intermediate level waste. Geoscience verification activities will be completed, or sufficiently completed, during the construction phase such that they directly support an operating licence application and updated repository Safety Case. In certain circumstances long-term demonstration experiments initiated during construction activities will continue into the operation phase. Analyses that have been performed to support the DGR Safety Case are based on very conservative assumptions and values for various geoscience parameters. Key geoscience parameters as noted in the GVP are the Excavation Damaged Zone (EDZ) thickness and permeability, geomechanical properties, fracture infill dates, excavation response and in situ stresses, two-phase flow and hydraulic head parameters, and long-term diffusivity. While not expected, given evidence presented in the DGR Safety Case, in the remote event that the data arising from any of the various geoscience verification activities are materially different than those used in DGR safety analyses, the following actions will be taken: (a) the data will be assessed to determine its reliability and (b) new analyses will be undertaken to test the implications on the DGR Safety Case. In most cases, it is likely that there will be an initial interpretation of field

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

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

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

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

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

Table 3: Approximate Timing of Geotechnical and Geoscience Verification Activities

Construction Milestone	Investigation or Monitoring Activity		
	Geotechnical (1)	Geoscience	Approximate Duration (2)
Shaft Sinking			
Start of shaft sinking	• Geological mapping • Probe hole drilling in advance of shaft excavation face • Seepage water collection	• Geological mapping • Sample collection for infill mineral studies and dating • Ground penetration radar for EDZ detection	Throughout sinking of Main Shaft and Ventilation Shaft with no impact on shaft sinking schedule
Shaft excavation reaches Bois Blanc Formation	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Bois Blanc and Bass Island Formation contact	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Bass Island Formation	• Excavation response measurement using extensometer array		One week
Shaft excavation reaches Salina F Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Salina C Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Salina A2 Unit		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Salina A1 Unit	• Excavation response measurement using extensometer and stress cell array • Overcoring in situ stress measurements (3) • Large diameter core sampling		One week

Construction Milestone	**Investigation or Monitoring Activity**		
	Geotechnical (1)	**Geoscience**	**Approximate Duration** (2)
Shaft excavation reaches Cabot Head Formation		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Queenston Formation	• Excavation response measurement using extensometers • Liner loading using pressure cells • Overcoring in situ stress measurements (3) • Large diameter core sampling	• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase for EDZ activities
Shaft excavation reaches Georgian Bay Formation	• Excavation response measurement using extensometers • Liner loading using pressure cells • Overcoring in situ stress measurements (3) • Large diameter core sampling	• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase for EDZ activities
Shaft excavation reaches Blue Mountain Formation		• Characterization of EDZ using geophysics, hydraulic testing and coring (3)	Two weeks initial; Extended monitoring during construction phase
Shaft excavation reaches Cobourg Formation	• Excavation response measurement using extensometer and stress cell array • Overcoring in situ stress measurements (3)		One week
Repository Development in Cobourg Formation			
Start of Lateral Development	• Geological mapping	• Geological mapping • Sample collection for infill mineral studies and dating	Throughout repository development
Shaft Station and Service Area Development	• Excavation response measurement using extensometer and stress cell array • Large diameter core sampling		Throughout repository development; Monitoring extends into operation phase for selected instruments

Construction Milestone	**Investigation or Monitoring Activity**		
	Geotechnical [(1)]	**Geoscience**	**Approximate Duration [(2)]**
Ramp (in Sherman Fall Formation)	• Overcoring in situ stress measurements		Three days
Start of Geoscience Room Construction	• Under-excavation test to verify in situ stress		Duration of Geoscience Room excavation
Repository Panel Development	• Excavation response measurement using extensometer, convergence pins and stress cell • LIDAR profiling at selected locations • Large diameter core sampling at selected locations • Seepage water collection if any	• Rock property and response data collected via geotechnical activities • Seismic reflection survey to characterize the configuration of Precambrian surface below the repository • EDZ characterization will be conducted in the vicinity of the panel access tunnels	Throughout construction phase Monitoring extends to the closure of emplacement rooms EDZ characterization work would occur during construction phase with additional periodic follow-up characterization work in the operations phase
Start Panel 1 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section
Mid-way through Panel 1 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section
Start of Panel 2 Development	• Seismic tomographic survey of selected pillar • Stress, deformation and geophysical measurements in selected pillar		Seismic tomographic survey - 3 days Pillar testing duration dependent on time required to excavate adjacent emplacement room section

Construction Milestone	Investigation or Monitoring Activity		
	Geotechnical (1)	Geoscience	Approximate Duration (2)
After Panel Development, in Geoscience Room		- Two-phase flow study - Long-term diffusion test - Microbiology study - Seal material performance test	Varies depending on activities. All activities except seal material performance tests will be completed in construction phase.

Notes:

1. Geotechnical data will be used to verify assumptions and parameters used in both geotechnical design of underground openings and in geomechanical analysis of long-term stability in support of DGR Safety Case.
2. Unless otherwise noted, investigation or monitoring activities will not have an impact on shaft sinking or repository development schedule.
3. Overcoring, in situ stress measurements and EDZ characterization work will be carried out in the Main Shaft only. The execution of these activities will require stopping the Main Shaft sinking activities for the duration shown.

Table 4: Geotechnical Field Verification Activities, Preliminary Trigger Values and Associated Actions

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

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

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

Measurement	Preliminary Trigger Value or Observation	Action
a) Geomechanical Testing b) Excavation Response & Stress Change Measurements c) Pillar Measurements	than 80 MPa and elastic modulus less than 30 GPa. b) Convergence of openings measured using MPBX (Multi-Point Borehole extensometer) installations, convergence pins and/or LIDAR surveys show deformation exceeds 10 mm. c) Deformation of rock is greater than 10 mm. Change in stress greater than 5 MPa. Horizontal borehole inspection and/or geophysical survey of a rock pillar(s) reveals a major structure or weakness in rock pillar which would reduce its load carrying capacity.	during preclosure period. b) Assess deformation and stress data, and perform geomechanical analysis to determine possible impact on stability during preclosure period. c) Assess pillar data and perform geomechanical analysis to determine possible impact on pillar performance during pre-closure period. If structures or weaknesses present, assess data and peform analysis to determine possible impact on stability of affected pillar during pre-closure period. Possible remedial actions include: a) add rock support to improve stability; b) modify geometry of openings; and/or c) underground layout to thicken pillars.
In situ Stresses by Under-Excavation Test.	a) Magnitude of major horizontal principal stress exceeds 34 MPa. b) Orientation of major principal horizontal stress direction falls outside the sector bounded by N40°E and N100°E.	a) Assess in situ stress data and perform geomechanical analysis to determine possible impact on stability during preclosure period. Possible remedial actions include: a) add rock support to improve stability; and/or b) modify geometry of openings. b) Assess data and perform geomechanical analyses to assess impact of measured in situ stress conditions on performance of underground openings at repository horizon. If necessary, change layout of the underground repository so that the orientation of emplacement rooms falls within the range +/- 30° of the major principal horizontal stress direction.

Enclosure to Attachment

OPG letter, Ms. Laurie Swami to Dr. Stella Swanson, “Deep Geologic Repository Project for Low and Intermediate Level Waste – Submission of Response to Information Request EIS-12-511”

January 30, 2014

CD#: 00216-CORR-00531-00220

OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Geoscientific Verification Plan

January 2014

Prepared by: Nuclear Waste Management Organization

NWMO DGR-TR-2011-38-R001

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

Geoscientific Verification Plan

January 2014

Prepared by: Nuclear Waste Management Organization

NWMO DGR-TR-2011-38-R001

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Document History

Title:	Geoscientific Verification Plan		
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Document Revision History

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

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

EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

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1. INTRODUCTION

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

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

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

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

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

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

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

2. DEEP GEOLOGIC REPOSITORY

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

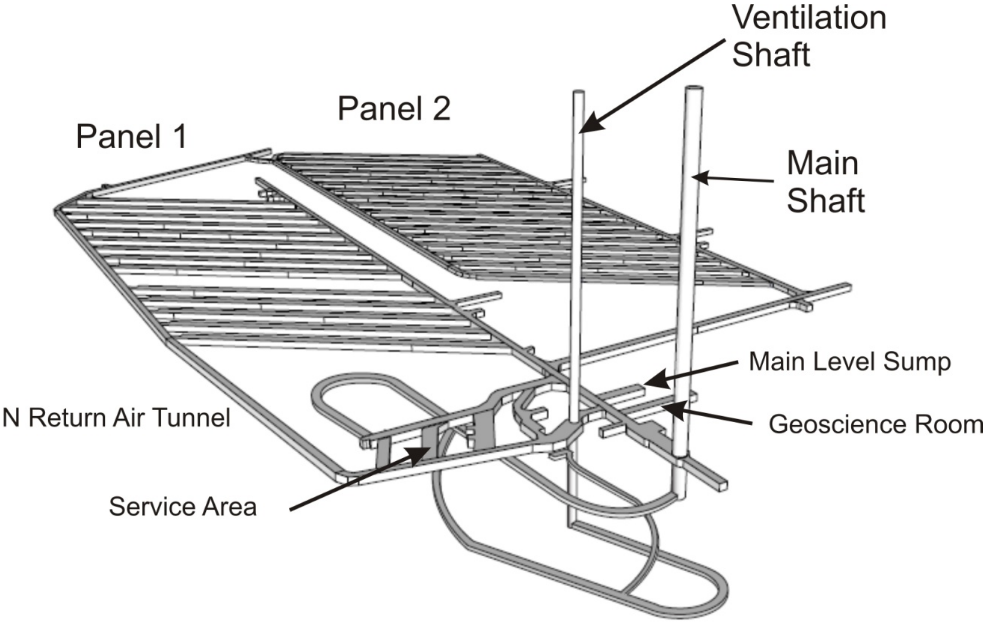

Figure 2.1: Proposed Underground Layout of the DGR

2.1 Shaft Design and Construction

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

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

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

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

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

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

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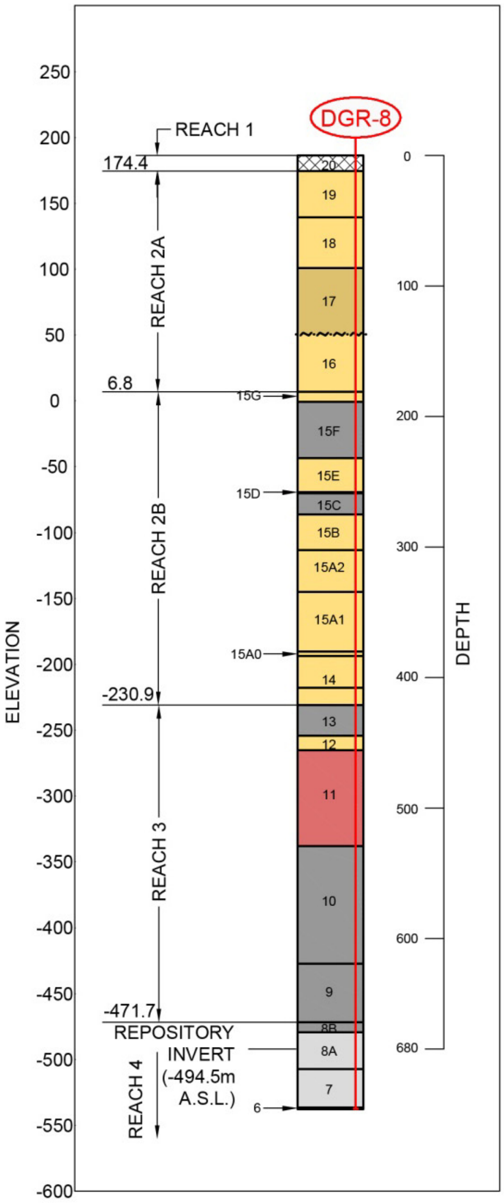
[1] *Contractor means a firm that contracts to supply labour and materials for the sinking of two shafts and/or the lateral development of the underground repository*.



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

STRATIGRAPHIC LEGEND:

PLEISTOCENE
- 20 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
- 19 LUCAS FORMATION - DOLOSTONE
- 18 AMHERSTBURG FORMATION - DOLOSTONE

LOWER DEVONIAN
- 17 BOIS BLANC FORMATION - CHERTY DOLOSTONE
- ·~~~~· SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN (SALINA)
- 16 BASS ISLANDS FORMATION - DOLOSTONE
- 15G G UNIT - ARGILLACEOUS DOLOSTONE
- 15F F UNIT - DOLOMITIC SHALE
- 15E E UNIT - BRECCIATED DOLOSTONE AND DOLOMITIC SHALE
- 15D D UNIT - ANHYDRITIC DOLOSTONE
- 15C C UNIT - DOLOMITIC SHALE AND SHALE
- 15B B UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITIC DOLOSTONE
- 15A2 A2 UNIT - DOLOSTONE AND ANHYDRITIC DOLOSTONE
- 15A1 A1 UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITIC DOLOSTONE
- 15A0 A0 - BITUMINOUS

MIDDLE SILURIAN
- 14 GUELPH, GOAT ISLAND, GASPORT, LIONS HEAD AND FOSSIL HILL FORMATIONS - DOLOSTONE AND DOLOMITIC LIMESTONE

LOWER SILURIAN
- 13 CABOT HEAD FORMATION - SHALE
- 12 MANITOULIN FORMATION - CHERTY DOLOSTONE AND MINOR SHALE

UPPER ORDOVICIAN
- 11 QUEENSTON FORMATION - RED SHALE
- 10 GEORGIAN BAY FORMATION - GREY SHALE
- 9 BLUE MOUNTAIN FORMATION - DARK GREY SHALE

MIDDLE ORDOVICIAN
- 8B COLLINGWOOD MEMBER - BLACK CALCAREOUS SHALE AND ARGILLACEOUS LIMESTONE (COBOURG FORMATION)
- 8A LOWER MEMBER - ARGILLACEOUS LIMESTONE (COBOURG FORMATION)
- 7 SHERMAN FALL FORMATION - ARGILLACEOUS LIMESTONE
- 6 KIRKFIELD FORMATION - ARGILLACEOUS LIMESTONE

END OF DGR -8

Figure 2.2: Stratigraphic Column at DGR-8

2.2 Underground Repository Design and Construction

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

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

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

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

2.3 Application of Observational Method

2.3.1 Geotechnical Design

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

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

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

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

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

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

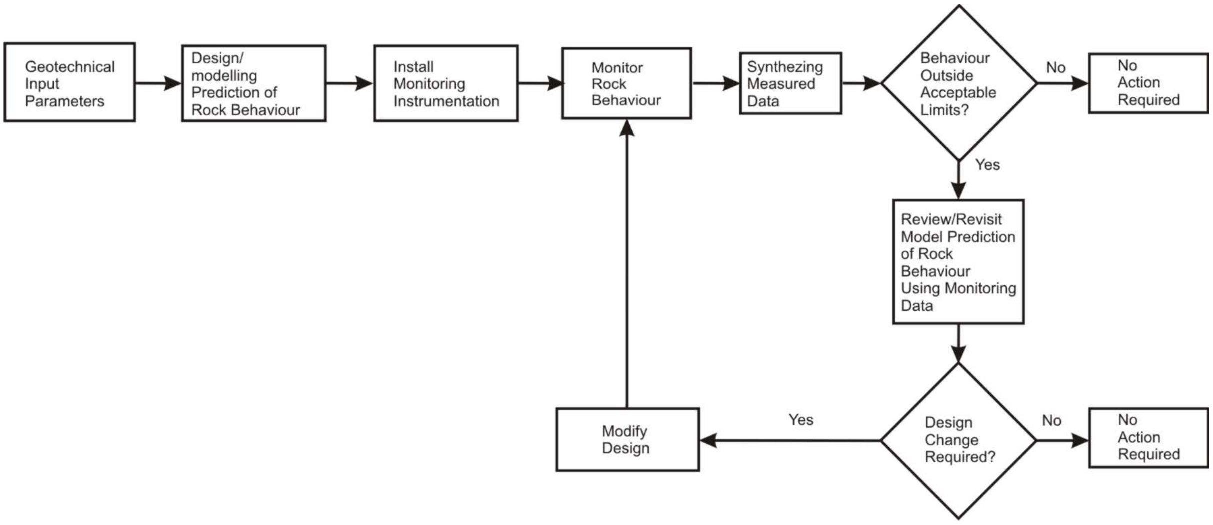


Figure 2.3: Observational Method during DGR Construction

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

2.3.2 Repository Safety Case

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

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

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

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

3. VERIFICATION OF GEOTECHNICAL DESIGN PARAMETERS

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

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

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

3.1 Key Geotechnical Parameters

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

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

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

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

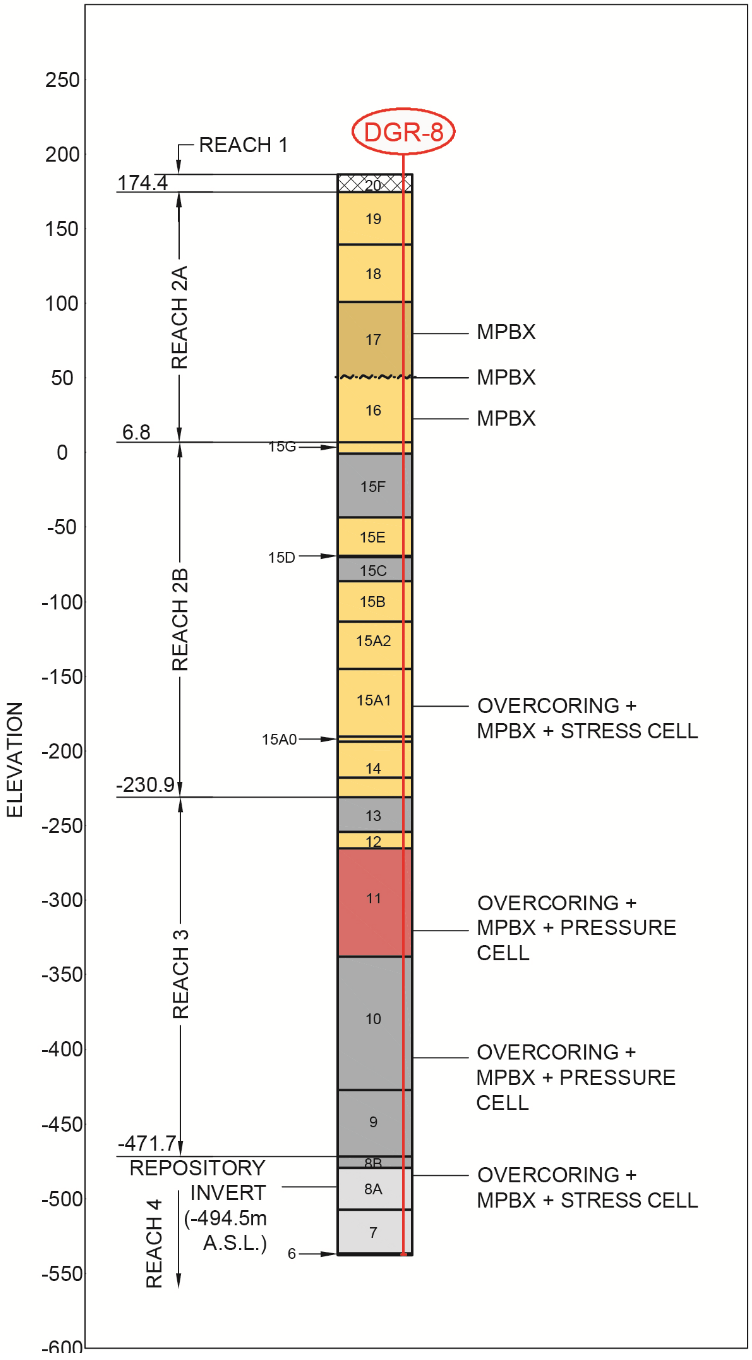
Note: (1) Unless otherwise stated, activity occurs in both Main Shaft and Ventilation Shaft

3.2 Shaft Sinking

3.2.1 Location of and Preparation for Investigation and Monitoring Activities

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

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



Legend:

MPBX – for deformation measurement using **M**ultiple **P**oint **B**orehole e**X**tensometer

PRESSURE CELL – for stress change measurement at rock/liner interface

OVERCORING – for in situ stress measurement

STRESS CELL – for monitoring stress change

Notes:

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

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

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

3.2.2 Geologic Mapping

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

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

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

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

3.2.3 Probe Hole Drilling

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

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

3.2.4 Observations of Groundwater Seepage

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

3.2.5 Excavation Response

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

3.2.5.1 Excavation Deformation Measurement

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

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

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

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

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

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

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

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

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

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

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

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

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

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

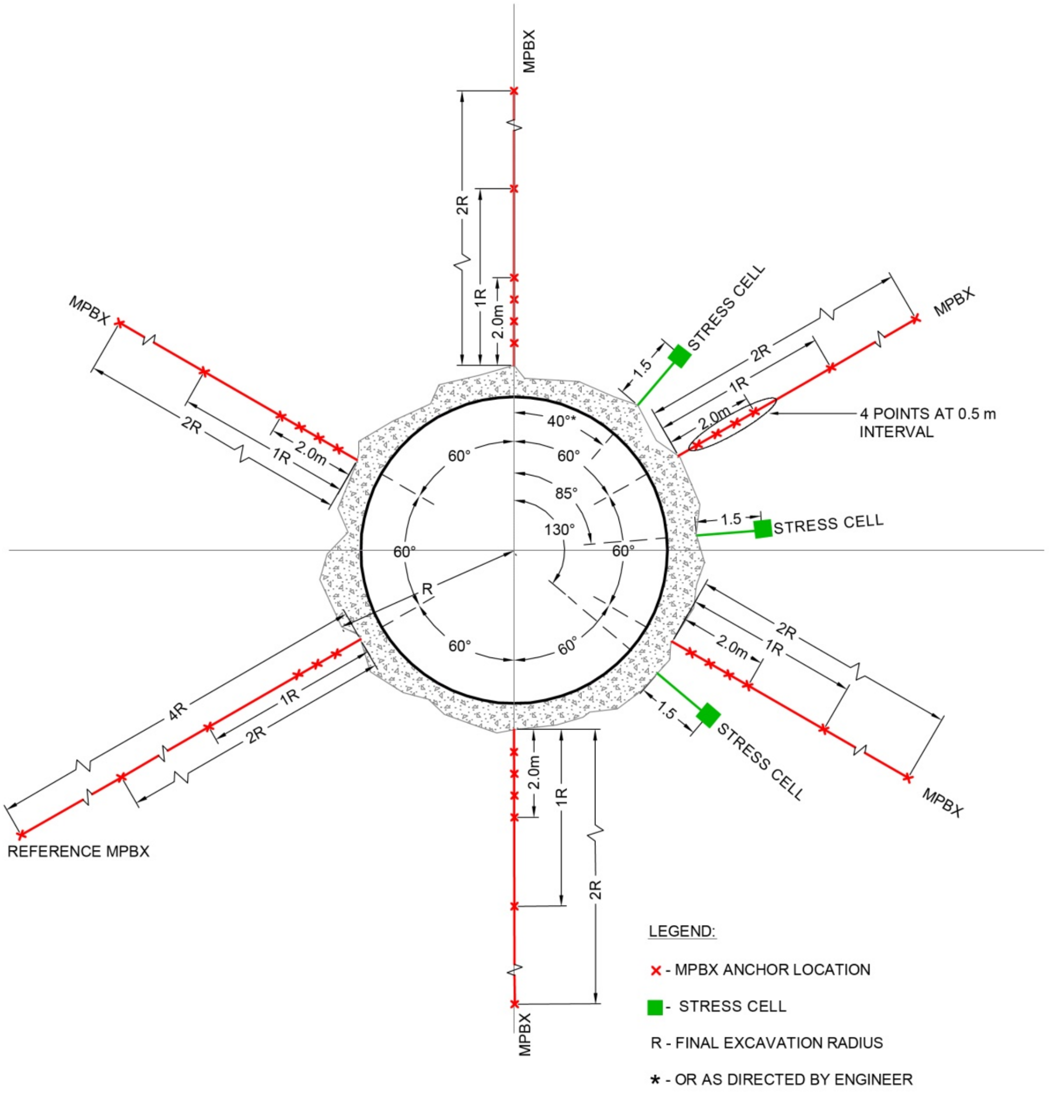


Figure 3.2: Configuration of Extensometer Array and Stress Cells at Selected Dolostone/Limestone Horizons

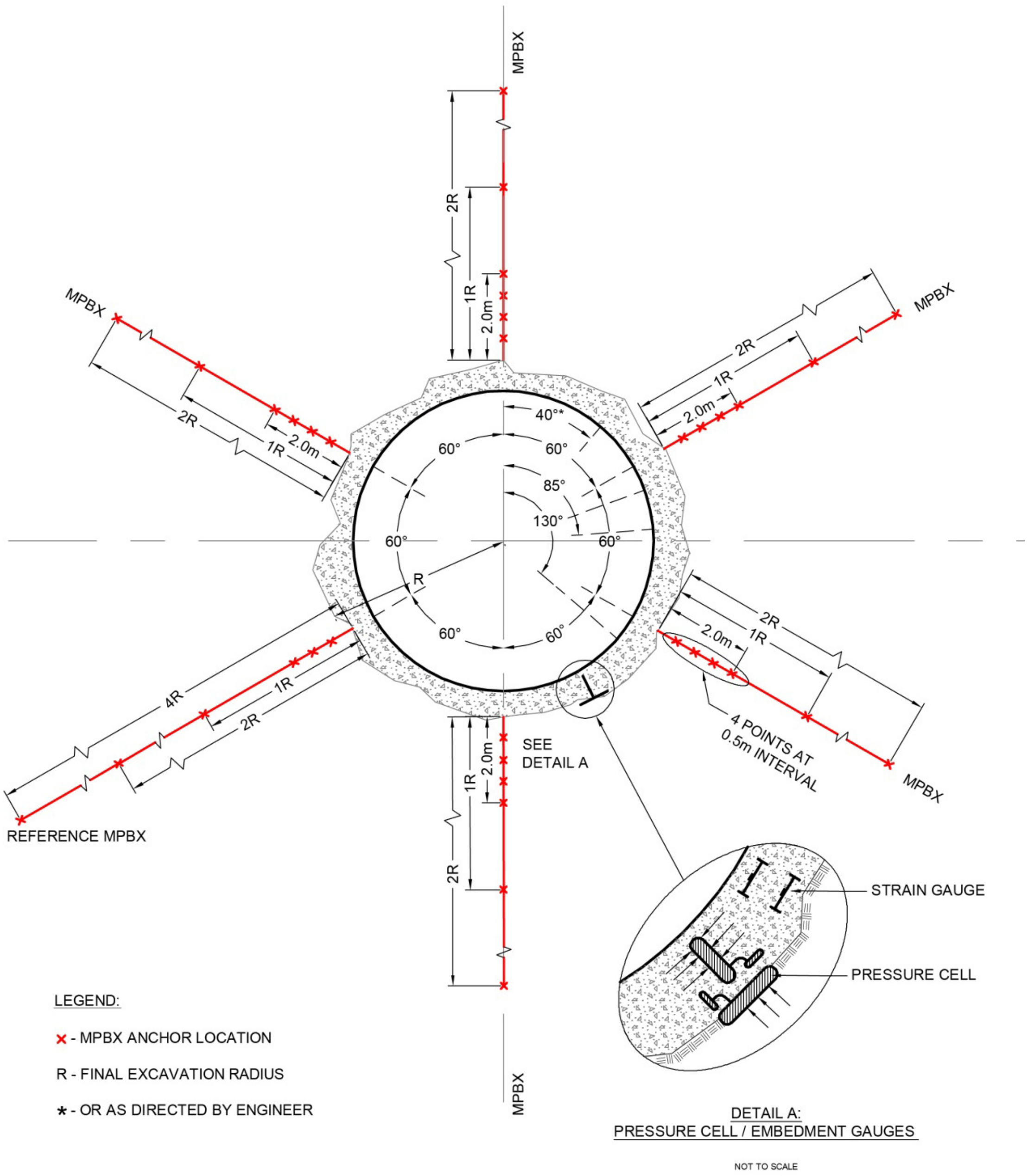


Figure 3.3: Configuration of Extensometer Array, Strain Gauges and Pressure Cells at Shale Horizons

3.2.5.2 Geomechanical Testing

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

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

3.2.6 In Situ Stress Measurements

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

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

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

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

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

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

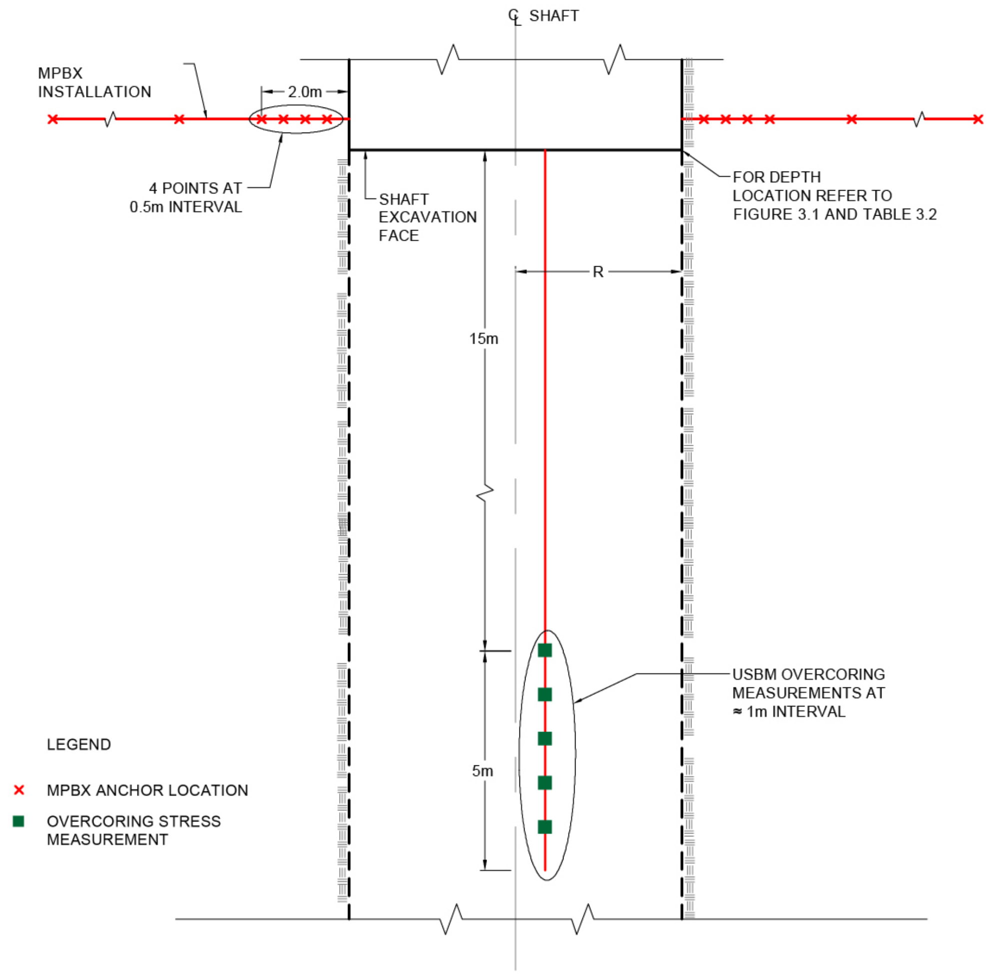


Figure 3.4: In situ Stress Measurement by Overcoring Method in the Main Shaft

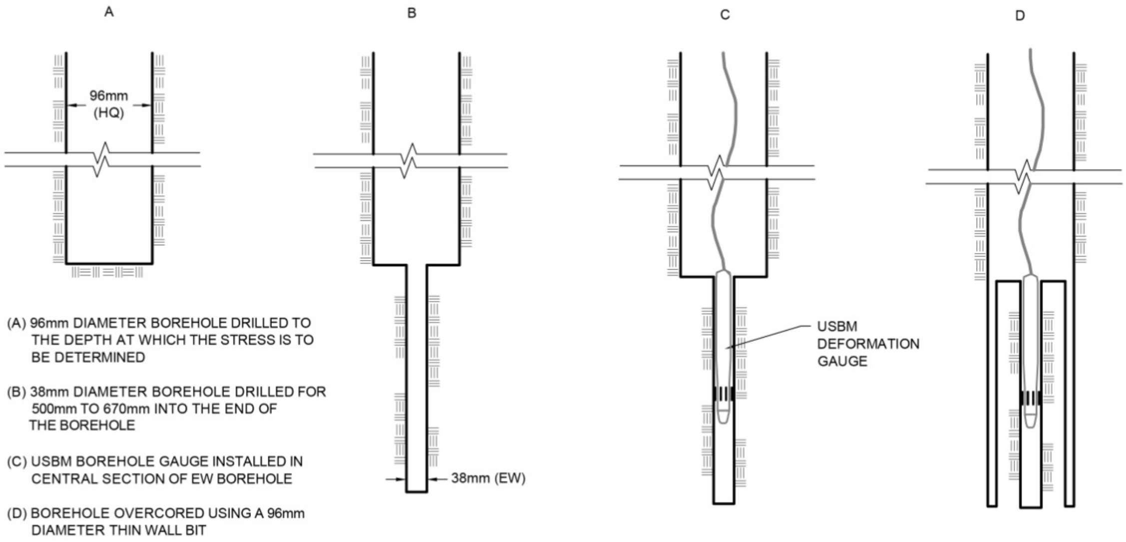


Figure 3.5: USBM Overcoring Method

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

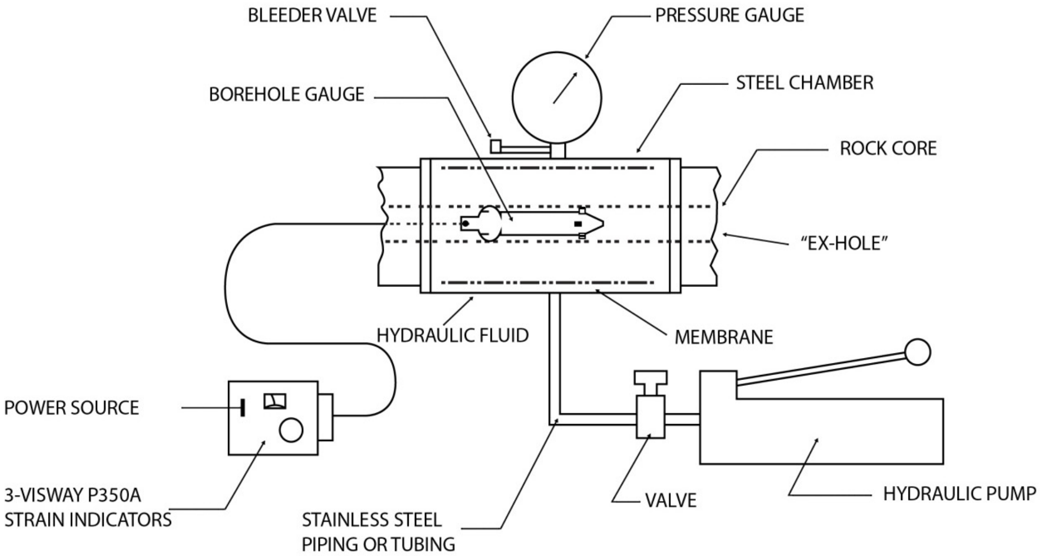


Figure 3.6: Biaxial Test Apparatus

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

3.3 Lateral Development

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

Some monitoring activities will continue into the operations phase.

3.3.1 Layout of Investigation Activities

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

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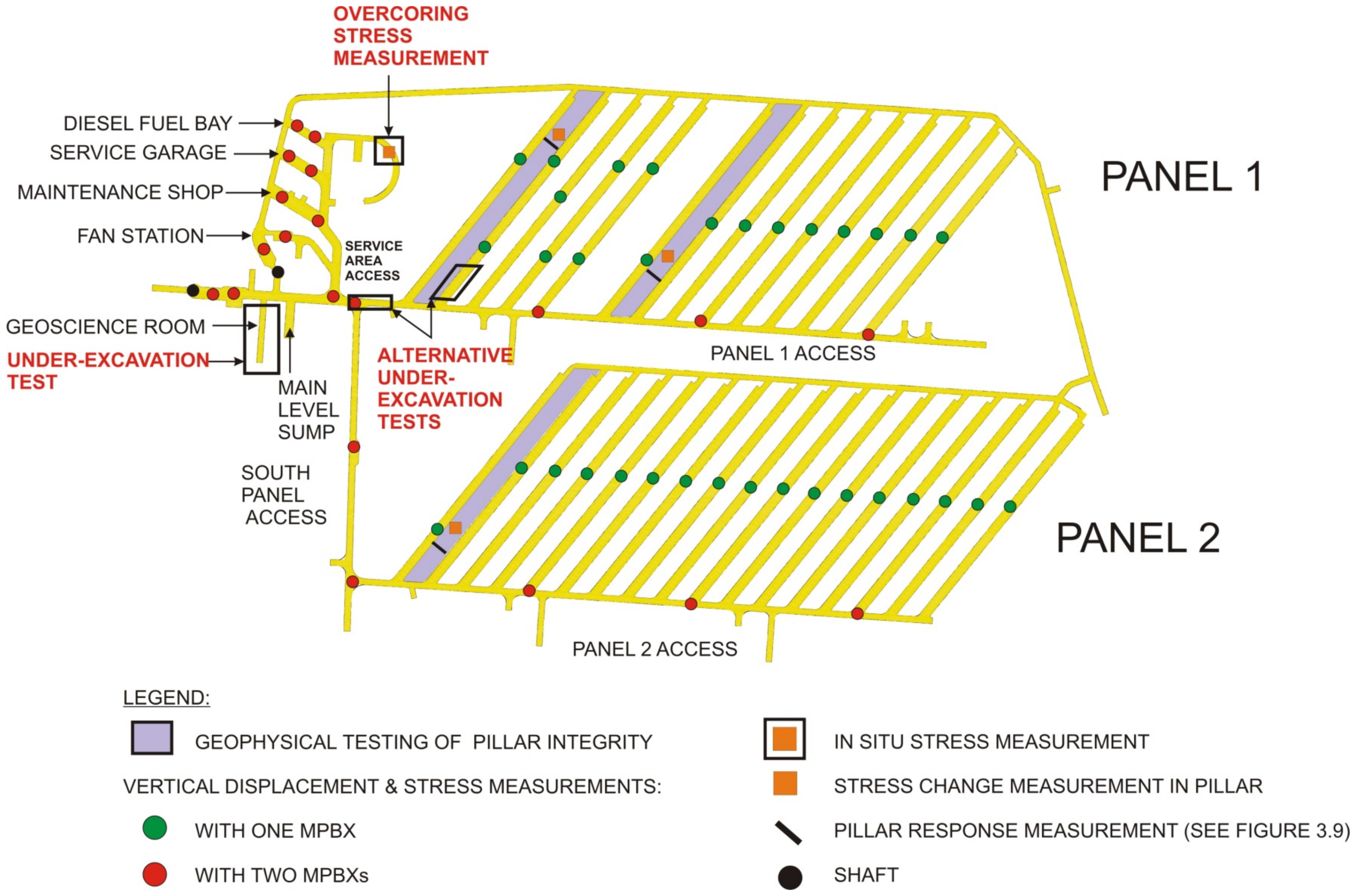


Figure 3.7: Plan View of Underground Repository Showing Location of Verification Activities

3.3.2 Geological Characterization

3.3.2.1 Geologic Mapping

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

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

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

3.3.2.2 Geophysical Testing of Pillar Integrity

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

3.3.2.3 Seepage Water Collection

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

3.3.3 Excavation Response

3.3.3.1 Excavation Deformation Measurement

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

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

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

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

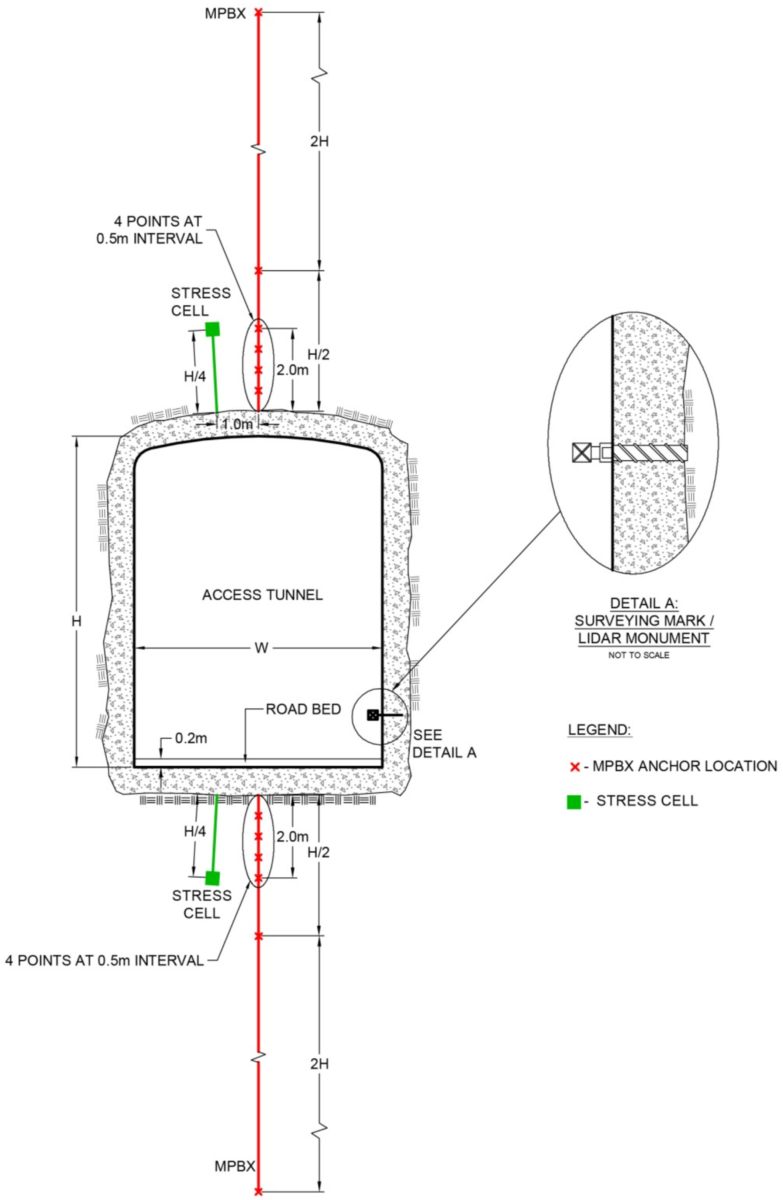


Figure 3.8: Typical Instrumentation Array in Access Tunnels

Table 3.3: Summary Instrumentation Arrays on Repository Level

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

3.3.3.2 Geomechanical Testing

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

3.3.3.3 Laser Profiling

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

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

3.3.3.4 Pillar Response Measurement

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

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

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

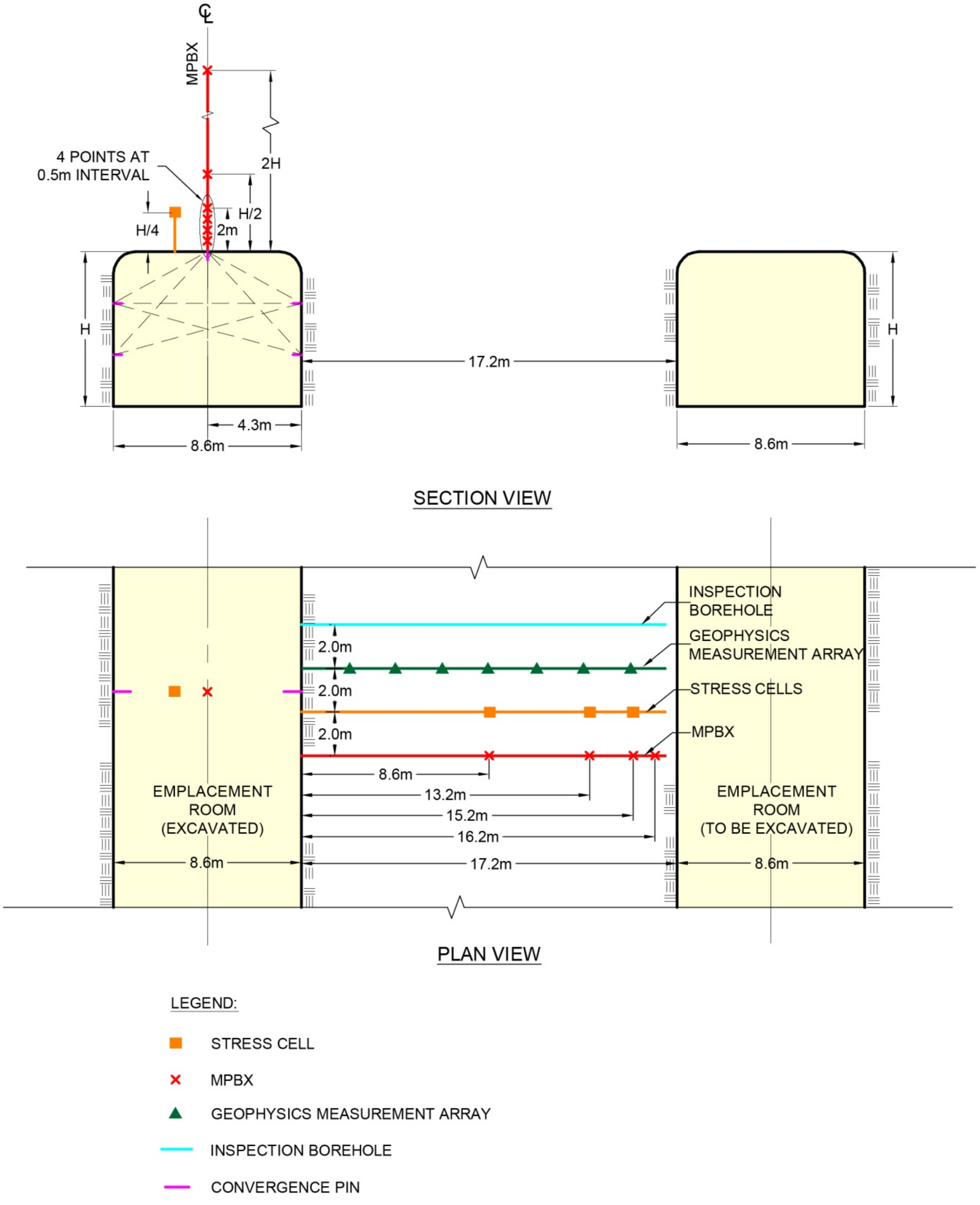


Figure 3.9: Arrangement of Boreholes and Instruments for Pillar Response Measurements

3.3.4 In Situ Stresses

3.3.4.1 Overcoring Stress Measurements

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

3.3.4.2 Under-excavation Test

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

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

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

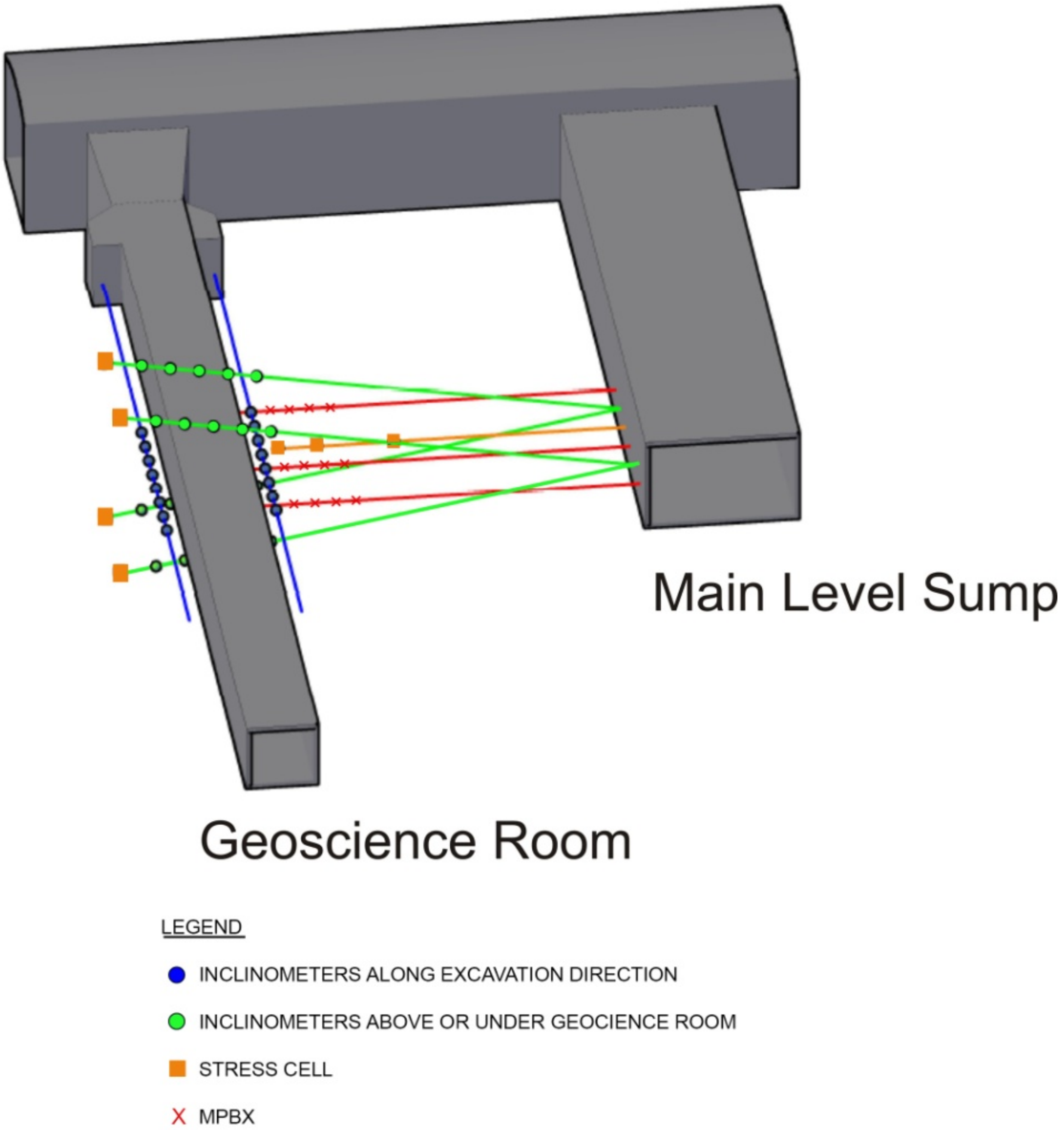
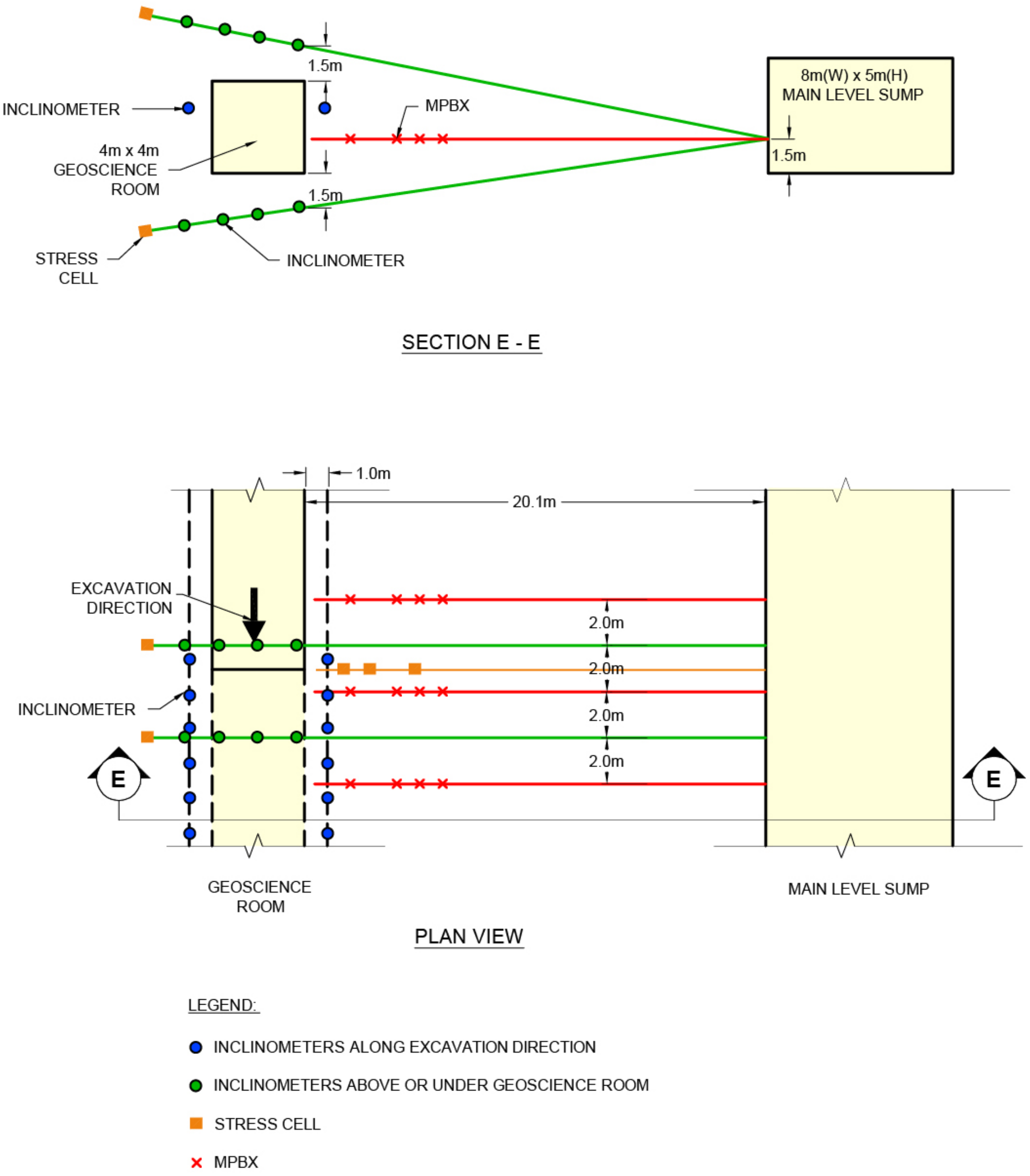


Figure 3.10: Isometric View of the Under-excavation Test



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

Figure 3.11: Under-excavation Test

4. VERIFICATION OF GEOSCIENCE PARAMETERS FOR THE SAFETY CASE

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

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

4.1 Key Geoscience Parameters

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

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

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

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

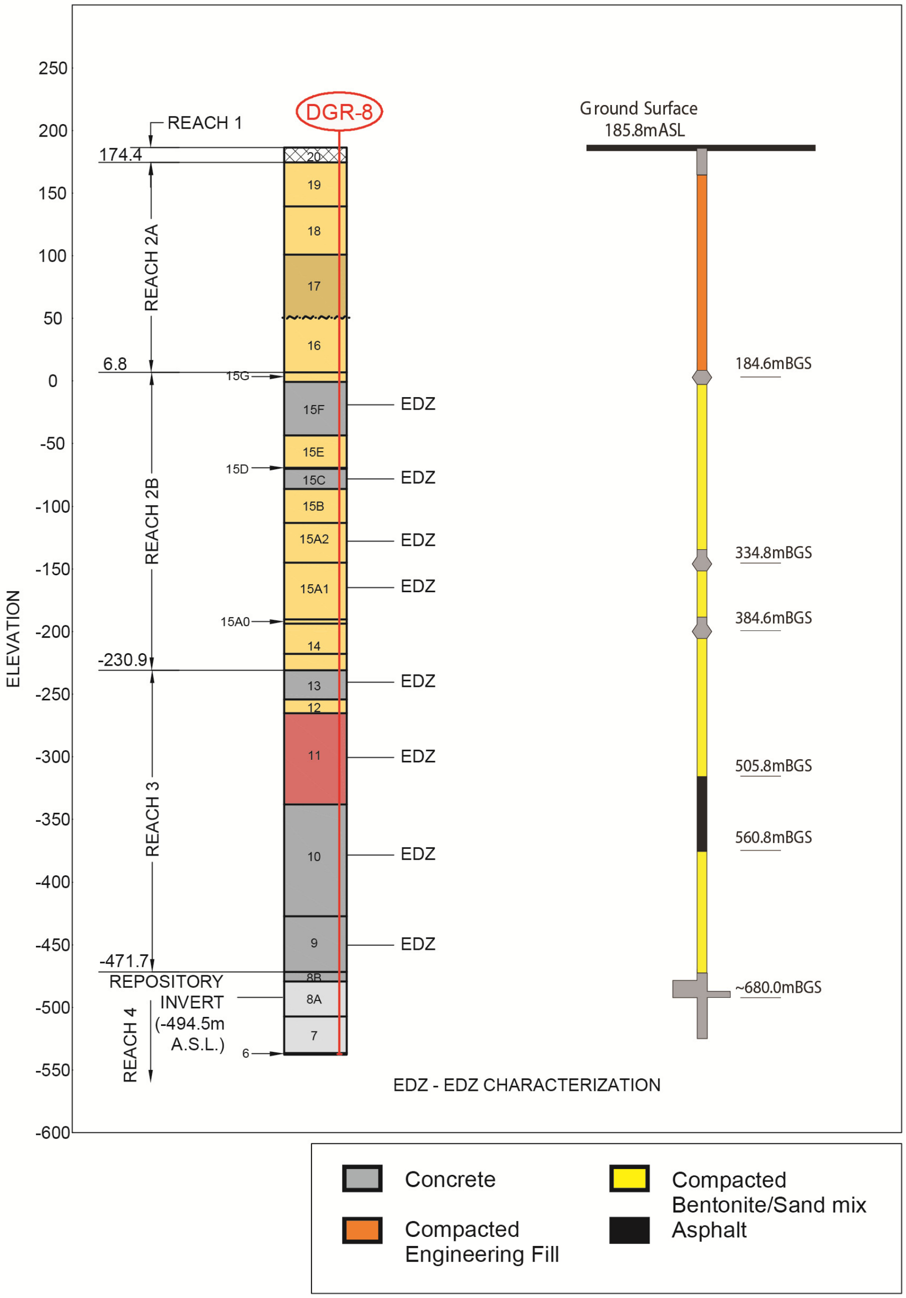
Note: (1) Unless otherwise stated activity occurs in both Main Shaft and Ventilation Shaft during shaft sinking

4.2 Shaft Sinking

4.2.1 Shaft Seal Design

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

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



NOTES

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

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

4.2.2 Layout of Investigation Activities

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

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

4.2.3 Geological Characterization

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

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

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

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

4.2.4 EDZ Characterization

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

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

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

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

4.2.4.1 Geophysical Testing

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

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

4.2.4.2 Core Retrieval

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

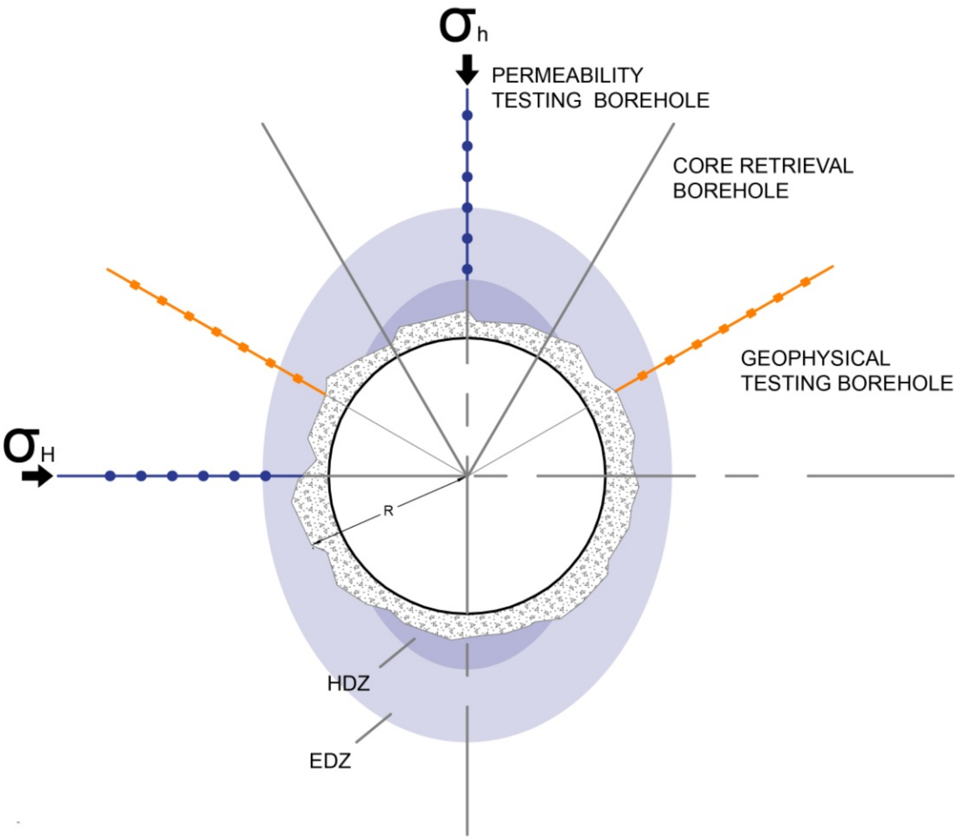


Figure 4.2: Proposed Borehole Configuration for EDZ Characterization

4.2.4.3 Permeability Measurement

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

4.2.5 Excavation Response

4.2.5.1 Excavation Deformation Measurement

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

4.2.5.2 Geomechanical Testing

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

4.2.5.3 In Situ Stress Measurement

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

4.2.6 Sealing Material Tests

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

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

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

4.3 Lateral Development

4.3.1 Layout of Investigation Activities

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

4.3.2 Geological Characterization

4.3.2.1 Geological Mapping

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

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

4.3.2.2 Geophysics

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

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

4.3.2.3 Seepage Water Collection

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

4.3.3 EDZ Characterization in Cobourg Formation

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

4.3.4 Excavation Response

4.3.4.1 Excavation Deformation Measurement

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

4.3.4.2 Geomechanical Testing

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

4.3.5 Geochemical and Microbiological Characterization

4.3.5.1 Fracture Infill Mineral Studies and Dating

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

The studies will be completed during the repository development phase.

4.3.5.2 Multi-phase Flow Study

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

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

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

4.3.5.3 Long-term Diffusion Test

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

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

4.3.5.4 Microbiology Related Study

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

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

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

4.3.6 DGR Sealing Material Performance Test

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

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

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

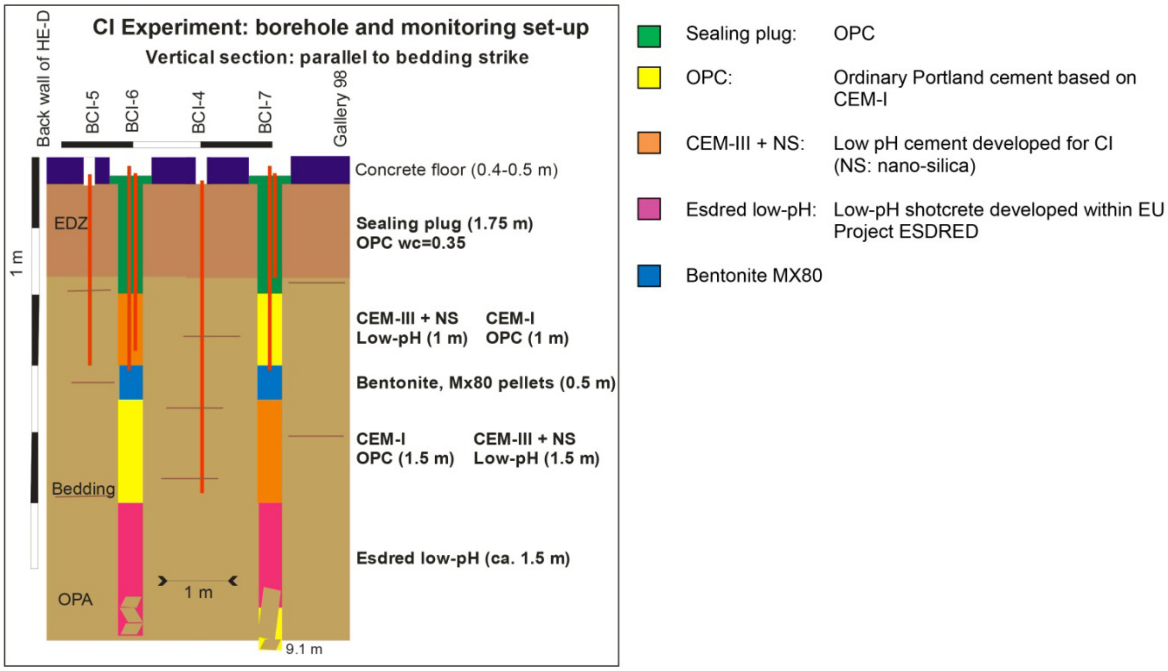


Figure 4.3: Mont Terri CI Experiment Concept and Layout in Opalinus Clay

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6. ABBREVIATIONS AND ACRONYMS

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