OPG's DEEP GEOLOGIC

# REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

## Geoscientific Verification Plan

March 2011

Prepared by: Nuclear Waste Management Organization

NWMO DGR-TR-2011-38

NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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**Document History**

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## EXECUTIVE SUMMARY

The Nuclear Waste Management Organization (NWMO), on behalf of Ontario Power Generation (OPG), is managing the development of a proposed Deep Geologic Repository (DGR) at the Bruce nuclear site in the Municipality of Kincardine, Ontario for the long-term management of Low and Intermediate Level Waste (L&ILW) from OPG owned or operated nuclear generating facilities. As envisioned the shaft accessed DGR would be constructed as an engineered facility comprising a series of access tunnels and 31 underground emplacement rooms at a nominal depth of 680 m below ground surface within the low permeability limestone of the Ordovician age Cobourg Formation.

A Geoscientific Site Characterization Plan (GSCP) initiated in 2006 by OPG has obtained site and regional data on relevant aspects of geology, geomechanics, hydrogeology, geochemistry and seismicity. 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. All DGR-series boreholes were located outside the DGR footprint. The GSCP results provide strong evidence at the repository horizon that the hosting and enclosing rock mass provide a significant barrier, which will contribute to the safe long-term containment and isolation of the L&ILW.

This report describes a Geoscientific Verification Plan (GVP) that is intent on gathering additional geoscientific information to confirm sub-surface geologic and geotechnical conditions, as understood from surface based studies, during vertical and lateral development of the DGR. These studies are primarily focused on the collection of geoscientific data to: i) support engineering decisions and DGR design; and ii) support the DGR safety case, prepared to subsequently support a future application to obtain an operating licence for the DGR.

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# 1. INTRODUCTION

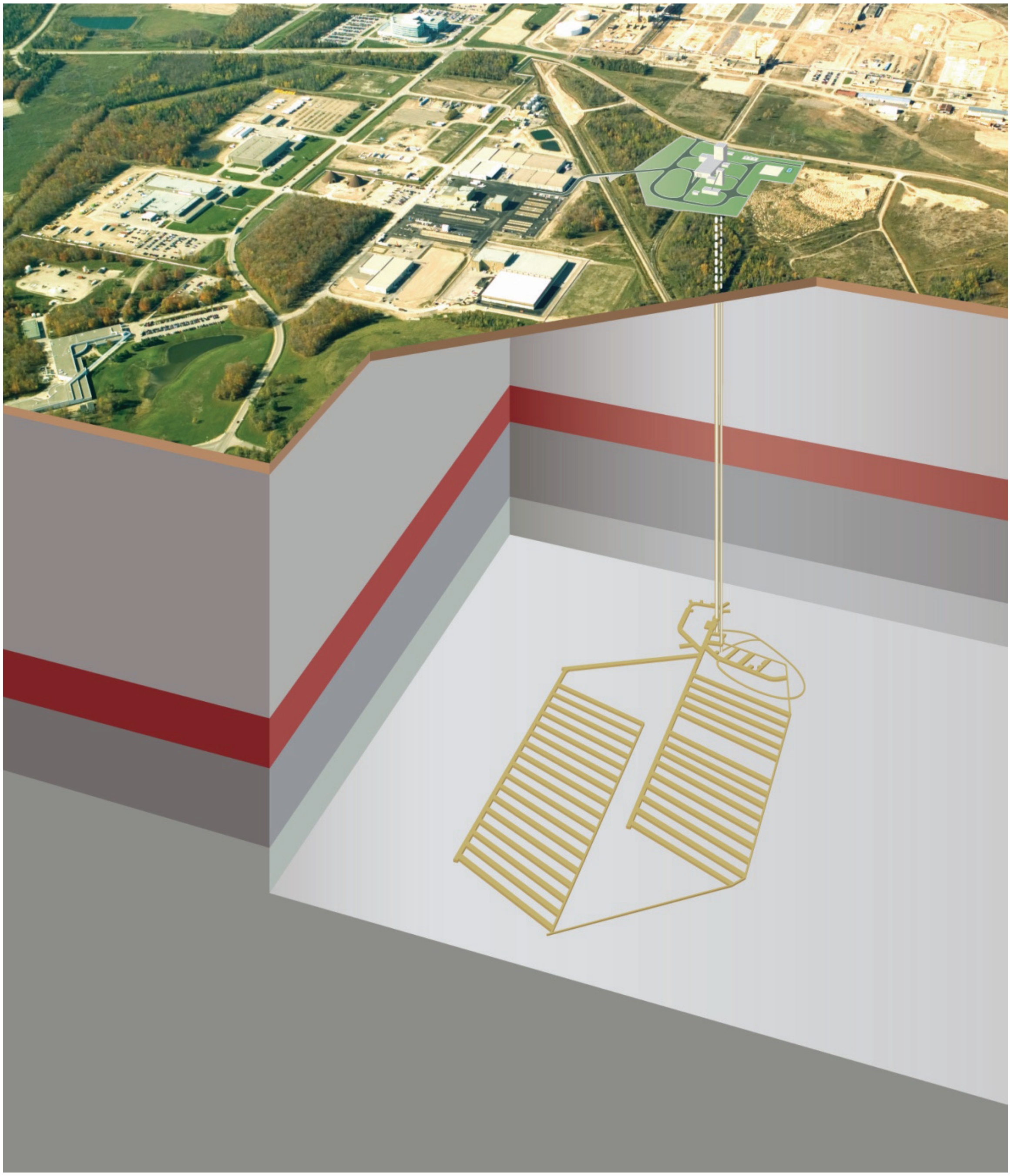
Ontario Power Generation (OPG) is proposing the development of a Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Waste (L&ILW) from OPG owned or operated nuclear generating facilities. The proposed DGR would be located on the Bruce nuclear site located approximately 225 km northwest of Toronto on the eastern shore of Lake Huron in the Municipality of Kincardine, Ontario. The site is underlain by an approximate 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 m. The Cobourg Formation is overlain by 200 m of shale-dominated upper Ordovician sediments. An artist's rendering of the proposed DGR is shown in Figure 1.1.

A key aspect of the DGR safety case is the integrity and long-term stability of the sedimentary sequence to contain and isolate L&ILW at timeframes relevant to repository safety. Early in the project, geoscientific studies that considered regional and site-specific public domain data sets indicated favourable geologic conditions for implementation of the DGR concept. In 2005, OPG initiated a process to develop a Geoscientific Site Characterization Plan (GSCP) (INTERA[1] 2006, INTERA 2008) that would guide further site-specifc exploration and assessment of the Bruce nuclear site to confirm it's suitability for implementation of the DGR concept.

Site-specifc 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 pre-existing 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. All borings are located outside the planned footprint of the underground repository. The results of all studies are documented in the Descriptive Geosphere Site Model (INTERA 2011) and synthesized with regional data in the DGR Geosynthesis (NWMO 2011). The DGR layout illustrating shaft, access tunnel and emplacement room locations and dimensions are described in the DGR Preliminary Safety Report (OPG 2011).

The surface-based geoscientific investigations conducted as part of the DGR project have provided strong evidence that the far-field bedrock proposed to host and enclose the DGR would provide multiple barriers to safely contain and isolate the L&ILW. The purpose of this report is to describe a series of planned geoscientific investigations to be performed during vertical and horizontal DGR development that are intent on verifying sub-surface conditions. The proposed investigations focus on gathering information necessary to further assess and demonstrate DGR safety and confirm DGR engineering design and layout. Among others, the proposed investigations would include the characterization of the Excavation Damaged Zone (EDZ), in situ rock stress measurements, bedrock formation permeabilities, diffusion properties, and hydrogeochemical and microbiological conditions. These studies are primarily focused on the collection of geoscientific data to: i) support engineering decisions and DGR design; and ii) support the DGR safety case, prepared to subsequently support a future application to obtain an operating licence for the DGR. All studies will be conducted in accordance with the NWMO Project Quality Plan (NWMO 2010).

[1] Currently known as Geofirma Engineering Ltd.



Note: Figure from OPG (2011).

**Figure 1.1: Proposed Layout of the DGR below the Bruce Nuclear Site**

# 2. VERIFICATION ACTIVITIES

The subsurface activities are subdivided into two major sections: 1) activities associated with the sinking of the vertical main and ventilation shafts (Lucas Formation (dolostone) to the Kirkfield Formation (limestone)); and 2) lateral development activities associated with the excavation of access tunnels, emplacement rooms and other openings at the repository horizon in the Cobourg Formation. Verification activities proposed in this plan may need to be revised based on experience gained in the execution of the plan.

## 2.1 Shaft Sinking

### 2.1.1 Shaft Sinking Operation

The shaft sinking will be carried out using controlled drill and blast techniques that are designed to minimise rock damage. The bedrock stratigraphy at the location of the shafts is shown in Figure 2.1. Both the main access and ventilation shafts, situated nominally 80 m apart, will be sunk simultaneously through the sequence of dolostones, limestones and shales. The finished diameter of the proposed concrete lined main and ventilation shafts through the bedrock sequence is 6.5 m and 5 m, respectively (OPG 2011).

### 2.1.2 Activities

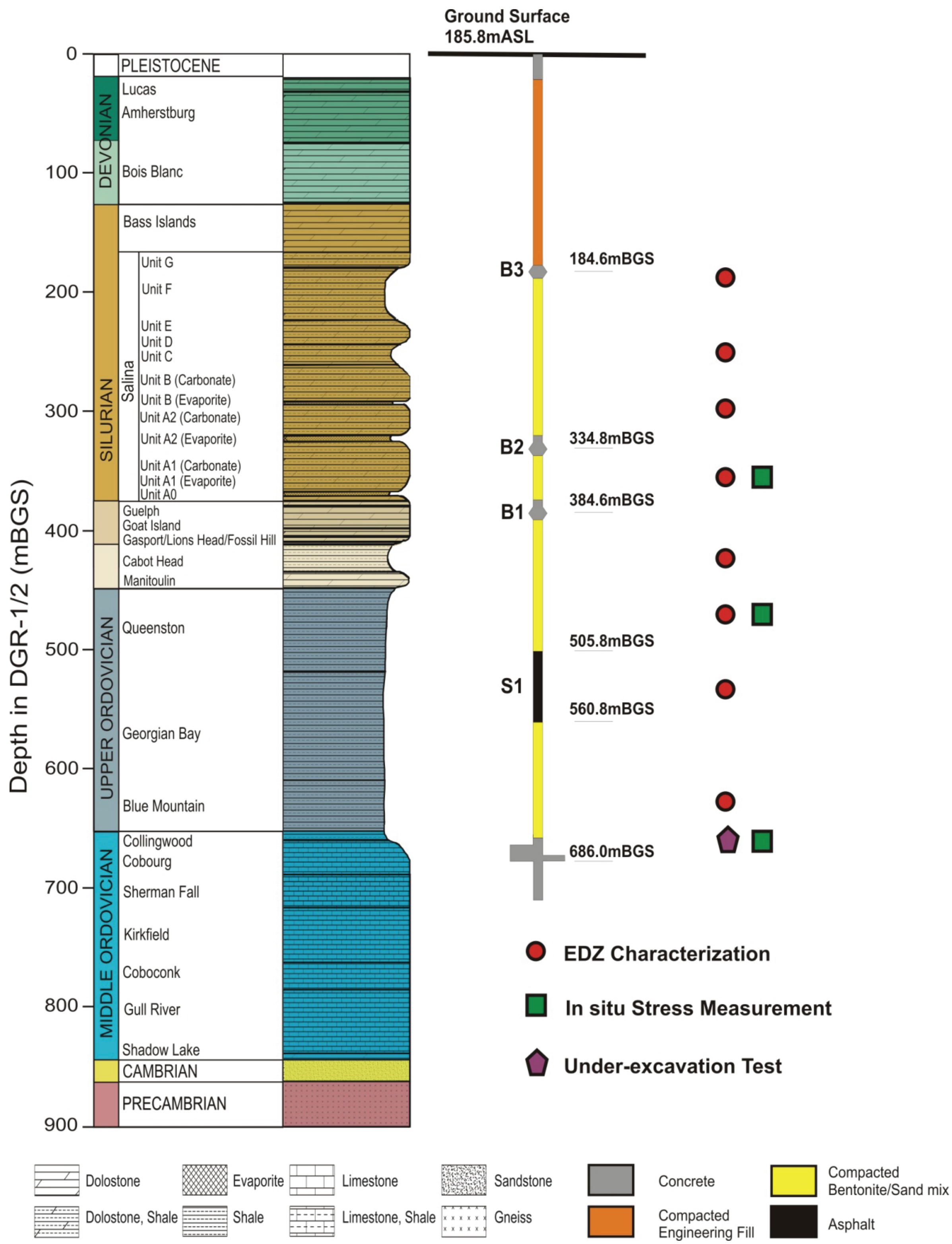
The location and type of geoscientific verification activities were determined, in part, on the proposed shaft seal design (OPG 2011). The general arrangement of the proposed shaft seals and selected station locations for verification studies are shown in Figure 2.1. These stations were selected to allow testing within a range of rock types, strengths and in situ stress conditions relevant to shaft seal performance. Testing will be performed at a minimum of 4 of the 8 locations shown in Figure 2.1. Depending on the shaft environment, specific areas for instrumentation will be prepared or constructed by the shaft sinking contractor as instructed by the Geologist/Engineer during excavation prior to the installation of the concrete shaft liner. Cleaning with air or water jetting or grouting of finished surfaces might also be required. The contractor is responsible for providing safe temporary access with sufficient lighting, for the testing, installation and monitoring of instruments. Tables 2.1 and 2.2 provide a description of all proposed geoscientific verification activities, including their rationale.

### 2.1.3 Geological Characterization

#### 2.1.3.1 Activity 1 – Geologic Mapping

During shaft sinking, geological mapping will be carried out in cycles continuously along the entire shaft wall to provide a complete record of lithology and structure. High resolution systematic overlapping still images of all shaft walls will be obtained. These images will be used as templates for geological mapping.

A computer-controlled automatic scanning laser profiler will be used to obtain a precise image and profile of the shaft walls. Still digital camera images may be utilized with the help of software, such as 3DMCalibCam or ShapeMetriX3D, to supplement this information. All image recording devices can be lowered from the working platform of the shaft sinking cage at a fixed position for recording.




Note: Figure modified from NWMO (2011).

**Figure 2.1: Proposed Shaft Seal Configuration and General Arrangement of Station Locations for Verification Program**

**Table 2.1: Summary of Geoscientific Verification Activities during Shaft Sinking**

| | Activity | Description | Rationale |
|---|---|---|---|
| Geological Characterization | 1. Mapping | Geological mapping and imaging shaft walls | To verify DGR borehole information on lithology, stratigraphy and structure, to characterize the rock mass and to provide a permanent record of rock type, structure and quality throughout the sedimentary sequence. |
| EDZ Characterization | 2. Geophysics | Ultrasonic velocity measurement<br>ATV and/or OTV inspection | To characterize and verify the radial extent of the EDZ as predicted by numerical simulation and to gain knowledge of EDZ evolution. |
| | 3. Core retrieval | Coring or overcoring to retrieve rock samples | To characterize the EDZ and verify the radial extent predicted in numerical analysis. Limited deformation modulus measurements will be conducted to determine the mechanical properties within the EDZ. |
| | 4. Permeability measurement | Packer testing and pressure monitoring | To characterize EDZ with respect to permeability distributions. |
| | 5. Acoustic Emission (AE) monitoring | AE measurements in pilot holes prior to conducting the under excavation test in the Cobourg Formation | To verify EDZ lateral/radial extent in Cobourg Formation. |
| Excavation Response | 6. Excavation deformation measurement | Monitor rock response of shaft immediately after excavation using multi-point borehole extensometers and convergence point arrays | To monitor the rock mass response due to excavation necessary to confirm DGR excavation design and modify/optimize shaft lining design as required. |
| | 7. In situ geomechanical testing | Conduct in situ geomechanical tests to determine properties at field scale | To confirm up-scaling of laboratory derived geomechanical properties. |

| | Activity | Description | Rationale |
|---|---|---|---|
| In Situ Stresses | 8. In situ stress measurement | Overcoring using USBM gauges in boreholes oriented in orthogonal directions | To verify estimates of in situ stress (magnitude/ direction) necessary for design verification and layout modification as required. |
| | 9. Under-excavation Test | Monitor rock response during excavation using strain gauge type inclinometers and stress change cells in pilot holes sub-parallel to excavation opening | To verify assumed in situ stress conditions in the Cobourg Formation that were used in the design of openings at repository level and allow layout modification as required. |

**Table 2.2: Summary of Activities Relative to Rock Formations**

| Rock Formation | Thk. (m) | Top of Formation (mBGS) | Activity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | EDZ | | | | Rock Response | | In Situ Stress | |
| | | | 1. Mapping | 2. Geophysics | 3. Core Retrieval | 4. Permeability Measurement | 5. AE Monitoring | 6. Excavation Deformation Measurement | 7. In Situ Geomechanical Testing | 8. Overcoring Stress Measurement | 9. Under-excavation Experiment |
| All formations | ~680 | | ■ | | | | | ■ | | | |
| Salina F | 43 | 179 | | ■ | ■ | ■ | | | | | |
| Salina C | 15 | 245 | | ■ | ■ | ■ | | | | | |
| Salina A-2 (Carb.) | 28 | 293 | | ■ | ■ | ■ | | | | | |
| Salina A1 | 40 | 326 | | ■ | ■ | ■ | | | | ■ | |
| Cabot Head | 24 | 411 | | ■ | ■ | ■ | | | ■ | | |
| Queenston | 73 | 448 | | ■ | ■ | ■ | | | ■ | ■ | |
| Georgian Bay | 89 | 518 | | ■ | ■ | ■ | | | ■ | | |
| Blue Mountain | 41 | 609 | | ■ | ■ | ■ | | | ■ | | |
| Cobourg | 36 | 652 | | | | | ■ | | | ■ | ■ |

■ (dark) Geoscience Verification Activity

(yellow) Horizons employed by EDZ Characterization

Note: Minimum of 4 stations selected for EDZ characterization.

Detailed geological mapping is required to verify rock mass characteristics, bedding plane thickness and distribution, stratigraphy, lithology, discontinuities and structure. 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. 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 allowing optimization of ground support and lining design. Suitable specimens of fracture infill materials will be collected, if possible, for fluid inclusion, mineralogy, mineral chemistry, and age dating (if possible). Any petroliferous zones will be described, imaged and sampled for possible testing. The shafts will be monitored for possible gas emission.

Horizon: All bedrock formations (Lucas to Kirkfield)

#### 2.1.4 EDZ Characterization

##### 2.1.4.1 Activity 2 – Geophysics

Geophysical measurements will be carried out at proposed seal locations (Figure 2.1) to characterize the EDZ. Ultrasonic velocity or other suitable geophysical methods will be used in 10 m long radial boreholes (Activity 3) to characterize the EDZ fractures and to correlate with hydraulic properties measured at adjacent boreholes. It is understood from the long-term shaft seal analysis (ITASCA 2011) that a majority of the EDZ will develop soon after the excavation or at the early stage of the facility life cycle. The extent of the EDZ around the shaft is not anticipated to change unless the stress condition around the shaft and shaft dimension(s) change. Based on this knowledge, the geophysical measurements should be performed soon after the completion of shaft excavation to best capture evolution of the EDZ. Depending on the site and access conditions, consideration will be given to permanently grouting the instruments in these boreholes after the initial testing to facilitate extended monitoring.

Recess panels in the shaft concrete liner and temporary accesses will be required to perform measurements at selected elevations. This activity will be conducted in conjunction with Activities 3 and 4 (below).

Prior to any testing and instrumentation, all boreholes in Activities 2, 3 and 4 will be inspected using a borehole camera (Optical Televiewer) and/or Acoustic Televiewer.

The proposed radial configuration of boreholes at a shaft testing horizon is illustrated in Figure 2.2.

##### 2.1.4.2 Activity 3 – Core Retrieval

Small diameter boreholes of 10 m in length will be drilled at selected locations along the shaft for the investigation of the EDZ at the perimeter of the shaft. A selection of these holes will be grouted with epoxy 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 and the extent of the EDZ. The characterization of EDZ may also include deformation modulus measurements to dertermine the variations in the rock property at various distances from the shaft wall at the test horizons.

Horizon: At or adjacent to seal locations (in Salina F, C, A2, A1, Cabot Head, Queenston, Georgian Bay and Blue Mountain formations)

This activity will be conducted in conjunction with Activities 2 and 4. Access to test locations will be the same as in Activity 2.

Horizon: At or adjacent to seal locations (Salina F, C, A2 and A1, Cabot Head, Queenston, Georgian Bay and Blue Mountain formations)

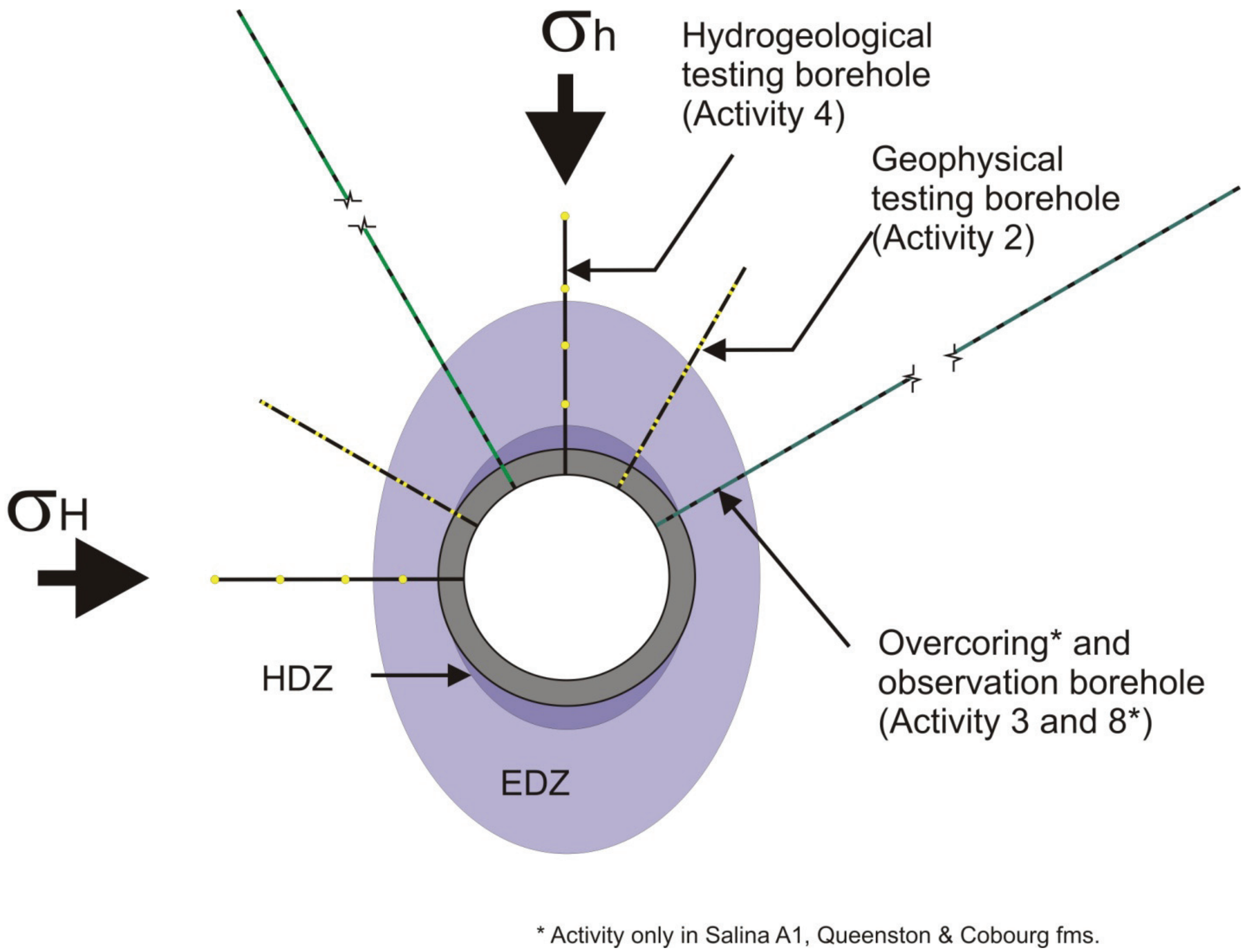



**Figure 2.2: Proposed Borehole Configuration for EDZ Investigation(s)**

#### 2.1.4.3 Activity 4 – Permeability Measurement

Measurements will be conducted in dedicated boreholes, 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. This activity will be conducted in conjunction and at the same location as Activities 2 and 3.

Horizon: At or adjacent to seal locations (in Salina F, C, A2, A1, Cabot Head, Queenston, Georgian Bay and Blue Mountain formations)

#### 2.1.4.4 Activity 5 – Acoustic Emission Monitoring

If feasible, Acoustic Emission (AE) sensors will be installed at selected locations in front of the excavation face to monitor AE activity during shaft sinking. Small diameter steeply inclined boreholes would be drilled in front of the advancing face. AE sensors and the deformation instruments (Activity 9) would be positioned in these boreholes to measure the rock response to excavation. This activity is to verify the extent and geometry of the EDZ. This activity would be carried out in conjunction with the under-excavation test described as part of Activity 9.

Horizon: Cobourg Formation

### 2.1.5 Excavation Response

#### 2.1.5.1 Activity 6 – Excavation Deformation Measurement

Routine ground control monitoring will be used to verify the predicted behaviour of the rock mass around the shafts during and after excavation. Multi-point borehole extensometers (MBPX), convergence point arrays (non-tape measuring type) and load cells could be installed during and after shaft sinking to monitor any time dependent shaft wall displacements (Figure 2.3). MBPX would monitor convergence of the shaft behind the excavated face at selected depths. The relative displacement along the excavated wall will be monitored using anchor points installed at various locations along the shaft wall. The MPBX and load cells, with possible remote connection at selected horizons, can be used to monitor shaft stability and observe excavation response.

Horizon: At multiple intervals consistent with requirement for routine ground control monitoring.

#### 2.1.5.2 Activity 7 – In Situ and Other Geomechanical Testing

The up-scaling of laboratory derived rock mass properties to field scale requires consideration of heterogeneity, anisotropy and the inelasticity of the rock mass. The strength and stiffness of the rock mass used in the shaft stability analysis were primarily derived from the uniaxial compression test results performed on 75 mm diameter vertically oriented core samples.

Shaft sinking provides an opportunity to verify the up-scaling assumptions in the numerical simulations by collecting block samples of intact rock and of joint/bedding features for large scale laboratory testing.

Horizon: Cabot Head, Queenston, Georgian Bay and Blue Mountain formations.

Measurement: Selected period during or after shaft sinking

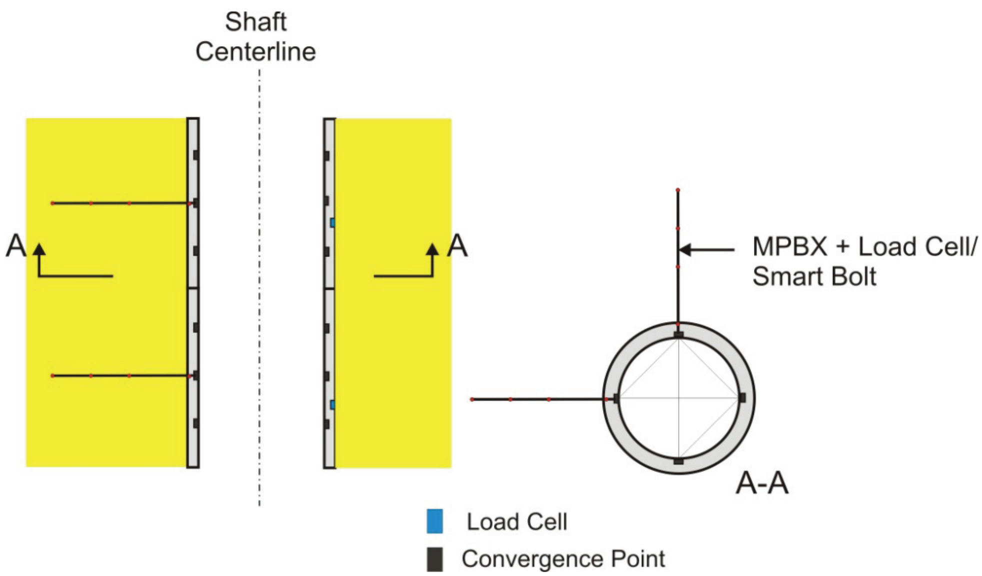



**Figure 2.3: Proposed Configuration of Deformation Array in Shaft**

### 2.1.6 In Situ Stress

#### 2.1.6.1 Activity 8 – In Situ Stress Measurement

Overcoring in situ stress measurements using USBM gauges will be carried out at four selected horizons, one each in the Salina A1 and Queenston formations and two in the Cobourg Formation (2 sets of tests in the Cobourg, one slightly below the Collingwood Member and the other at the repository horizon). At each horizon, two boreholes will be drilled in orthogonal directions approximately 25 m to extend beyond the zone of stress re-distribution. Five tests are planned in each borehole at various distances from the shaft wall for the determination of the stress tensor. A strain gauge type inclusion stress cell will be installed at the end of each overcoring hole in the Queenston Formation and possibly near the Collingwood Member depending on in situ rock conditions. An adjustment of the testing arrangement will be needed to combine the under-excavation test and overcoring in the Cobourg Formation.

Horizon: Salina A1, Queenston and Cobourg (2 testing horizons) formations

#### 2.1.6.2 Activity 9 – Under-excavation Test

Up-scaled rock mass parameters in the disturbed zone and in situ stress will be verified during shaft sinking using the under-excavation technique (Figure 2.4). A number of instrumented pilot holes with deformation strain gauge type inclinometers will be drilled in advance of the shaft excavation in the Cobourg Formation. At the end of the selected pilot holes, stress change cells will be installed. Rock mass response will be measured and analyzed to confirm the rock mass modulus. The rock deformation measured as the shaft advances can then be back-analyzed to estimate in situ stresses at this instrumented horizon. This in situ stress estimate will be compared with overcoring measurements described in Activity 8.

This activity could be conducted in conjunction with Activity 5 provided the rock in the test stratum is sensitive to AE signal transmission.

Horizon: Cobourg Formation (including Collingwood member)

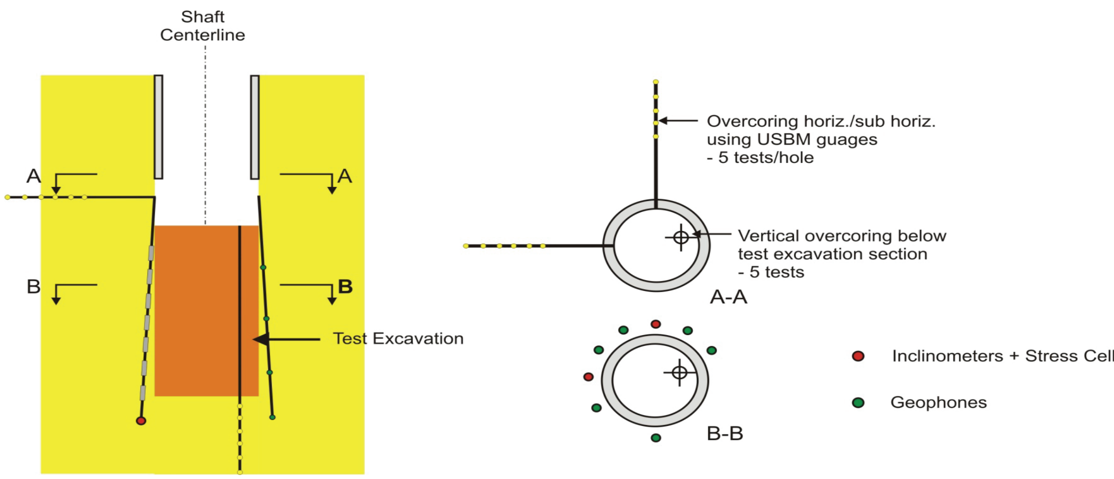



**Figure 2.4: Under-excavation Test**

## 2.2 Lateral Development

To verify the rock mass parameters of the Cobourg host rock used in the engineering design and the long-term stability analysis, a comprehensive subsurface investigation program is proposed during the DGR lateral development. Similar to the shaft investigation, specific areas, and test stations for instrumentation and in situ testing will be prepared or constructed by the contractor as instructed by the Geologist/Engineer during the excavation. Area preparation will likely be required during the instrumentation stage. Temporary access to instrumented areas will be needed for the testing, installation and monitoring of instruments during and after the lateral development.

### 2.2.1 Excavation Sequence

Controlled drill and blast will be used for lateral development. A rock dump at the repository level will be used to channel excavated rock into a loading pocket located near the base of the ventilation shaft. From there, the excavated rock will be removed up through the ventilation shaft to surface. Rock support may be required between advance lengths in the DGR. In some areas requiring large room heights, heading and benching may be required to allow support of the roof during the heading excavation while it is practical and efficient to access prior to benching the excavation to full height.

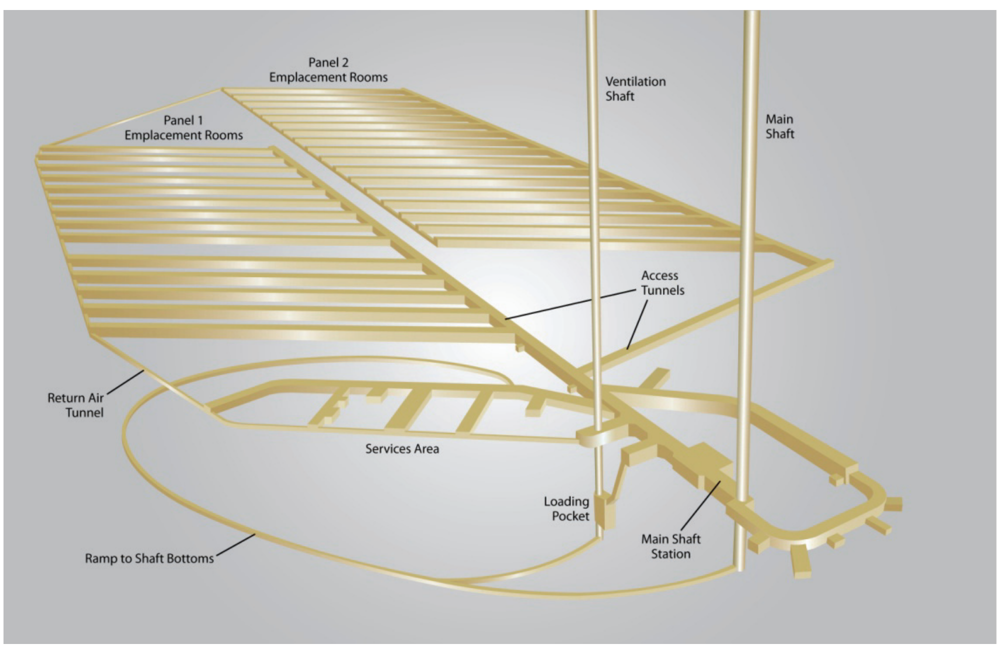
### 2.2.2 Repository Panel Layout

The underground layout of the repository includes two vertical shafts. In the vicinity of the shafts are facilities included offices, a workshop, wash bay, refuge stations, lunch room and a geotechnical laboratory. A main access tunnel is driven from the main shaft station to the east, passing the ventilation shaft and then proceeding towards the emplacement room panels. The overall underground arrangement enables all underground infrastructure to be kept in close proximity to the shaft, while keeping the emplacement areas away from normally occupied and high activity areas (OPG 2011).

There will be two panels of emplacement rooms. 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 (Figure 2.5). The emplacement rooms are all aligned with the reasoned major principal horizontal in situ stress direction in the lower member of the Cobourg Formation (i.e., east-north-east) and may be subject to modification depending on the results of the proposed sub-surface in situ stress measurements.

The proposed design incorporates 31 emplacement rooms, of which 17 are identical in cross-section (7.0 m high, 8.6 m wide) and will be dedicated to the ‘standard-type’ LLW (bins and racks). All rooms are nominally 250 m in length, but the widths and height of some rooms vary (5.8 – 7.2 m high, 7.4 – 8.6 m wide) to provide optimization of space dependent on the type, dimensions and stacking limitations of the various packages. All stated dimensions are norminal excavated dimensions to be confirmed during next stage of design. Panel 1 will have 14 rooms and Panel 2 will have 17 rooms. The width of rock pillars between parallel emplacement rooms has been established to be at least twice the span of the emplacement rooms.

A summary of all the geoscientific activities and their rationale is provided in Table 2.3.




(Reference: OPG 2011)

**Figure 2.5: Isometric View of Underground DGR Level**

**Table 2.3: Summary of Verification Activities during Lateral Development**

| | Activity | Description | Rationale |
|---|---|---|---|
| Geological Characterization | 1. Mapping | Geologic mapping and imaging (LIDAR) of all lateral and inclined openings | To verify DGR borehole information through rock mass characterization and to provide a permanent record of rock structure and quality and optimization of ground support design. |
| | 2. Geophysics | Seismic reflection survey in all emplacement rooms after excavation completion | To verify geologic structure below repository and across pillars. |
| | 3. Seepage water collection | Seepage collecting where possible (Cobourg, Sherman Fall and Kirkfield) | To provide information on groundwater geochemistry. |
| EDZ Characterization | 4. Geophysics | Ultrasonic velocity measurement<br>ATV and/or OTV inspection | To characterize and to verify the EDZ lateral extent predicted in numerical analysis and to gain knowledge on the evolution of the EDZ. |
| | 5. Core and bulk sample retrieval | Coring or overcoring to retrieve rock samples. Also to obtain block samples (if possible) | To characterize and to verify the extent of EDZ predicted in numerical analysis and input parameters used within numerical modelling to allow further optimization of room geometries. Limited deformation modulus measurements will be conducted to determine the mechanical properties within the EDZ. |
| | 6. Permeability and hydraulic head measurement | Packer testing and pressure monitoring | To characterize the EDZ in term of rock permeability. |
| Excavation Response | 7. Excavation deformation measurement | Monitoring rock response of excavation openings | To verify the performance of excavation design and allow modification as required. |

| | Activity | Description | Rationale |
|---|---|---|---|
| | 8. LIDAR survey | Conduct high resolution 3-D laser scanning of excavated openings | To provide detailed profile of excavation openings for rock response monitoring and numerical modeling. |
| | 9. Geomechanical Property Up-scaling | Conducting geomechanical tests to determine properties at field scale | To verify previous assumptions and provide measurements for final design confirmation and provide a detailed permanent record of the underground excavation geometry. |
| Chemical and Microbiological Characterization | 10. Fracture infill mineral studies and dating (Cobourg, Sherman Fall and Kirkfield) | Collecting fracture in fill materials for mineral chemistry, fluid inclusion studies, analysis of stable isotopes, cathodoluminescence imaging and radiometric age dating | To verify characteristics of in fill materials and time of emplacement to support safety case. |
| | 11. Two-phase flow study | To characterize multi-phase (fluid-gas-oil) pore saturations and transport properties | To verify pore saturation and effective rock matrix permeability/solute transport properties. |
| | 12. Long-term diffusion Test | Long-term monitoring of dedicated boreholes in a secure location | To verify estimated rock matrix diffusion coefficients and support DGR safety case. |
| | 13. Microbiology related study | Characterization of microbial activity and influence on DGR performance. | To evaluate the occurrence and postclosure effects of microorganisms on geochemistry and gas generation within the DGR. |
| DGR Engineered Sealing Materials | 14. Sealing Materials Demonstration Test | In situ testing of DGR sealing material performance within boreholes. | To assess the performance materials used in engineered sealing systems in support of DGR safety case. |

### 2.2.3 Geological Activities

This section discusses subsurface investigation pertinent to lateral development. The program would consist of multiple geological, hydrogeological, geomechanical, geochemical and geophysical activities, as described in the following sections. Figure 2.6 shows the proposed layout of the repository and the location of proposed verification activities.

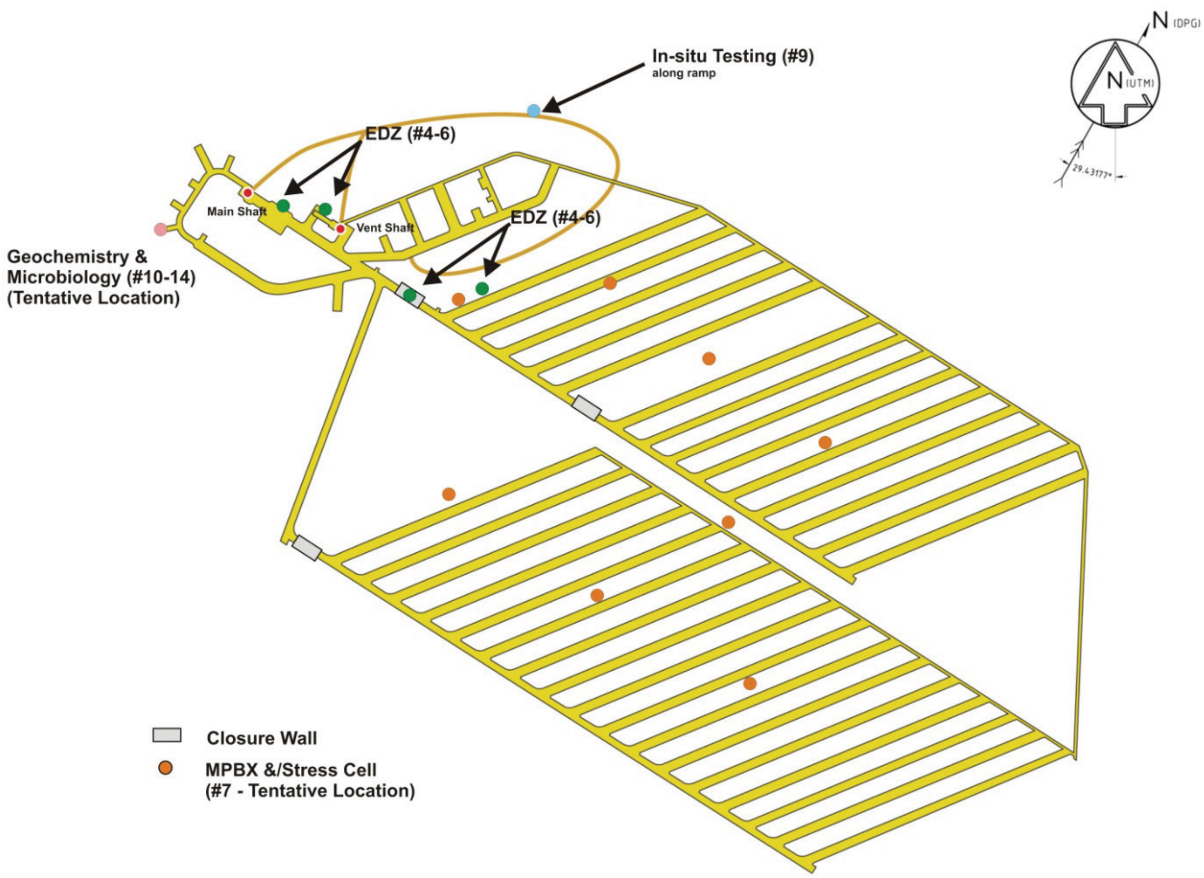



**Figure 2.6: DGR Layout Showing Location of Proposed Verification Activities**

### 2.2.4 Geological Characterization

#### 2.2.4.1 Activity 1 – Mapping

During lateral development, mapping will be carried out in cycles near the tunnel heading along all of the emplacement rooms, access tunnels and any other laterally excavated structure. High resolution systematic overlapping still images of all tunnel walls and crown will be obtained. These images will be used as templates for geological mapping.

A computer-controlled automatic scanning laser profiler will be used to obtain a precise image and profile of the tunnels. Still digital camera images may be utilized with the help of software, such as 3DMCalibCam or ShapeMetriX3D, to supplement this information. All imaging devices will be positioned at a fixed location along the tunnels for imaging.

Detailed geological mapping of lateral walls to verify rock mass characteristics, stratigraphy, lithology, discontinuities, structure and other rock conditions will be conducted during each excavation cycle/shift. Geological, geomechanical (rock mass behaviour) and any hydrogeological features will be observed, imaged, measured and recorded. Joint and bedding plane orientations, spacing and characteristics will be measured, analyzed and used to verify the structural stability of the underground openings. Suitable specimens of fracture infill materials will be collected for laboratory analysis. Any petroliferous zones will be mapped and described in detail, imaged and sampled for possible testing. All excavations will be monitored for possible gas emission.

Horizon: Cobourg, Sherman Fall and Kirkfield formations

#### 2.2.4.2 Activity 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 explore for potential features between room pillars, to characterize the configuration of the Precambrian surface below the DGR, and to identify any structural discontinuities present in the Precambrian basement.

Horizon: Cobourg Formation

#### 2.2.4.3 Activity 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 would be monitored.

Horizon: Cobourg, Sherman Fall and Kirkfield formations

### 2.2.5 EDZ Characterization

#### 2.2.5.1 Activity 4 – Geophysics

Geophysical measurements will be carried out at selected tunnel intervals (Figure 2.6) to characterize the EDZ in the vicinity of the shaft station. Ultrasonic velocity or other suitable geophysical methods will be used to characterize the EDZ fractures and to correlate with hydraulic properties. Prior to any testing and instrumentation, all boreholes in these activities will be inspected using a borehole camera (optical televiewer) and/or acoustic televiewer.

Horizon: Cobourg Formation

#### 2.2.5.2 Activity 5 – Core and Bulk Sample Retrieval

Small diameter short boreholes will be drilled at selected locations along the periphery of the seal locations in the access tunnels for the investigation of the EDZ. As in the shafts, these holes will be grouted with epoxy resin and a metal (or fiberglass) rod will be inserted.

Overcoring will be used to extract the resin filled zone for EDZ fracture analysis. The characterization of EDZ may also include deformation modulus measurements to dertermine the variations in the rock property at various distances from the shaft wall at the test horizons.

Horizon: Cobourg and Sherman Fall formations

In order to confirm the parameters used in the emplacement room stability and ground support requirement analysis, block samples of bedrock from selected locations may be obtained for large scale laboratory testing to determine the shear strength of specific discontinuities.

Horizon: Cobourg and Sherman Fall formations

#### 2.2.5.3 Activity 6 – Permeability and Hydraulic Head Measurements

A number of short boreholes will be drilled perpendicular to the access tunnel to characterize the EDZ. Hydraulic conductivity testing with a packer system will be conducted along these holes to determine the hydraulic properties of the zone. Core samples will also be collected from these holes.

Horizon: Cobourg and Sherman Fall formations

### 2.2.6 Excavation Response

#### 2.2.6.1 Activity 7 – Excavation Deformation and Stress Change Measurement

A number of deformation monitoring arrays will be established at selected locations along the access tunnels and the emplacement room panels as part of routine construction monitoring (Figure 2.7). These monitoring arrays shall consist of extensometers, convergence points and possible deflectometers. These instruments will be best accompanied by stress change cells to capture the behaviour of the excavation opening. These convergence points shall be in the form of thread bar with hook assembly grouted in the rock wall and should be installed in conjunction with MBPX arrays. The locations of the deformation array will be determined as the lateral development of the DGR progresses.

MBPX will be installed in the roof of selected emplacement rooms to monitor roof deformation.

Horizon: Cobourg Formation

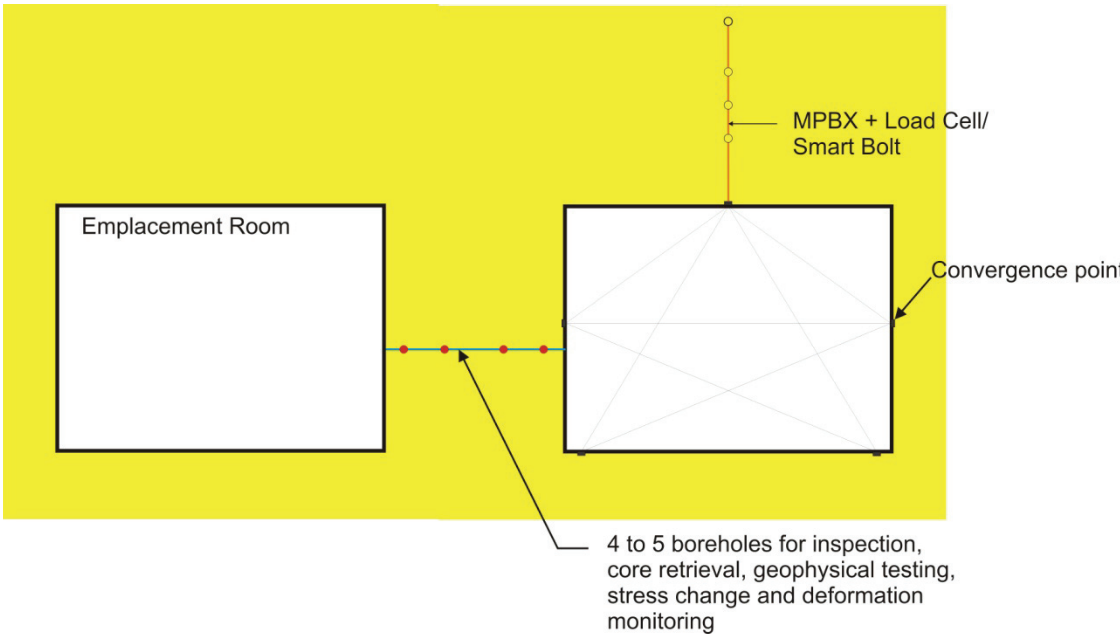



**Figure 2.7: Typical Deformation Monitoring**

#### 2.2.6.2 Activity 8 – LIDAR Survey

To optimize the length of time that a geologist spends mapping at the tunnel face and to obtain a detailed permanent record of the geometry of the excavated openings, 3-D laser scanning by means of the Laser Imaging Detection and Ranging (LIDAR) technique and high resolution digital photography will be performed to characterize the rock mass and to identify key structural features which affect the kinematic stability of the excavated opening. An attempt will be made with the 3-D survey to monitor the time dependent deformation of rock and any response resulting from the excavation of adjacent emplacement rooms by placing fixed mounts for the LIDAR equipment at specific locations to precisely re-survey these locations at various elapsed times after excavation. It is anticipated that the survey will be routinely carried out by the resident geological staff. The LIDAR data will also be processed and analyzed by an external specialist.

Horizon: Selected locations in Cobourg Formation

#### 2.2.6.3 Activity 9 – Geomechanical Property Up-scaling

Like the shaft stability analysis, the strength and stiffness of the rock mass input to the cavern stability analysis were derived from the results of uniaxial compression testing on 75 mm diameter core samples. Geomechanical testing involving large undisturbed volumes of the rock mass to obtain values of the modulus of deformation and other geomechanical parameters at a larger scale is needed to verify property up-scaling applied in repository design.

Horizon: Cobourg and Sherman Fall Formations

### 2.2.7 Geochemical and Microbiological Characterization

#### 2.2.7.1 Activity 10 – Fracture Infill Mineral Studies and Dating

Fractures with infill materials will be identified and mapped in the field during lateral development Activity 1. 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.

Horizon: Cobourg, Sherman Fall and Kirkfield formations

#### 2.2.7.2 Activity 11 – 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.

Horizon: Cobourg Formation

#### 2.2.7.3 Activity 12 – 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 would be conducted within a secure test area unaffected by DGR construction or operational activities.

Horizon: Cobourg Formation

#### 2.2.7.4 Activity 13 – 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 would be conducted within a secure test area unaffected by DGR construction or operational activities.

Horizon: Cobourg Formation

### 2.2.8 DGR Sealing Materials

#### 2.2.8.1 Activity 14 – Sealing Material Performance

In situ borehole testing of proposed DGR sealing materials, including bentonite-bentonite/sand mixtures, asphalt and low heat high performance concrete will be conducted within a secure test area niche at the repository level. The purpose of these tests is to demonstrate the long-term performance of these sealing materials in the highly saline, low permeability, low porosity rock mass setting. The borehole tests would be designed to demonstrate hydraulic, material interface and structural properties, as well as, chemical compatibility necessary to understand long-term sealing performance. Information gathered on the performance of sealing materials will be used to support the DGR safety case. Due to in situ conditions it is possible that full test completion may require monitoring beyond a future submission in support of an operating licence application.

Horizon: Cobourg Formation

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## 4. ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AE | Acoustic Emission |
| ANDRA | Agence Nationale pour la Gestion des Déchets Radioactifs (France) |
| ATV | Acoustic Televiewer |
| CSIRO | Commonwealth Scientific and Research Organization (Australia) |
| DGR | Deep Geologic Repository |
| EDZ | Excavation Damaged Zone |
| GSCP | Geoscientific Site Characterization Plan |
| 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 |