OPG's Deep Geologic Repository for Low & Intermediate Level Waste Preliminary Design Report

April 2010

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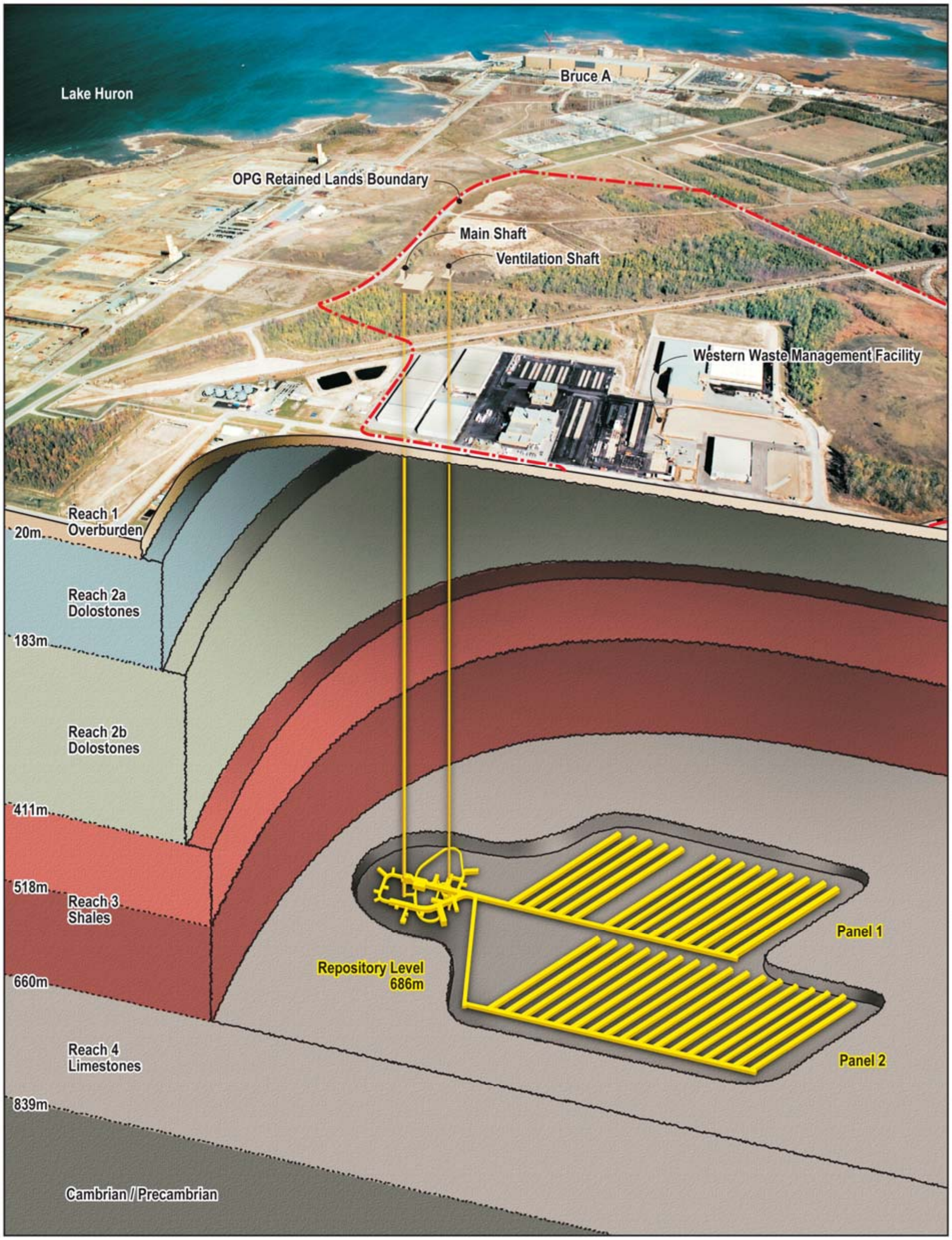
Preliminary Design Report



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Executive Summary

Currently Ontario Power Generation (OPG) manages between 5,000 to 7,000 m^3 of low and intermediate level radioactive waste (L&ILW) each year from the nuclear generating stations at Bruce, Darlington and Pickering in Ontario. Low level waste (LLW) typically consists of industrial items and materials, such as clothing, tools and equipment, which have become contaminated with low levels of radioactivity. This waste is sent to OPG's Western Waste Management Facility (WWMF) where it is processed and placed into interim storage. There are also some large objects, such as Heat Exchangers and Steam Generators, which are and will be replaced during refurbishment work at the stations and fall into the category of LLW. Intermediate level waste (ILW) consists primarily of used reactor components and resins used to clean the reactor water circuits, which are stored in in-ground containers at the WWMF site. This report describes the preliminary design for OPG's proposed Deep Geologic Repository (DGR) for L&ILW to support the application for a site preparation and construction licence and provide the basis for future engineering.

This current study updates and advances the conceptual design that was produced in 2008. The scope of work described in this report involves consideration of all aspects of the DGR including its construction, the receipt of waste from the WWMF and nuclear generating stations and subsequent emplacement in the DGR.

The DGR consists of surface infrastructure for the receipt of waste packages and transfer underground via a 6.5 metre finished diameter Main Shaft to the repository horizon at a nominal 686 metres below the shaft collars. The shaft collars have been set at a nominal 186 m above sea level. The downcast Main Shaft will have a concrete headframe equipped with a large six-rope Koepe friction hoist to raise and lower a large cage with external dimensions of 18.5 metres high x 5.6 metres long x 3.0 metres wide. The payload capacity of the hoisting system is 44 tonnes, which is made up of a maximum waste package mass of 36 tonnes and an 8 tonnes allowance for transfer carts, pallets and rigging. A second two-rope Koepe friction hoist will be used to hoist a two-deck auxiliary cage for transfer of personnel into and out of the repository. A ventilation supply system, including heaters (for winter operations), will supply air at a controlled range of temperatures to ensure that freezing does not occur in the downcast shaft, underground conditions are suitable for workers, and the atmosphere is maintained in a reasonably steady and dry state to limit corrosion of structures and waste packages.

The 5.0 metre finished diameter Ventilation Shaft will be an upcast shaft with main Exhaust Fans on surface to pull the spent air out of the repository. Additionally, a second egress double drum hoist will be installed in this shaft, which will be equipped during operations with a cage on one rope counterbalanced by a skip on the other rope. During repository construction, this hoist will also remove the excavated rock from underground using two skip conveyances.

Shafts will be excavated by traditional drill and blast methods. Ground freezing and / or grouting will be employed to sink the shafts through the upper approximately 160 metres of the dolostones to ensure that water ingress is minimal during that portion of the sinking.

Level development of all excavations on the repository level will use drill and blast as the reference method for excavation.

Waste rock piles for the complete excavated volume of rock (911,600 m^3 bulked volume) will be accommodated to the north-east of the two shafts in a Waste Rock Management Area. Of this volume, it is anticipated that approximately 79,700 m^3 would be re-used on site for surface construction. The bulk of the remaining rock will be limestone which will be managed in a rock pile that has a footprint area of about 8.7 ha and is 15 metres high.

A storm water run-off management system of ditches and a storm water management pond will be provided to control the outflow of discharge water from the site before release into Lake Huron. The discharge water will be monitored to confirm that the concentrations of potential contaminants are within acceptable limits. Based on the chemical properties of the different rock types, it is not expected that individual chemical concentrations will exceed regulatory limits. Berms and vegetation will be used to limit the aesthetic impact of the rock piles and control dust and suppress noise. Protection will also be provided to certain environmentally sensitive areas, which have been identified at the site.

Figure I provides an extract from the site base plan showing the key surface structures and facilities for the DGR. The location of some ancillary facilities (e.g. Electrical Substation and Emergency Diesel Generator) may change as the design is further optimised.

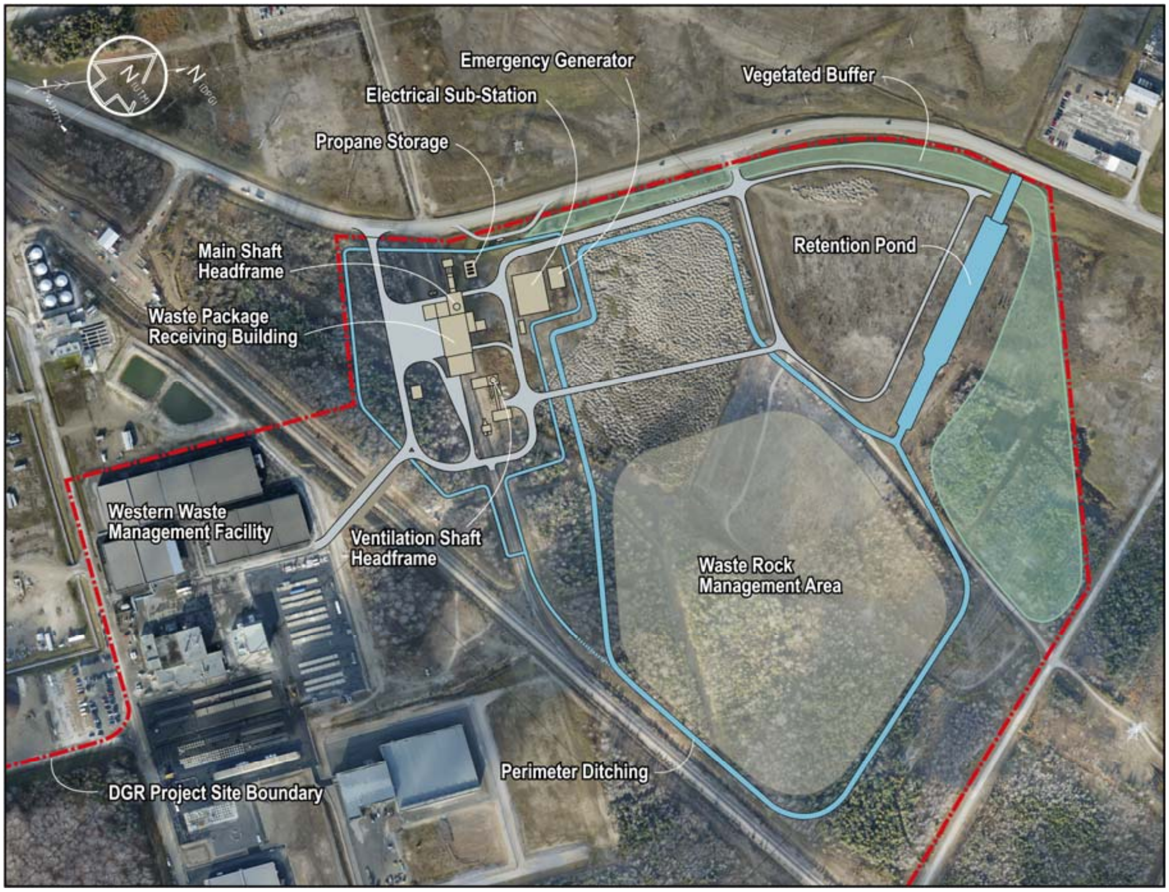


Figure I – DGR Surface Layout

The reference capacity of the repository is nominally 200,000 m^3 of emplaced waste and will be fully developed during initial construction, so that once waste emplacement operations commence, no mining activities, other than inspection and maintenance of rock support, concrete linings, concrete floors and ventilation systems will need to occur.

The underground layout of the repository has the two vertical shafts as an islanded arrangement with a shaft services area, in which offices, a workshop, wash bay, refuge stations, lunch rooms and geotechnical laboratory are provided. 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.

The emplacement rooms are all aligned with the assumed direction of the major principal horizontal in-situ stress of the rock mass in the Lower Member of the Cobourg Formation (i.e. east-north-east) to maximise roof stability in the emplacement rooms during the period in which the repository could remain open. 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. (See Figure II.)

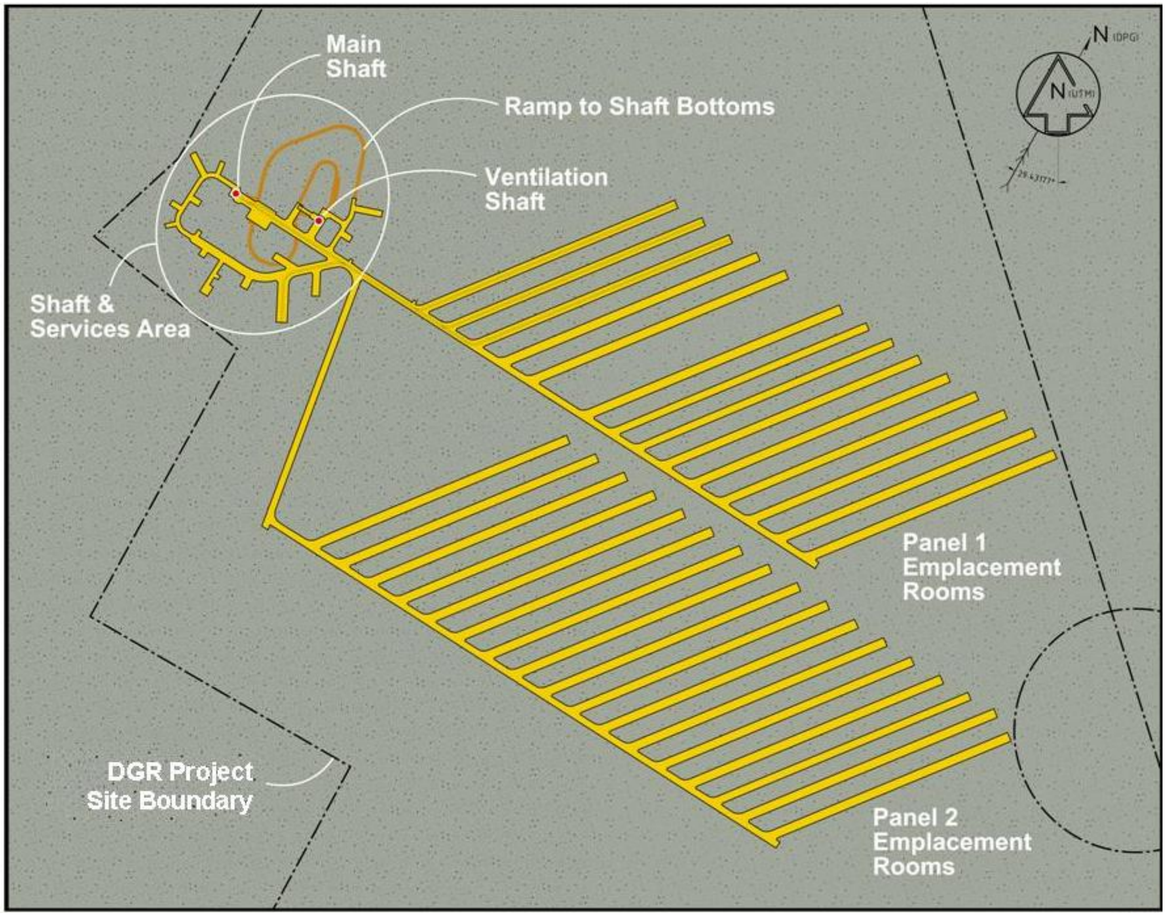


Figure II – DGR Underground Layout

Panel 2 will be filled first with the majority of the backlog of waste packages that will be in storage at the WWMF at the time emplacement operations commence. Both panels will contain LLW and ILW rooms. In general, LLW and ILW packages will not be stored in the same room. Three rooms in Panel 1 will be equipped with rail tracks and will used to emplace the packages, which are not forkliftable, i.e. the IC-2 and IC-18 Tile Hole Equivalent (T-H-E) Liners, Heat Exchangers and Shield Plug Containers.

All the emplacement rooms are “dead-ended”, in that there is only one way in and out of them from the panel access tunnels. To control ventilation air exhausting from the repository, all emplacement rooms and access tunnels will be equipped with solid ventilation ducts to contain air that has flowed over waste packages and duct it right up to discharge in the upcast Ventilation Shaft. In this manner, workers will work in the cleanest air and be isolated from the potential of contaminated air.

All waste packages delivered to the DGR will be required to meet waste acceptance criteria for the DGR. It is currently assumed that the majority of the waste packages that are retrieved from WWMF storage can be transferred “as is” to the DGR. Major exceptions will be the ILW, which will require shielding to protect workers during transfer operations, and a portion of LLW containers, which will likely require overpacking. The shields and overpacks are sacrificial and will remain on the waste packages after emplacement underground. In addition some of the large object wastes, such as the Steam Generators and some Heat Exchangers, will be sectioned into smaller segments to allow transport within the Main Shaft cage.

Waste packages will be transferred into and out of the Main Shaft cage by means of a self-propelled, rail-based transfer cart (with the exception of T-H-E Liners). Diesel-powered forklifts or an overhead crane will load packages onto empty carts in the waste package loading area of the Waste Package Receiving Building (WPRB). The packages will be secured on the cart as required to ensure that the load will remain stable while the cart is moved into and out of the Main Shaft cage and while the cage is in motion. For the majority of the waste packages (i.e. LLW bins), the rail cart will move two or more packages per trip; the number will depend on their individual mass and size. Due to their individual mass and / or size, other packages will only be transferred at one package per trip.

The majority of the waste packages will be transferred from the staging area at the Main Shaft station on the repository level to the emplacement rooms by diesel-powered forklifts. However, the Heat Exchangers and Shield Plug Containers will not be off-loaded at the staging area, but will be taken to their emplacement room on the rail carts, where they will be off-loaded by a gantry crane.

A reference concept has been developed for the handling and transfer of T-H-E Liners into the DGR. In this concept, the T-H-E Liners will be transferred underground and to their emplacement rooms in a re-usable Transfer Bell. These shielded wastes are heavy (at a mass of about 32 tonnes) and long (12 metres) and will be transferred using a custom designed rail car handling device (T-H-E Handler), which will load a liner in its Transfer Bell into the cage in a vertical orientation at the Main Shaft collar on surface. A second T-H-E Handler will then remove the loaded shield from the cage at the DGR level station, rotate the Transfer Bell to the horizontal and transport the waste package to the rail-equipped emplacement room in Panel 1. In this room, a Horizontal Emplacement Machine (HEM) will hydraulically push the T-H-E Liner out of its Transfer Bell and into a mass Concrete Pipe Array, which will provide the necessary permanent shielding. The T-H-E emplacement room will be equipped with a gantry crane to transfer these long and awkward packages from the T-H-E Handler onto the HEM.

There will be a total of 31 emplacement rooms, of which 17 are identical in cross-section and will be dedicated to the 'standard-type' LLW (bins and racks). All rooms are nominally 250 metres in length, but the widths and height of some rooms vary to provide optimisation of space dependent on the type, dimensions and stacking limitations of the various packages. Panel 1 will have 14 rooms and Panel 2 will have 17 rooms. The rooms and their designated contents are summarised in Table I below.

At the start of DGR operations, a large volume and quantity of waste packages, amounting to approximately 70% and 50% of the total reference LLW and ILW volume respectively, is forecast to be in storage at the WWMF. The design will allow transfer of the majority of the backlog of LLW bin-type packages within a period of approximately 5 years. During this same 5-year period ILW and large or irregularly-shaped LLW (i.e. Steam Generator Segments and Encapsulated Tile Holes) will be emplaced in four of the Panel 2 rooms.

Following the closure of Panel 2, emplacement would commence in the rooms furthest away from the shafts in Panel 1. After a further 15 years, the first nine rooms of Panel 1 will be full of packages and will then be closed. The remaining waste packages in the inventory will be emplaced in the final open rooms over the next 15 years. At the end of waste emplacement operations the remaining open rooms in Panel 1 will also be isolated by a closure wall. After a period of monitoring, an application would be made to the regulator to decommission the facility, which would include constructing engineered seals in each shaft.

Profile	Number of Rooms	Contents	Length (m) (Nominal)	Width (m)	Height (m)
P1	17	Group A Bin-Type Waste	250	8.6	7
P2	1	Bruce A Steam Generator Segments Encapsulated Tile Holes Tile Hole Liner Racks Unshielded Resin Liners Resin Liner Shield 2 Resin Liner Shells from Quadricells	250	8.6	6.35
P3	5	Unshielded Resin Liners Resin Liner Shield 1, 2, and 3	250	8.4	5.8
P4	3	ILW Shields Retube Waste Containers	250	7.4	6.5
P5	2	Pickering Steam Generator Segments Bruce B Steam Generator Segments	250	8.4	6.2
P6	3	Shield Plug Containers Heat Exchangers T-H-E Liners (in Concrete Arrays)	250	8.1	7.2

Table I – Rooms and their Designated Contents

In addition to the specific aspects of the preliminary design noted above, geotechnical modelling has been undertaken to confirm the optimal excavation sizes and pillar widths and define the necessary rock support measures that will be employed. Both shotcreting and rock bolts have been proposed.

The width of rock pillars between parallel emplacement rooms has been established to be twice the span of the emplacement rooms on the basis of a most probable cost, reliability-based design approach for expected Cobourg Lower Member intact rock conditions of 110 MPa Unconfined Compressive Strength.

Shield walls and closure walls would be constructed in each panel of rooms. Once filled and if required, a shield wall will be erected at the entrance to an emplacement room with access panels in the wall for ventilation connections. The primary purpose of the shield wall will be to protect workers from radiation as they travel along access tunnels and past waste-filled rooms. Monitoring of gas emissions and contaminant levels will be undertaken using instrumentation installed in the return air ducts and at the inlet to the exhaust fans on surface at the Ventilation Shaft. Should contaminant levels show a trend that may lead to safety limits being exceeded, measures, such as reducing or closing off ventilation from any room that is found to be the source of increased levels and retrieval of the offending waste packages.

Closure walls will be constructed in the access tunnels to isolate a group of waste-filled rooms. Since ventilation and all other services to those rooms would then be suspended, explosive gases could build-up in the closed-off section of the panel. This wall will be designed to withstand the blast pressure waves that could be generated in the unlikely event of ignition of those gases.

Waste retrieval will be possible, if required, by reversing the process of emplacement to remove any packages that have been identified for retrieval. All the waste package handling equipment (forklifts, gantry cranes, emplacement machines and rail cars) will be able to perform such operations in a similar manner to that used during the emplacement process, although it would be expected that some of the larger, heavier or more awkward packages, such as the T-H-E Liners, would take a considerable amount of care and time to retrieve.

A conceptual design has been produced for the final repository shaft sealing system, which will provide the long-term post-closure isolation of the repository from the biosphere. The column of seal materials in each shaft will be founded on a concrete monolith, which will be designed to withstand a internal gas pressure up to 14 MPa. Prior to placing the engineered seal materials in each shaft, the shaft lining and any highly damaged rock in the shaft barrel would be removed to remove potential permeable pathways around the low permeability seal materials. A compacted bentonite clays and sand mixture will provide the primary sealing mechanism to limit the overall effective hydraulic conductivity. A column of asphalt is included to provide a level of redundancy in the overall shaft seal design. Concrete bulkheads will be used for structural support within the column of seal materials.

All preliminary design work has been produced to meet the System Requirements. One of the important requirements is a 100 year design life. To this end, key structural items in the shaft areas (steelwork, piping, platework etc.) will all have sacrificial thickness and corrosion protection applications well in excess of what would normally be found in an industrial or mining plant. Waste package shielding has been designed to ensure that radiation dose rates can be limited to 2 mSv/hr on contact and 0.1 mSv/hr at 1 metre.

The design has generally been based on using proven methods and equipment for both construction and operations. New technology, which could require an unknown level of development to produce a fully viable and safe product, has been avoided where possible. During concept studies, it was recognised that there was one aspect where equipment will be used in a somewhat unconventional manner; namely, the rail car-mounted device (T-H-E Handler) to rotate the T-H-E Liners between the horizontal and vertical for transferring these waste packages in the shaft cage and the emplacement machine (HEM) to push the T-H-E Liners out of the transfer bell and into the mass concrete pipe array. However, the emplacement of these wastes in the horizontal concrete arrays remains a risk and consideration of alternatives should be undertaken.

The preliminary design has been reviewed to confirm that the repository can be expanded, if required, to accommodate an assumed additional volume of 200,000 m^3 of emplaced waste. Such an expansion would require having a future development and construction campaign. For this the waste emplacement operations would be suspended and both shafts used to support the mining effort in as short a period as is reasonable. The underground infrastructure would already be in place and re-commissioning of the loading pocket and dumping system, construction material stores and workshops would be easily accomplished. The skip would be re-installed in the Ventilation Shaft conveyance to remove the excavated rock. To achieve this expanded capacity, the south access tunnel could be extended and two more panels could be developed running parallel and to the south of the first two panels.

Preliminary Design Report
Index

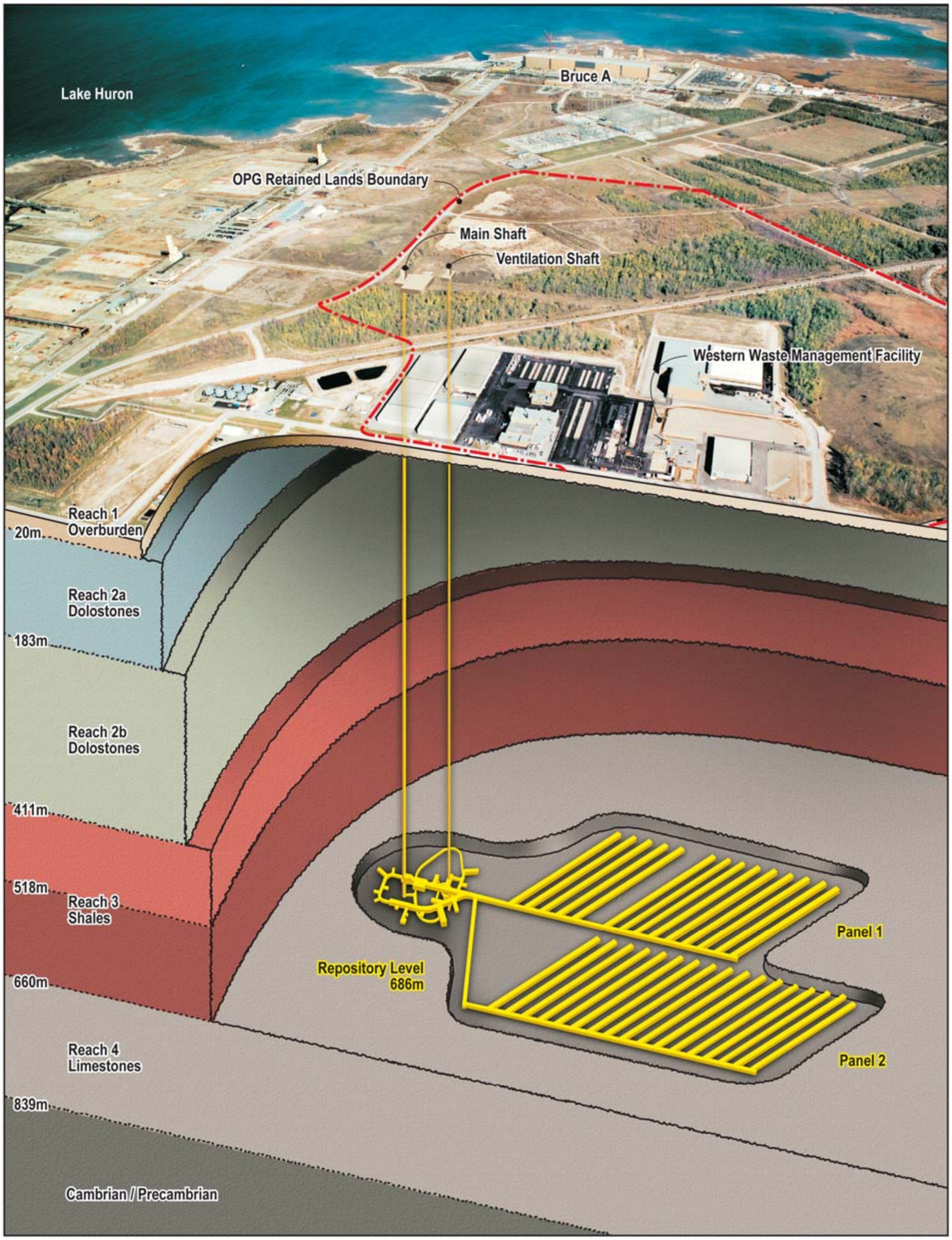


Table of Contents

Appendix A – List of References

Appendix B – Definitions and Abbreviations

Appendix C – Compliance with System Requirements

Appendix D – Waste Package Category Information Sheets

Appendix E – Drawings (see separate volume)

List of Figures

List of Tables

1. Introduction

1.1 Background and Purpose

On behalf of Ontario Power Generation (OPG), the Nuclear Waste Management Organization (NWMO) is managing the development of the Deep Geologic Repository (DGR), in which all operational Low and Intermediate Level Waste (L&ILW) generated by the OPG-owned nuclear generating stations will be disposed. This engineering design report will support the application for a site preparation and construction licence and provide the basis for the next phase of engineering.

L&ILW resulting from the operation and refurbishment of OPG-owned nuclear generating stations is primarily stored at interim facilities at the OPG-operated Western Waste Management Facility (WWMF), which is within OPG-retained lands on the Bruce nuclear site in the Municipality of Kincardine.

The Bruce nuclear site is owned by OPG, although with some exceptions, the land and generating stations are currently leased to Bruce Power. The Bruce nuclear site is located about 225 km north-west of Toronto, between the towns of Kincardine and Port Elgin on the east shore of Lake Huron. The WWMF is centrally located on the site, approximately 2 km from the Bruce A Nuclear Generating Station (NGS), 1.5 km from the Bruce B NGS and 1 km from Lake Huron.

The WWMF storage structures provide interim storage of L&ILW. Although current storage practices are safe, these wastes will eventually need to be transferred to a long-term management facility as some of the wastes remain hazardous for thousands of years. It is proposed that the DGR be constructed at a location immediately adjacent to the WWMF. The DGR would be used for the long-term management of all L&ILW currently in storage at WWMF as well as the operational and refurbishment L&ILW from on-going operation of OPG-owned reactors.

Based on current OPG planning assumptions, it has been assumed that the DGR will operate for about 40 years to allow receipt of all L&ILW generated by the existing fleet of Ontario reactors. However, to ensure development of a robust design and to provide operational flexibility, a repository design has been developed which would be capable of supporting waste emplacement operations for at least 100 years.

Once the DGR ceases to receive waste, and after a period of environmental monitoring, regulatory approval would be sought to decommission the facility. On receiving a decommissioning licence, the DGR would be closed by sealing the vertical repository access shafts with engineered sealing materials.

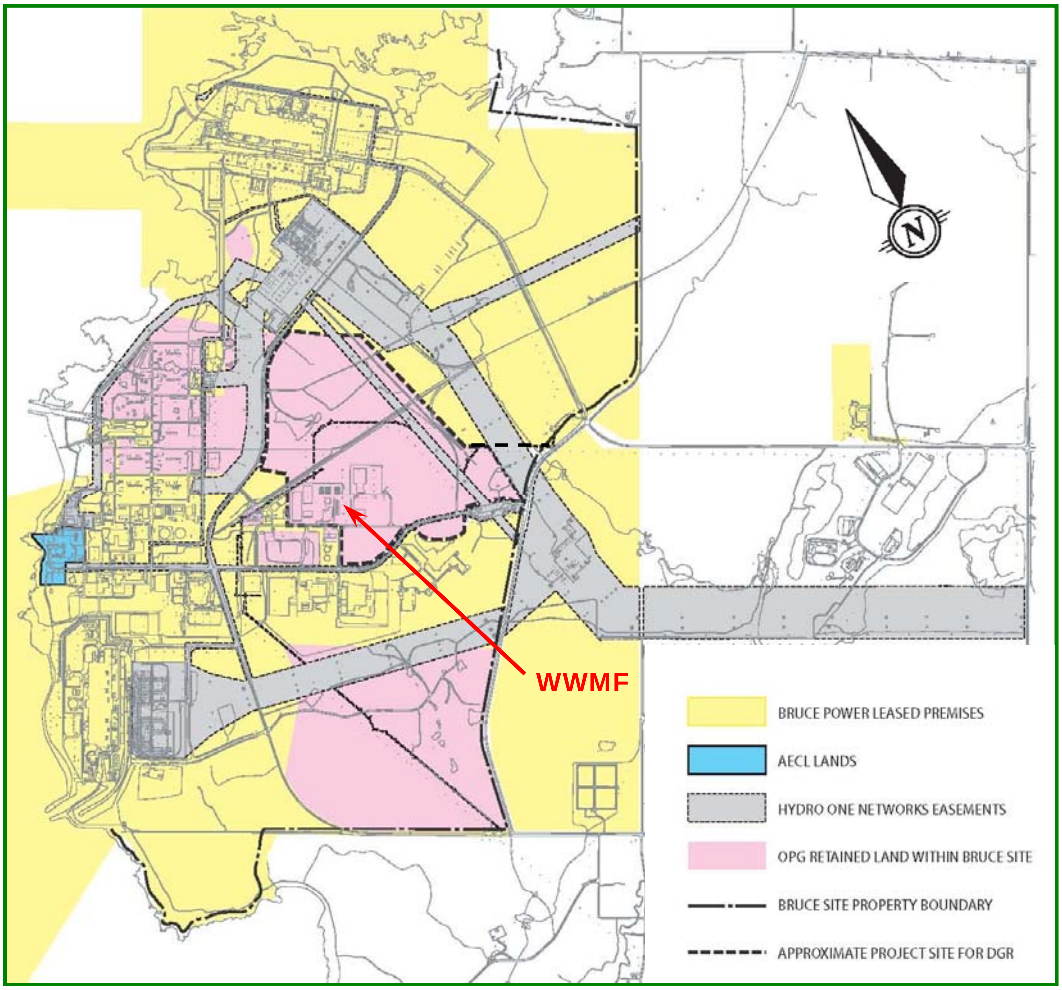


Figure 1-1 – Bruce Nuclear Site with WWMF and DGR Project Site Location

Annually, between 5,000 and 7,000 cubic metres of L&ILW is currently received at the WWMF. After receipt and processing, the waste is placed into storage. Approximately fifty percent of operational waste from existing reactors to be emplaced in the proposed DGR is already stored at the WWMF. This L&ILW will be retrieved from the various storage structures and, when required, processed and / or repackaged, then transferred to the DGR.

Low level waste (LLW), which consists of minimally contaminated materials such as mop heads, rags, paper towels, floor sweepings and protective clothing, is received at the Waste Volume Reduction Building (WVRB). It is then either moved directly into a Low Level Storage Building (LLSB), or processed by incineration or compaction to reduce its volume before transfer to a LLSB. Following volume reduction, the LLW is placed in carbon steel bins that are stacked inside the above-ground concrete LLSBs.

Intermediate level waste (ILW) consists primarily of used reactor components, resins and filters used to keep reactor water systems clean. The ILW is loaded into specially reinforced and shielded transfer packages and stored directly in shielded storage structures, Quadricells, trenches, tile holes and in-ground containers (ICs). Some wastes may require additional processing and packaging before transfer to the DGR facility.

Large object wastes currently in storage at WWMF include Heat Exchangers, tanks and Steam Generators that were removed during various station refurbishment projects.

1.2 Overview of Preliminary Design

1.2.1 Background (Previous Studies)

Previous conceptual studies for LLW and ILW repositories were conducted in 2003, 2004 and 2008, all of which have concluded that disposing of L&ILW in a deep underground facility is feasible:

- 2003 – Geotechnical feasibility study of the feasibility of a covered above-ground concrete vault and a deep rock cavern vault in either shale or limestone formations. [R1]
- 2004 – Conceptual design for L&ILW disposal in a deep repository located 660 metres underground in the Cobourg Formation. [R2]
- 2008 – Conceptual design for L&ILW disposal in a Deep Geologic Repository located 680 metres underground in the Cobourg Formation. [R3]

In the previous DGR concept, which was developed in the [R3] study, two vertical concrete-lined shafts were arranged in close proximity to each other and the WWMF and connected underground at the repository level by a ring-shaped shaft service area. Two panel access tunnels radiated to the south and east from the shaft island and horizontal emplacement rooms branched out at an angle of 55 degrees on both sides of each access tunnel.

1.2.2 Preliminary Design Study Approach

This preliminary design study has reviewed and advanced the previous [R3] concept. The approach for all the elements of this study was to review the previous concept, identify changes required as a result of new or updated information, and improve the level of detail of designs. Trade-off studies were conducted on specific features of the design to confirm preferred systems for inclusion in the preliminary design. This process has led to certain changes compared to the [R3] concept, which are identified in Section 1.2.3 below.

Major aspects of the study included:

- Review of the latest OPG Waste Inventory Report [R4] and confirmation of designs for shielding of Resin Liner and Tile Hole Equivalent (T-H-E) Liner wastes.
- Geotechnical modelling of the rock mass, emplacement rooms and shaft pillars to determine the optimal layouts and pillar sizes.
- Consideration of different underground layouts and shaft locations to provide an improved arrangement and longer term performance of openings with respect to assumed horizontal rock mass stresses.

- Review excavation and construction methods.
- Types and sizes of equipment for construction and waste emplacement operations.
- Arrangements of the surface infrastructure, including access from the WWMF and size and location of the waste rock piles.
- Repository sealing design at closure.
- Optimisation of the repository ventilation design considering humidity versus temperature control and confirmation of the ventilation flow direction.
- Review of closure method and ventilation of emplacement rooms once filled with waste packages.
- Confirmation of type and size of hoists for each shaft.
- Review and selection of preferred hoist conveyance arresting system.
- Review and selection of preferred shaft cage chairing system.
- Loading, shaft transport and off-loading methods to move the waste packages to the repository level.
- Type of construction for the Main Shaft Headframe.
- Optimisation of the layout of the Waste Package Receiving Building (WPRB).
- Optimise dewatering services both on surface and underground.

1.2.3 Changes compared to Conceptual Design

The trade-off and review studies have led to changes to the following compared to the [R3] study:

- The underground layout was revised to align all emplacement rooms with the assumed major principal horizontal rock mass stresses in the Cobourg Formation, and provide flexibility for variations in the actual stress direction, which can only be determined once the shafts have been sunk.
- The underground Shaft and Services Area was re-arranged to place the Main Shaft in the loop rather than internal to the previous ring tunnel.
- A ramp to both shaft bottoms and Ventilation Shaft loading pocket was added.
- The shaft positions were adjusted to create an effective pillar of 20 m from other openings apart from the shaft stations and access tunnels.
- Excavation methods were assumed to be drill and blast rather than mechanical means.
- Surface layouts were adjusted to suit the change to the underground layout, although this does not represent a fundamental change from the conceptual design.

- Propane was adopted as the method for heating DGR ventilation air in winter as the previous assumption of using natural gas could not be supported by availability in the region of the Bruce nuclear site.
- Underground ventilation flows were adjusted in line with work performed at the end of the conceptual design phase to ensure that any contamination due to a spillage at the Main Shaft station could not be entrained in the air flow through the entire underground repository.
- Closure walls were moved to access tunnels and now isolate groups of waste-filled rooms. These walls are blast-resistant and enable ventilation of emplacement rooms to be limited to a period of ten to fifteen years instead of throughout the full life of the DGR.
- An auxiliary hoist was added to the Main Shaft in place of a ladder way. This now enables personnel to access the repository without normally travelling in the large conveyance, which would transport the waste packages.
- The Ventilation Shaft hoist was converted to a double drum arrangement to facilitate underground development of the repository and ensure waste rock removal did not become a bottleneck in the process.
- A chairing system, similar to Siemag [R5], for the Main Shaft waste package conveyance, which prevents vertical movement of the cage, either up or down, during waste package loading and off-loading was adopted as the reference instead of the previously proposed Levelok [R6] system.
- The Siemag / Selda [R7] type of conveyance arresting system was selected as the reference overwind protection gear. The conceptual design had proposed two alternatives, but not specified a preferred method.
- All waste packages will be transferred from the surface WPRB to the underground DGR level on rail carts to improve safety during shaft conveyance loading and off-loading.
- Some simplification of the shaft seals to be installed on decommissioning and closure of the facility.

1.3 Scope of Report

This report describes the preliminary design for the DGR, which has been developed to the point where it represents approximately 7 % of total engineering for the DGR facility. The report covers the following specific investigation and design areas:

- Location and layout of the DGR facility, including surface infrastructure and buildings for the Main and Ventilation Shaft areas, connection to the WWMF, and Waste Rock Management Area (WRMA) within the delineated DGR Project Site.
- Underground repository arrangement, including layout and sizes of emplacement rooms and support infrastructure.

- Construction methods and operations' equipment for the shafts, underground tunnels, emplacement rooms, and a ramp to shaft bottom to provide access for waste rock, water and shaft bottom management.
- Repository ventilation, modelling and conditioning of air throughout the year, including heating system and main fans.
- Geotechnical analysis of stratigraphy, modelling of the underground excavations to determine optimal pillar and room sizes, rock support and grouting requirements, repository depth in the Lower Member of the Cobourg Formation (hereafter referred to as the Cobourg Lower Member), and grade of access tunnels and emplacement rooms to remain within the formation.
- Waste package handling & emplacement, including review and update of the inventory of waste packages, taking account of revised methods for transferring waste packages on surface, transfer into, down and out of the shaft conveyance, underground transfer to the emplacement rooms and emplacement, and designing and selecting specific handling equipment to achieve all the steps in the transfer process.
- Updating support services, namely dewatering, potable water, compressed air, electrical, lighting, communications requirements, control and monitoring.
- Fire protection and detection, emergency response, radiological zoning, and control and monitoring systems for air and water.
- Repository construction and development sequences and labour complements.
- Operations schedule and sequence of waste emplacement, labour complements and equipment requirements.
- Final sealing of repository at closure.

Each key aspect of the study is addressed within the report with reference as relevant to previous work and best practice. Figures are used to illustrate layouts, equipment and methods proposed. A separate Appendix Volume E contains key dimensioned drawings to support the designs.

2. Site Location and Characteristics

The DGR is centrally located on the 932-ha Bruce nuclear site and adjacent to OPG's WWMF. The Bruce nuclear site is located approximately 225 kilometres north-west of Toronto near Tiverton, Ontario. The following sections present information that describes current surface and subsurface conditions in the vicinity of the proposed location for the DGR. The salient features of the topography, water courses, existing structures, obstructions and environmentally sensitive aspects in the immediate vicinity of the DGR Project Site are shown in Figure 2-1. To provide context, the location of the key elements of the proposed DGR surface infrastructure (shaft positions and WRMA) are also included on this figure.

2.1 Topography and Drainage

2.1.1 Site Topography

The Bruce nuclear site is generally flat with open natural and anthropogenic landscapes, as well as both hardwood (in the uplands) and coniferous (in the lowlands) forested areas (see Figure 2-2). A detailed topographic survey of the Bruce nuclear site was completed using Light Detection and Ranging (LIDAR) method (the base reference for the survey is UTM NAD 83, Zone 17 [R8]).

The topographic map indicates that within the DGR site boundaries shown on Figure 2-1 elevation ranges between 180 and 195 m above mean sea level (mASL), while Lake Huron is at 176 mASL. However, in locations to be occupied by various DGR surface facilities, elevation ranges from 187 mASL in the southern portion of the site, to 181 mASL in the northern extent. (Note that the elevation values given in Figure 2-1 are for the current ground levels).

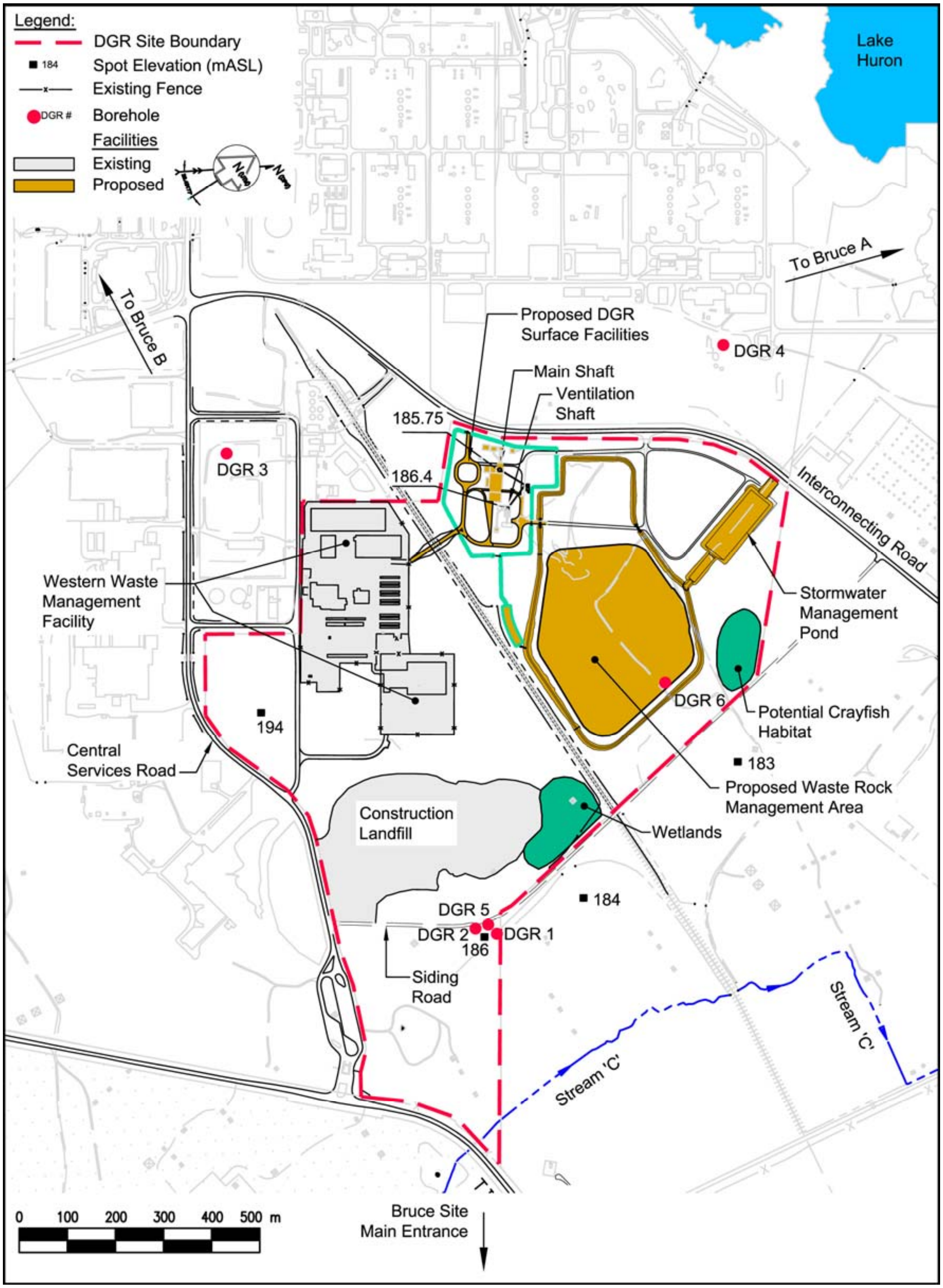
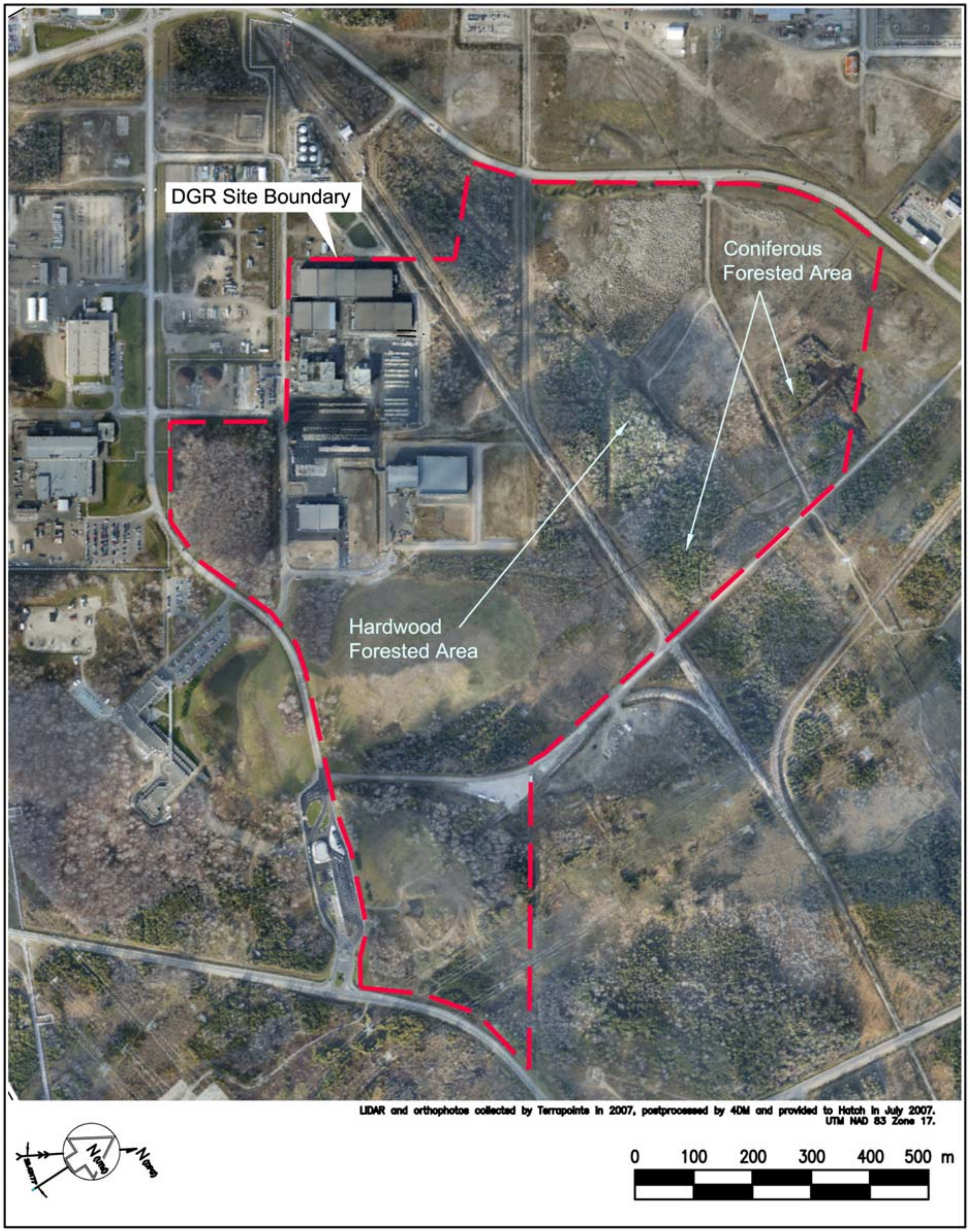


Figure 2-1 - DGR Project Site



LIDAR and orthophotos collected by Terrapoints in 2007, postprocessed by 4DM and provided to Hatch in July 2007.
UTM NAD 83 Zone 17.

Figure 2-2 - Aerial Photograph of DGR Project Site

2.1.2 Drainage

An extensive drainage system, including sewer lines, catch-basins, manholes and open ditches provide drainage for the Bruce nuclear site, including the OPG-retained lands. All drainage from the Bruce nuclear site eventually enters Lake Huron, either through one of several outfalls, or via a natural drainage feature. Stream C, shown in Figure 2-1, is the sole source of natural drainage crossing the Bruce nuclear site; this stream is a former tributary of the Little Sauble River that was diverted to Baie du Doré during development of the Bruce nuclear site in the 1960s.

The existing watershed in the proposed location of the DGR is drained by a system of ditches along roadways and railways; the majority of these ditches are expected to be dry for the majority of the year [R9].

Drainage generally flows from the vicinity of the DGR surface facilities and WRMA in a north-westerly (Douglas Point Grid (DPG)) direction, discharging into Lake Huron through drainage ditches on the Bruce nuclear site. The exception is the south-eastern portion of the WRMA, which drains into the abandoned railway ditch, eventually flowing into Lake Huron via Stream C. [R9].

2.1.3 Significant Constraints

In the vicinity of the DGR Project Site, there are certain restrictions on the positioning of the DGR surface facilities. These features are shown on Figure 2-1 and include:

- Environmentally sensitive railway ditch, which traverses the property from east to west, just north of the WWMF.
- Low voltage power line running from near the wetlands to the west and then south (DPG) towards the LLSBs at the WWMF.
- High voltage power line running near the eastern boundary of the site.
- Potential crayfish habitat identified on the eastern boundary.
- Old construction landfill site south-east of the WWMF.

The potential chimney building crayfish habitat is situated in a locally low portion of the DGR site (see Section 4.2.3 and drawing H333000-WP404-10-42-0001). The catchment for this feature is located primarily to the east of the DGR site, while the outflow from the feature is to the north-west (DPG), where it connects with the aforementioned drainage ditches.

2.2 Climatic Conditions

2.2.1 Temperature and Precipitation

Climatic normals for nearby meteorological stations were obtained from Kincardine, Hanover and Wiarton, Ontario (Table 2-1, Table 2-2 and Table 2-3, respectively). In general, climatic characteristics at this site are expected to be influenced by the close proximity to Lake Huron.

Average temperature for the year is 7.8 °C in Kincardine, 6.5 °C in Hanover, and 6.1 °C in Wiarton. Monthly average lows for all locations occur in January and February, with temperatures averaging around -7 °C to -8 °C, while average highs occur in July with temperatures around 19 °C. Monthly average precipitation in this region varies from 68 to 120 mm, with an average annual precipitation of 1030.1 mm in Kincardine, 1048.7 mm in Hanover and 1041.3 mm in Wiarton.

Wind data for the area is available from the Wiarton airport. Data from this station indicate that winds are primarily from the south to south-west, with the exception of April where winds were predominantly from the north, as shown in Table 2-3. Average annual wind speeds for the year are 13.5 km/h, with January having the highest monthly average (17.1 km/h), and July having the lowest monthly average (10.2 km/h). The maximum gust speed for this site of 126 km/h was recorded on 30 April 1984.

	Month												**Year**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Temperature													
Monthly Daily Average (°C)	-4.8	-3.9	-0.3	5.2	11.6	17.6	19.6	19.4	16.2	10.0	4.0	-1.5	7.8
Monthly Daily Maximum (°C)	-1.4	0.0	3.9	10.0	16.8	22.8	24.5	24.2	21.2	14.1	7.1	1.4	12.1
Monthly Daily Minimum(°C)	-8.1	-7.8	-4.5	0.4	6.4	12.4	14.6	14.5	11.1	5.9	0.8	-4.4	3.4
Precipitation													
Monthly Rainfall (mm)	27.2	24.7	42.3	64.8	78.3	80.4	76.5	95.6	104.8	84.1	69.1	39.3	740.5
Monthly Snowfall (cm)	89.9	41.1	34.5	8.3	0.0	0.0	0.0	0.0	0.0	1.3	30.5	84.0	289.7
Monthly Precipitation (mm)	119.7	72.9	68.6	63.3	91.1	70.3	62.5	68.1	104.0	84.1	108.4	117.2	1030.1

* Latitude: 44° 10.120' N / Longitude: 81° 37.120' W **/** Elevation: 203.00 mASL / Source: [R10]

Table 2-1 – Kincardine, Ontario Climate Normals (1995-2005)

	Month												**Year**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Temperature													
Monthly Daily Average (°C)	-7.1	-6.7	-1.7	5.4	12	16.9	19.5	18.5	14.3	8.3	2.4	-3.8	6.5
Monthly Daily Maximum (°C)	-3	-2	3.2	10.9	18.6	23.3	26	24.7	20.2	13.3	6	-0.2	11.8
Monthly Daily Minimum(°C)	-11.2	-11.4	-6.6	0	5.4	10.4	13	12.3	8.4	3.3	-1.3	-7.5	1.2
Precipitation													
Monthly Average Rainfall (mm)	27.2	24.7	42.3	64.8	78.3	80.4	76.5	95.6	104.8	84.1	69.1	39.3	787.1
Monthly Average Snowfall (cm)	83.2	46.9	30.1	9.5	0	0	0	0	0	1.2	28.5	62.2	261.6
Monthly Average Precipitation (mm)	110.4	71.6	72.4	74.3	78.3	80.4	76.5	95.6	104.8	85.3	97.6	101.5	1048.7
Extreme Daily Rainfall (mm)	34.9	51.2	35.8	44.5	78	60	56.2	95.8	68.8	36.8	44.6	50.3	
Extreme Daily Snowfall (cm)	33.6	30.5	36	25.9	0	0	0	0	0	17	39.5	40	
Extreme Daily Precipitation (mm)	34.9	53.3	36	44.5	78	60	56.2	95.8	68.8	36.8	44.6	50.3	

* Latitude: 44° 7.200' N / Longitude: 81° 0.600' W **/** Elevation: 270.00 mASL / Source: [R11]

Table 2-2 – Hanover, Ontario Climate Normals (1971-2000)

	Month												**Year**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Temperature													
Monthly Daily Average (°C)	-6.8	-6.9	-2.2	4.7	10.9	15.6	18.6	18.1	14	8.4	2.6	-3.3	6.1
Monthly Daily Maximum (°C)	-2.8	-2.4	2.4	9.5	16.6	21.3	24	23.2	19	12.8	6	0.2	10.8
Monthly Daily Minimum(°C)	-10.8	-11.3	-6.8	-0.1	5.1	9.8	13.1	12.8	9	4	-0.8	-6.8	1.4
Precipitation													
Monthly Average Rainfall (mm)	21.8	20.7	36.6	54.9	74.3	74.4	71.2	85.2	104.3	86.9	77.7	32.4	740.4
Monthly Average Snowfall (cm)	125.2	74.3	46.4	15.3	1.1	0	0	0	0	4.4	47.7	112.1	426.6
Monthly Average Precipitation (mm)	105.3	68	73.4	68.1	75.3	74.4	71.2	85.2	104.3	91	115.6	109.5	1041.3
Extreme Daily Rainfall (mm)	32	48	36.1	45.3	48.8	67.8	104.6	73.4	88.6	69.3	46	45.5	
Extreme Daily Snowfall (cm)	51.4	30.7	45.5	26.8	14.5	0	0	0	0.2	23.6	32.5	38.4	
Extreme Daily Precipitation (mm)	47.6	48.6	47.2	45.3	48.8	67.8	104.6	73.4	88.6	69.3	46	45.5	
Wind													
Speed (km/h)	17.1	14.7	14.6	14.4	11.8	10.5	10.2	10.3	11.9	14.5	15.9	16	13.5
Most Frequent Direction	S	S	S	N	SW	SW	SW	SW	S	S	S	S	S

* Latitude: 44° 45.000' N / Longitude: 81° 6.000' W / Elevation: 222.20 mASL / Source: [R12]

Table 2-3 – Wiarton, Ontario Climate Normals (1971-2000)

Note: "Precipitation" in Table 2-1, Table 2-2 and Table 2-3 is the water equivalent of all types of precipitation. At most ordinary stations the water equivalent of snowfall is computed by dividing the measured amount by ten. At principal stations it is usually determined by melting the snow that falls into Nipher gauges. The amount of snow determined by this method normally provides a more accurate estimate of precipitation than using the 'ten-to-one' rule. Even at ordinary climate stations the normal precipitation values will not always be equal to rainfall plus one tenth of the snowfall. Missing observations is one cause of such discrepancies.

Using this data set as a basis, further analysis of the surface climatic conditions were undertaken and used in both determining intake air conditions for ventilation modelling particularly with regard to heat loads (see Section 5.5) and also in location of the two shafts relative to each other (See Section 5.1).

As an extensive set of data was required for this analysis, including historical hour by hour information related to atmospheric conditions, it was necessary to locate the closest weather station to the DGR site with such information. This was found to be the Wiarton weather station. All data is obtained from Environment Canada for the weather station located at this station.

As well as examining the dry bulb temperature (usually reported as simply temperature, as in Table 2-3), it is important to understand the wet bulb temperature as well. The wet bulb is a measure of the evaporating capacity of the air and is directly related to the ability of the air to remove metabolic heat from personnel and therefore required for underground ventilation heat load modelling.

The wet bulb temperature is not reported through Environment Canada and must be calculated from the relative humidity (RH) using psychrometry. Calculating the wet bulb also assists in that the wet bulb temperature in conjunction with the dry bulb and barometric pressure also allows the calculation of the density and other important psychrometric properties of the ventilating air.

Table 2-4 shows the calculated wet bulb and density for average daily surface climate conditions.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Dry Bulb (°C)	-6.8	-6.9	-2.2	4.7	10.9	15.6	18.6	18.1	14.0	8.4	2.6	-3.3
Relative Humidity (%)	81	77	74	70	71	74	75	77	78	75	78	81
Barometric Pressure (kPa)	98.8	99.0	98.9	98.8	98.8	98.8	98.9	99.0	99.0	99.1	98.9	98.9
Wet Bulb (°C)	-7.6	-7.8	-3.5	2.6	8.2	12.9	15.7	15.6	11.8	6.4	1.2	-4.2
Density (kg/m³)	1.29	1.29	1.27	1.24	1.21	1.19	1.17	1.18	1.20	1.22	1.25	1.28

Table 2-4 – Monthly Average Surface Conditions

Table 2-5 shows the calculated wet bulb and density for maximum daily surface climate conditions while Table 2-6 shows the calculated wet bulb and density for minimum daily surface climate conditions.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Dry Bulb (°C)	-2.8	-2.4	2.4	9.5	16.6	21.3	24.0	23.2	19.0	12.8	6.0	0.2	10.8
Relative Humidity (%)	79	73	68	61	59	63	62	65	68	68	75	79	68
Barometric Press. (kPa)	98.8	99.0	98.9	98.8	98.8	98.8	98.9	99.0	99.0	99.1	98.9	98.9	98.9
Wet Bulb (°C)	-3.4	-3.8	0.3	6.1	12.1	16.6	18.9	18.6	15.2	9.6	4.1	-1.0	7.8
Density (kg/m³)	1.27	1.27	1.25	1.21	1.18	1.16	1.15	1.16	1.17	1.20	1.23	1.26	1.21

Table 2-5 – Monthly Average Maximum Surface Conditions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry Bulb (°C)	-10.8	-11.3	-6.8	-0.1	5.1	9.8	13.1	12.8	9.0	4.0	-0.8	-6.8
Relative Humidity (%)	83	81	81	80	82	86	87	90	88	83	82	83
Barometric Press. (kPa)	98.8	99.0	98.9	98.8	98.8	98.8	98.9	99.0	99.0	99.1	98.9	98.9
Wet Bulb (°C)	-11.4	-11.9	-7.6	-1.2	3.8	8.6	11.9	11.8	8.0	2.9	-1.8	-7.5
Density (kg/m³)	1.31	1.32	1.29	1.26	1.23	1.21	1.20	1.20	1.22	1.24	1.26	1.29

Table 2-6 – Monthly Average Minimum Surface Conditions

Whilst average values for dry and wet bulbs for the year are helpful, another valuable method of analysis is to look at the hourly distribution of temperatures throughout the year. A data set has been gathered for each hour of each day at Wiarton weather station for the years 1998 to 2008 inclusive and averaged for that period of time. Again, the data source is Environment Canada. Figure 2-3 and Figure 2-4 show this distribution for both dry bulb and wet bulb values. Ranges are in 5 °C increments.

Temp Range (°C)	Average Hours	Cummulative Hours
<= -30	0	0
-30 <= -25	1	1
-25 <= -20	13	14
-20 <= -15	87	102
-15 <= -10	293	395
-10 <= -5	714	1109
-5 <= 0	1185	2294
0 <= 5	1492	3786
5 <= 10	1237	5023
10 <= 15	1279	6301
15 <= 20	1339	7641
20 <= 25	885	8526
25 <= 30	220	8746
>30	12	8758

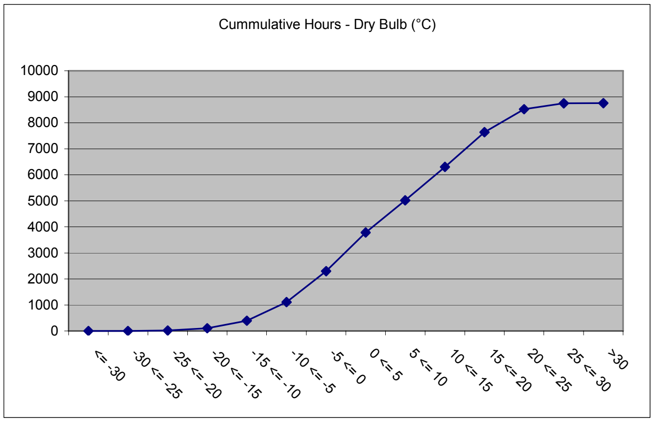


Figure 2-3 – Cumulative Distribution for Yearly Dry Bulb Temperatures

Temp Range (°C)	Average Hours	Cummulative Hours
<= -30	0	0
-30 <= -25	1	1
-25 <= -20	17	19
-20 <= -15	104	123
-15 <= -10	355	477
-10 <= -5	832	1310
-5 <= 0	1355	2665
0 <= 5	1589	4254
5 <= 10	1298	5552
10 <= 15	1530	7083
15 <= 20	1355	8437
20 <= 25	317	8754
>25	3	8758

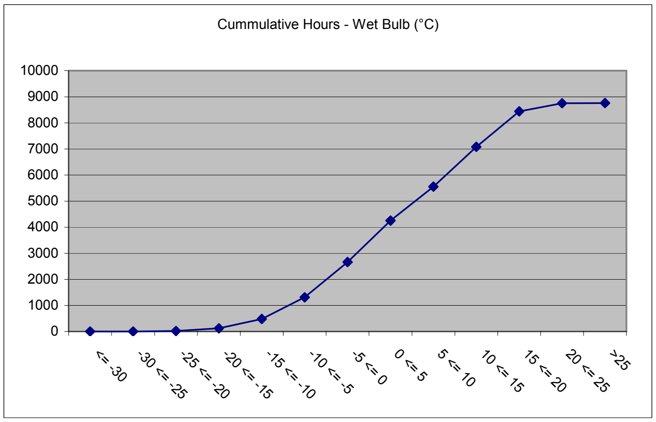


Figure 2-4 – Cumulative Distribution for Yearly Wet Bulb Temperatures

Further analysis was undertaken with regards to wind direction and speed. Information was gained through review of [R13] as well as reviewing hourly data collected at the Bruce nuclear site between 2002 and 2006.

A data set was reviewed with regard to frequency of wind speed and direction for the following:

- Annual.
- Daytime.
- Night-time.
- Spring.
- Summer.

- Fall.
- Winter.

The windrose, as presented in [R13], is shown in Figure 2-5. Both wind direction and speed at each primary azimuth point are shown. Reviewing the annual wind-rose and comparing against the Bruce data, the lowest frequency of wind direction (all wind speeds) is blowing from the ESE (112.5° azimuth) at a frequency of around 3 percent of the time.

However, whilst consideration of the frequency of all wind speeds indicates that the wind is least likely to come from the ESE direction, if consideration is specifically given to the frequency of occurrence of the higher wind speeds (> 11 km/h), then both E and ESE wind directions display a similar frequency of occurrence.

Indeed, comparing the night-time wind speeds with the daytime, the higher wind speeds are less likely to occur from the E wind direction. Seasonally, in both spring and summer, again the higher wind speeds are least likely to originate from the E wind direction. During winter and fall, it is seen that similar frequencies of occurrence from both E and ESE wind directions are experienced.

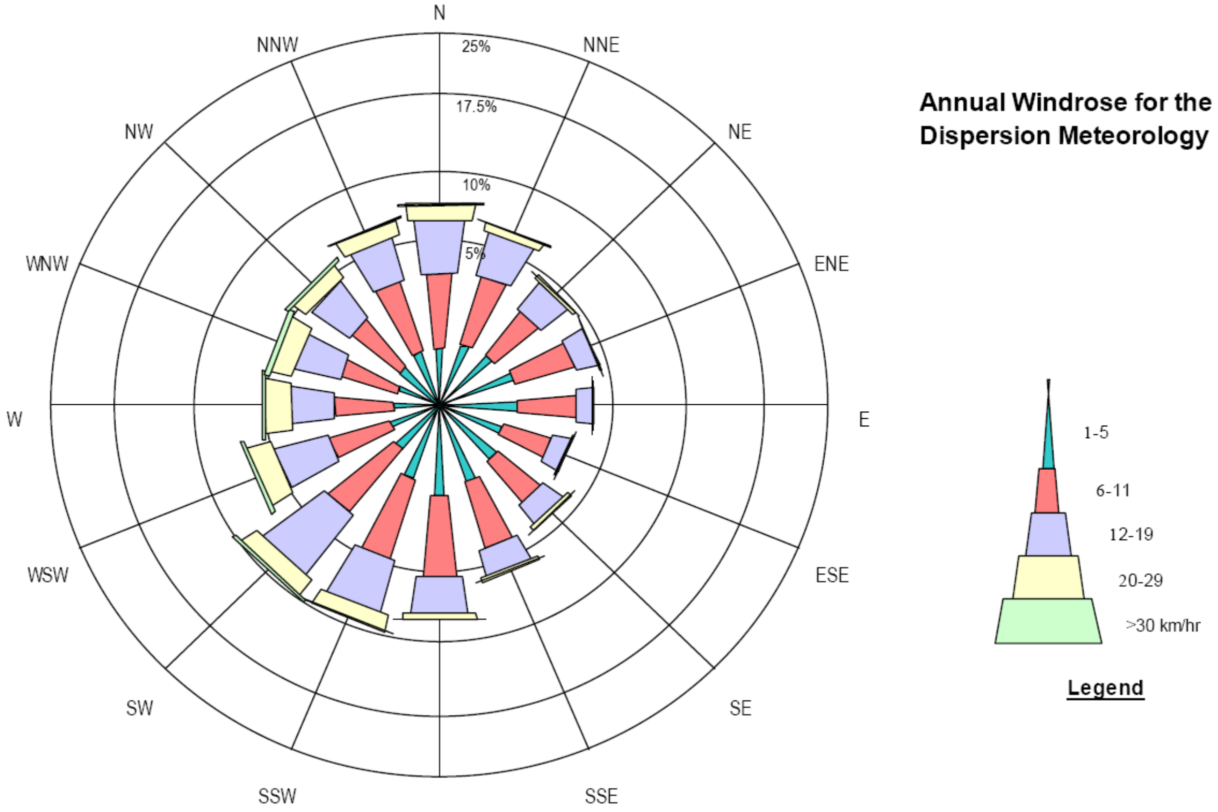


Figure 2-5 – Annual Windrose

2.3 Generalised Area Geology

The Bruce nuclear site is underlain by approximately 840 metres of relatively undeformed, horizontally-bedded carbonates and shales, which rest on the crystalline Precambrian basement. In general, the stratigraphic sequence is comprised of an upper 390 m to 420 m of Devonian and Silurian-age dolostones with some shale layers. In the geologic past, Silurian salt formations with combined thickness up to 100 m were solution-weathered from within this upper sequence of rocks, which has contributed to enhanced permeability in the upper dolostone formations. The lower half of the sequence is Ordovician in age and is comprised of an upper 250 m of shale and a lower 180 m of argillaceous limestone.

The two DGR shafts will be excavated through overburden and potentially water-bearing dolostone formations near the top of sedimentary sequence. Shaft excavation would continue through bottom half of the dolostone sequence, through the Ordovician shales and ending upper portion of the Ordovician limestones.

The emplacement rooms, ancillary rooms and access tunnels of the DGR will be constructed in limestone of the Lower Member of the Cobourg Formation (henceforth referred to as the Cobourg Lower Member). The proposed repository is to be constructed at a nominal depth of 686 mBGS (metres below ground surface) at the location of the two DGR shafts, where “ground surface” is assumed to be at an elevation of +186.0 mASL. The geologic, hydrogeologic and geotechnical conditions beneath the Bruce nuclear site that are relevant to the design and construction of the DGR are summarised below.

More detailed information can be obtained in the Underground Structures Geotechnical Interpretive Report – Access Tunnels and Emplacement Rooms [R14], the Descriptive Geosphere Site Model [R15] and in reference documents cited in each section below.

2.3.1 Desk Study

As part of a previous study relating to the DGR, an interpreted stratigraphic sequence at the Bruce nuclear site was established in 2003 through a review of local deep natural gas exploration wells [R1]. The stratigraphic interpretation was based upon drill records primarily from the Texaco #6 exploration well, located 3 km south-east of the site and is considered representative of the full Palaeozoic sequence to depths of 880 m where the granitic Precambrian basement rocks were encountered. In addition to the Texaco #6 exploration well, the stratigraphic column was developed with consideration of the Union Gas Company Kincardine #1 and Texaco #4 well records.

From 1986 through 1988, the bedrock stratigraphy directly underlying the proposed DGR Project Site was investigated to an approximate depth of 100 m over several geotechnical investigations carried out for Ontario Hydro. A total of six boreholes (US-1 to US-6) were drilled in the immediate vicinity of the WWMF and the proposed DGR shaft access area for part of previous waste management investigations [R16]. The investigations are referred to as the “US boreholes”.

The relative location of the Texaco #6, Texaco #4, Union Gas Company Kincardine #1 and US boreholes relative to the proposed DGR project site are shown in Figure 2-6.

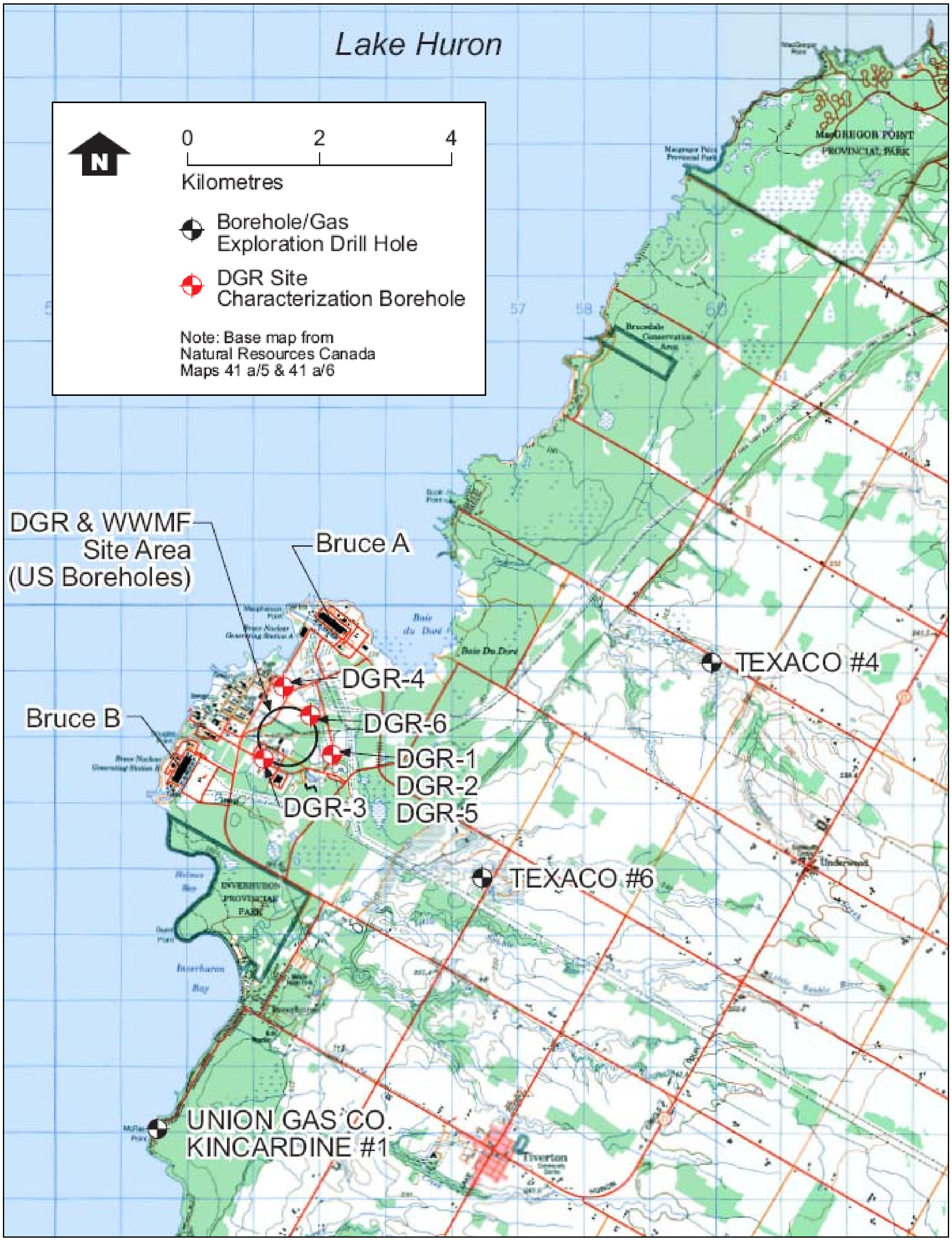


Figure 2-6 – DGR Project Site Showing Area Topography and Location of Geologic Investigations

2.3.2 Geoscientific Site Characterization Program

As part of the DGR Geoscientific Site Characterization Program (GSCP), a series of vertical and inclined boreholes have been completed. The field and laboratory investigations have been undertaken in accordance with plans documented in [R17] and [R18]. Results of these investigations to date are summarised in [R15].

The geoscientific investigations are comprised of two phases of site investigation work including six deep borings. Locations of all boreholes can be seen in Figure 2-7 and the scope and status of investigations for each phase is described below.

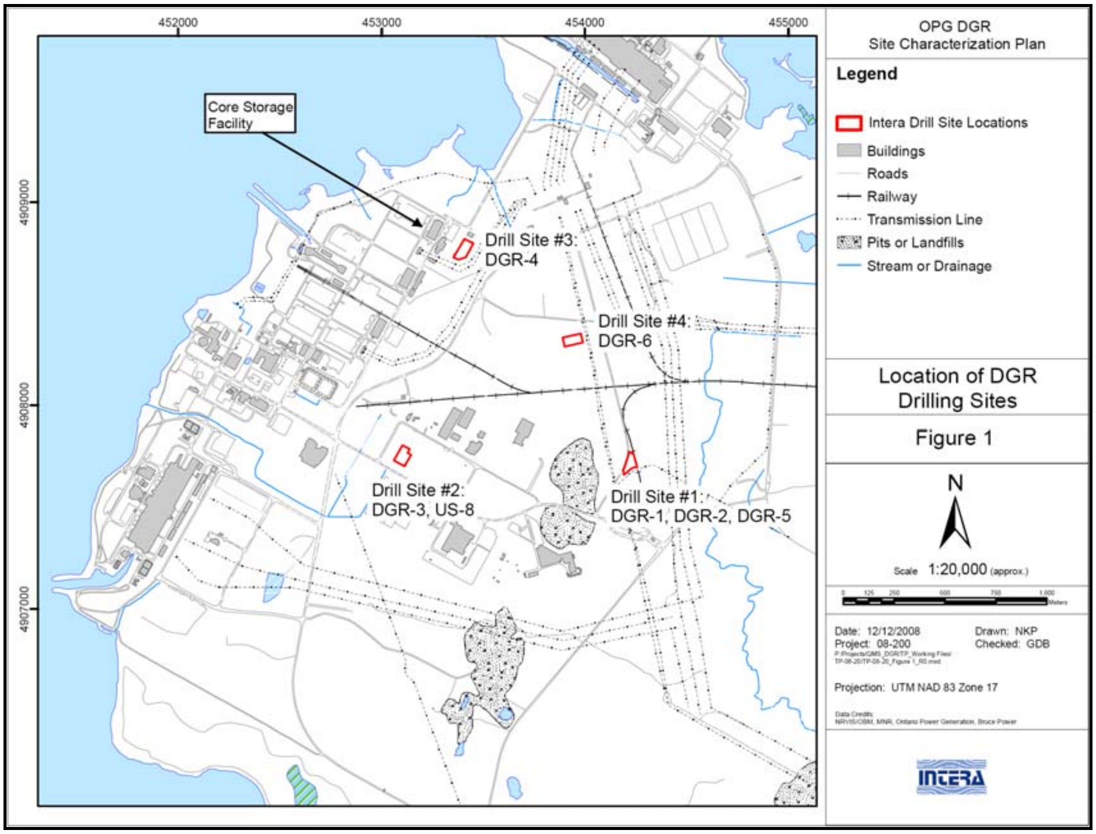


Figure 2-7 – DGR Borehole Location Plan

2.3.2.1 Phase 1

The two Phase 1 borings, DGR-1 and DGR-2, were drilled at one location, approximately 40 m apart from each other. This location is east-south-east of the proposed DGR facilities. Surface conductor casings were installed in both DGR-1 and DGR-2 during December 2006. Rock coring was completed in DGR-1 during the period 24 January to 4 April 2007, and in DGR-2 during the period 14 April to 3 August 2007.

After setting surface casings through the surficial deposits, both borings were continuously cored to depths of approximately 462 and 862 mBGS, respectively. Both of these boreholes were drilled vertically. Borehole diameters at the ground surface were 159 mm. The coring equipment provided rock core with a diameter of 76 mm.

The details of the drilling, testing and sampling accomplished for the two borings are described in [R19], [R20], [R21] and [R26]. These reports describe the procedures used for the work (with references to specific procedural documents), present the geoscientific logs and outline test results for the two borings.

2.3.2.2 Phase 2A

Phase 2A comprises two vertical boreholes, DGR-3 and DGR-4, which were drilled at separate locations north-west and south-west of the proposed DGR facilities, respectively.

DGR-3 was drilled during the period 22 April to 18 July 2008, while DGR-4 was drilled during the period 31 July to 24 October 2008. Similar to DGR-1 and DGR-2, the rock core obtained from DGR-3 and DGR-4 had a diameter of 76 mm. Borehole diameters varied with depth depending upon the depth of casing installation and the addition of telescoping sections of casing, including reaming of the upper rock subsequent to coring to allow casing to be carried as deep as approximately 210 m prior to continued coring.

DGR-3 was drilled to an approximate depth of 869 mBGS, and DGR-4 was drilled to an approximate depth of 857 mBGS. Details are provided in [R22], [R23], [R24], [R25] and [R26].

2.3.2.3 Phase 2B

Phase 2B comprises two inclined boreholes, DGR-5 and DGR-6, which were drilled at separate locations south-east and north-east of the proposed DGR facilities, respectively. Borings DGR-5 and DGR-6 were drilled as inclined borings in order to provide enhanced observations of the steeply dipping joints and fractures in the rock mass.

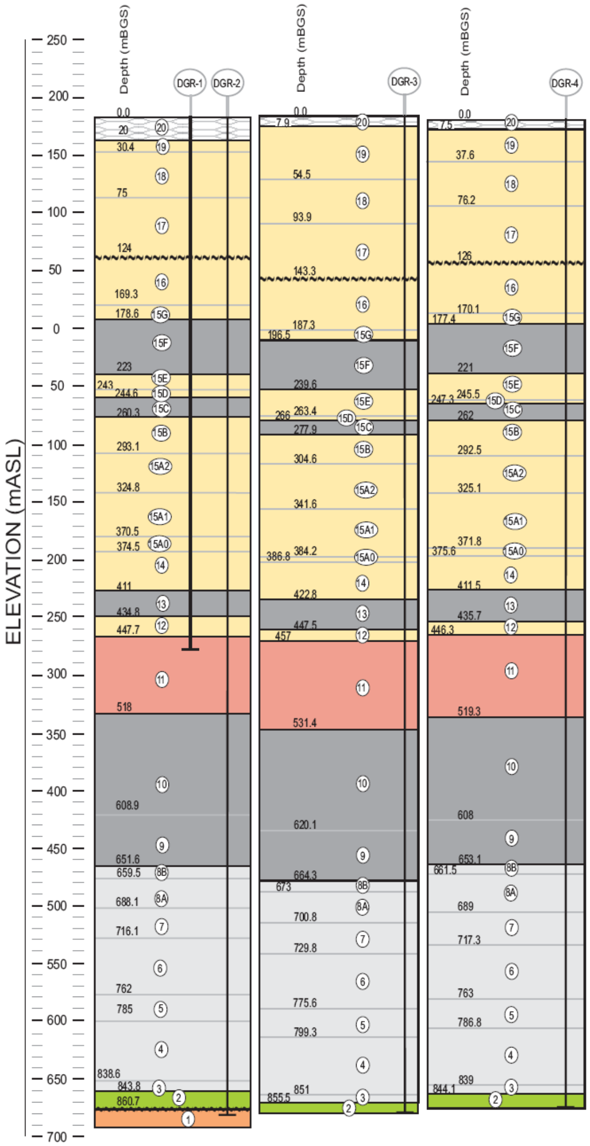
DGR-5 is located in close proximity to the locations of DGR-1 and DGR-2. Drilling for DGR-5 began on 16 December 2008 with the installation of casing to a length of 200 m as measured along the inclined borehole. Casing installation was completed on 08 February 2009. Coring began on 08 September 2009 and finished on 29 October 2009. Final vertical depth for the borehole was 807 m along the incline. It was drilled at an initial azimuth of 190° and an inclination to the vertical of 25° (plunge angle of 65° to the horizontal); however, the final azimuth was approximately 200° and the inclination steepened as the boring progressed, reaching near 10° to the vertical when drilling was completed.

Drilling for DGR-6 began on 03 May 2009 with the installation of casing to a length of 213 m as measured along the inclined borehole. Casing installation was completed on 04 June 2009. Initial coring took place from 13 July 2009 to 09 August 2009 and then resumed from 23 November 2009 to 24 January 2010. Final depth for the borehole was 906 m along the incline. It was drilled at an initial azimuth of 090° and an inclination to the vertical of 30° (plunge angle of 60° to the horizontal). The final azimuth was approximately 072° with an inclination of near 33° to the vertical (plunge angle of 57° to the horizontal) when drilling was completed.

2.3.2.4 Stratigraphic Columns

Based on the observations and logging of recovered rock core from the Phase 1 and Phase 2 borings, a site-specific stratigraphy has been developed for the Bruce nuclear site. The observed stratigraphy is consistent with regional stratigraphic framework in terms of the formations observed in each of the borings and the observed thicknesses of those formations.

The stratigraphic columns developed from observations during all DGR series boreholes are presented in Figure 2-8.



LEGEND - BRUCE SITE STRATIGRAPHY

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
16 BASS ISLANDS FORMATION - DOLOSTONE
15 SALINA FORMATION
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 ANHYDRITE
15A2 A2 UNIT - DOLOSTONE AND ANHYDRITIC DOLOSTONE
15A1 A1 UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITIC DOLOSTONE
15A0 A0 - BITUMINOUS DOLOSTONE

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
8 COBOURG FORMATION
8B COLLINGWOOD MEMBER - BLACK CALCAREOUS SHALE AND ARGILLACEOUS LIMESTONE
8A LOWER MEMBER - ARGILLACEOUS LIMESTONE
7 SHERMAN FALL FORMATION - ARGILLACEOUS LIMESTONE
6 KIRKFIELD FORMATION - ARGILLACEOUS LIMESTONE
5 COBOCONK FORMATION - BIOTURBATED LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LAKE FORMATION - SILTSTONE AND SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. SUBSURFACE STRATIGRAPHIC NOMENCLATURE AFTER ARMSTRONG AND CARTER (2006)

Bedrock Stratigraphic Column at the Bruce Site Based on DGR-1/2, DGR-3 and DGR-4 Data
Technical Report: TR-08-12 Field Bedrock Formations in DGR-1, DGR-2, DGR-3 and DGR-4 Boreholes

Prepared by: NKP
Reviewed by: KGR
Date: Oct 18, 2009

FIGURE 2
Doc. No.: TR-08-12_Figure 2_R0B.cdr

INTERA

Figure 2-8 – Stratigraphic Columns for DGR-1, DGR-2, DGR-3 and DGR-4 [R26]
Note: Labels '15G' and '15F' should be reversed on both plots

2.3.3 Classification by Reach

Based on the stratigraphic sequence and the anticipated hydraulic conductivity of the various rock units, the ground units at the DGR project site were categorised into four different geologic units (denoted as “reaches”) on the basis of generalised anticipated engineering behaviour. These reaches are shown in Figure 2-9. A brief description of these reaches follows with all quoted thicknesses made on the basis of DGR-1 through DGR-4 borehole investigations.

- **Reach 1 – Overburden**
    - 7.5 m to 20 m in thickness.
- **Reach 2 – Dolostones**
    - **Reach 2a – Permeable Dolostones**
        - 160 m to 190 m in thickness.
    - **Reach 2b – Lower Permeability Dolostones**
        - 230 m in thickness.
- **Reach 3 – Shales**
    - 250 m in thickness.
- **Reach 4 – Limestones**
    - 180 m in thickness.
    - Cobourg Lower Member, repository floor level at 686 mBGS.

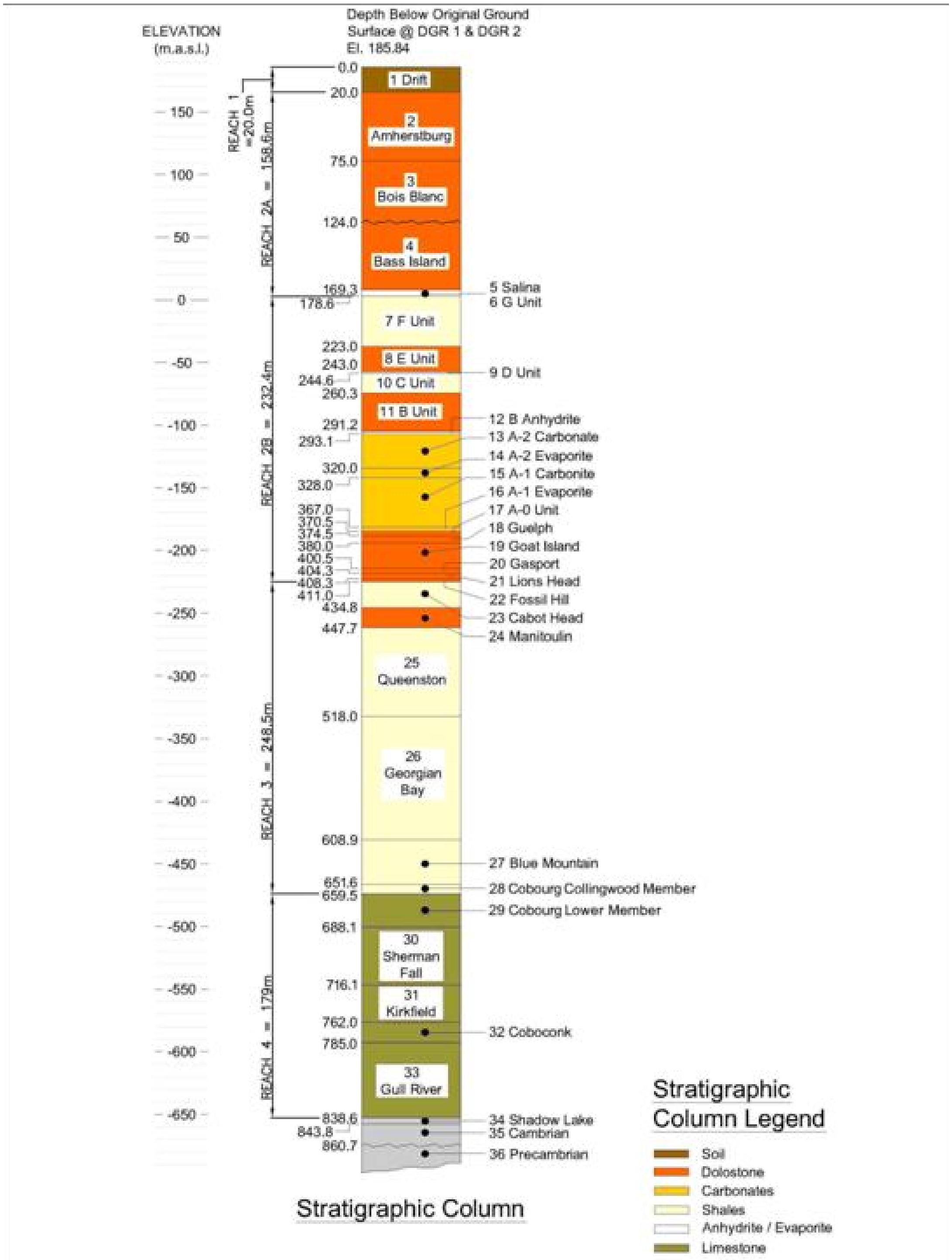


Figure 2-9 – Bedrock Stratigraphic Column based on Investigation Boreholes DGR-1 and DGR-2 showing Reach Characterization

2.3.4 Overburden Deposits (Reach 1)

The total overburden thickness at the proposed DGR site is expected to be between 7.5 to 20 m on the basis of the DGR series and US boreholes. The sequence is subdivided in descending order into the following units:

- A surficial layer of sand and gravel;
- Weathered brown till horizon 2 to 4 m thick overlying fresh grey till comprised of dense silty sand to very hard clayey silt with sand and boulders; and
- A basal gravel unit.

The till has been described as massive in character and although saturated, it appears ‘dry’ when excavated due to its well-graded fine-grained composition and low permeability. In some locations the till is split by a middle sand layer of quite variable thickness and lateral extent that is locally in direct contact with the bedrock. The glacial till is frequently underlain by a basal sand and gravel unit at the weathered bedrock surface.

2.3.5 Bedrock Geology (Reaches 2-4)

The overburden is underlain by near horizontal thick sequence of Paleozoic sedimentary rocks deposited directly upon the Precambrian basement rocks. This sedimentary sequence is dominated by marine sediments deposited in shallow inland seas. These rocks span geologic time periods that include the Cambrian, Ordovician, Silurian and Devonian Periods, which encompass a range of time from approximately 570 million years ago to 360 million years ago. The Paleozoic in Southern Ontario is as much as 1,500 m thick, although at the Bruce site the thickness is in the range of approximately 860 m.

Two sedimentary basins underlie the Southern Ontario peninsula. These are separated by a north-east-south-west trending structural high in the Precambrian basement termed the Algonquin Arch. The Michigan Basin lies to the west of the Arch and the Appalachian Basin lies to the east. The Bruce site is located west of the Arch along the eastern margin of the Michigan Basin, as shown in Figure 2-10. The generalised sequence of Paleozoic rocks in the vicinity of the Bruce site, from oldest to youngest are: Cambrian sandstones and carbonates; Ordovician limestones; Ordovician shales; Silurian rocks in which the lower portion is dominated by dolostones and the upper portion comprises a mix of carbonates and evaporates; and Devonian rocks that are dominated by carbonate formations.

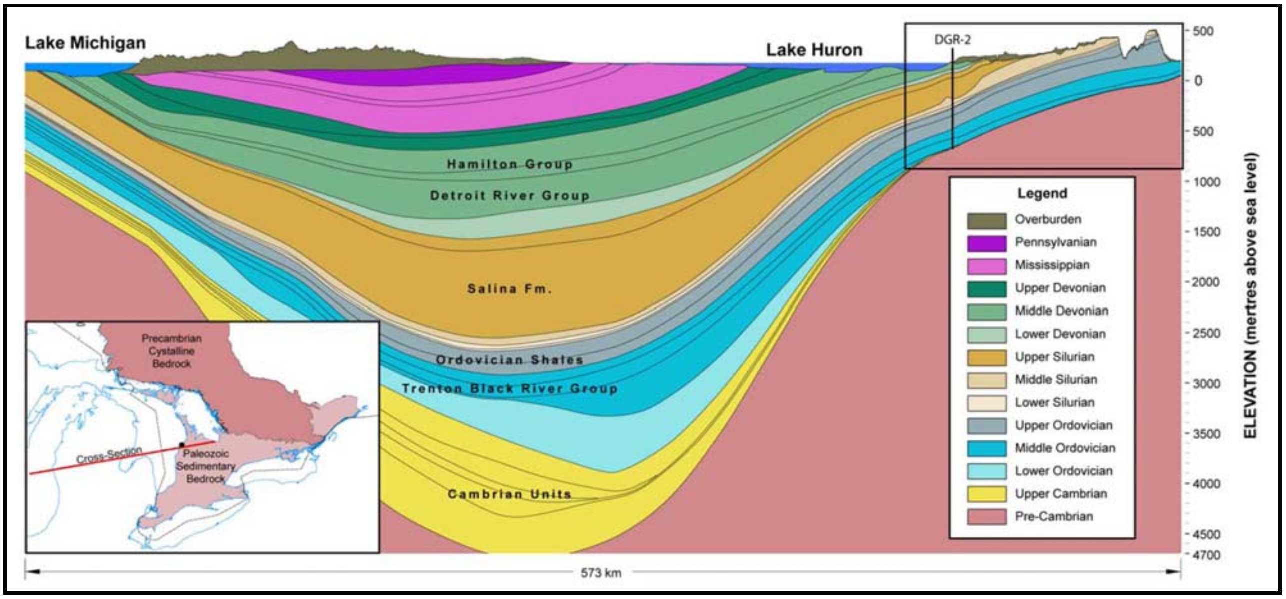


Figure 2-10 – Geological Cross-Section of the Michigan Basin [R14]
Note: DGR-2 Borehole is Offset from Geological Cross-Section

The entire Palaeozoic sedimentary sequence beneath the Bruce nuclear site is in the order of 840 m to 860 m thick and overlies the Precambrian basement. Below the overburden the sequence consists of 390 m to 420 m of Devonian and Silurian age dolostones extending downward through the Lucas, Amherstburg, Bois Blanc, Bass Island, Salina, Guelph, Gasport, Lions Head and Fossil Hill Formations. This sequence is underlain by an approximately 250 m thick section of predominately shale consisting of the Lower Silurian age Cabot Head Formation and Manitoulin Formation dolostone as well as the Upper Ordovician age Queenston, Georgian Bay and Blue Mountain Formations and the Cobourg Collingwood Member. The shales overlie a 180 m thick sequence of Middle Ordovician limestone including the Cobourg Lower Member, Sherman Fall, Bobcaygeon, Gull River and Shadow Lake Formations. Directly below this is a 15 m thick Cambrian sandstone layer which lies above the Precambrian basement.

Correlations between the stratigraphic sequences encountered at the Bruce nuclear site and to similar stratigraphic sequence and units on the south shore of Lake Huron north shore of Lakes Erie and Ontario confirm that the lateral continuity of strata within this sequence (including thickness variations) can be demonstrated over south-western Ontario. Along the north shore of Lake Ontario and east of Toronto, the Ordovician limestone formations come to surface and are exposed within rock quarries and tunnels which have been driven within the Cobourg Lower Member at the Darlington NGS and the previously proposed Wesleyville Thermal Generating Station. These stratigraphic sections demonstrate the lateral continuity of the formations across Southern Ontario including into the Ottawa area, providing evidence that the rock properties established within the strata adjacent to Lake Ontario can be extrapolated to the Bruce nuclear site where the strata occur at depth.

2.3.5.1 Reach 2 Dolostones

Reach 2 consists primarily of dolostone and shaley dolostones in the rock formations listed in Table 2-7.

Formation	Rock Type	Age
Lucas	Dolostone	Middle Devonian
Amherstburg	Limestone and Dolostone	Middle Devonian
Bois Blanc	Cherty Dolostone	Lower Devonian
Bass Island	Dolostone	Upper Silurian
Salina	Predominantly Dolostone and Shale, Anhydrite and Evaporites	Upper Silurian
Guelph, Goat Island and Gasport	Dolostone	Middle Silurian
Lions Head	Limestone / dolostone	Lower Silurian
Fossil Hill	Dolostone	Lower Silurian

Table 2-7 – Reach 2: Dolostone and Shaley Dolostone Formations

The **Lucas Formation** is comprised of light to grey brown, thin to medium bedded, fine crystalline dolostone with stromatolitic laminations. US-series boreholes indicate poor to fair core quality and moderately to highly fractured conditions characterize the Lucas Formation. Several broken zones are also evident [R15].

The **Amherstburg Formation** is a tan to grey-brown, fine- to coarse-grained, bituminous, bioclastic, fossiliferous limestone and dolostone with vuggy horizons and frequent open weathered fractures and brecciated zones. At the Bruce nuclear site the Amherstburg Formation is a dolostone characterized by the presence of abundant rugose and tabulate corals, especially in the bottom 5 to 10 m of the formation. It is considered to be moderately to highly fractured with a fair poor quality [R15].

The **Bois Blanc Formation** is a grey to brown, fine grained limestone and dolostone. Bedding is massive and chert nodules are abundant throughout the formation. The chert material is known to spall when exposed. Joints are very rough with bituminous coatings.

The **Bass Islands Formation** is a light brown, faintly porous, fine grained dolostone with occasional black shale partings. The dolostone is petroliferous with bedding of medium thickness and occasional stylolite beds. Based on borehole-derived measurements at the Bruce nuclear site, the Bass Islands Formation is considered to be of lower quality than the units above, which are described as moderately fractured and of poor to fair quality. A mean Rock Quality Designation (RQD) value of 33% for this unit indicates a rock mass of “poor” quality [R15].

The **Salina Formation** is over 200 m thick and is interbed with numerous dolostone to dolomitic limestone and shale layers. The dolostone within this formation is thinly to medium bedded, medium grained with vugs or infillings of gypsum. Bedding is medium to massive for the dolomitic limestone. Within the shale layers, thin anhydrite beds are present. The shale material tends to slake when exposed. Discontinuities are smooth and planar in the mudstones and shales. In the massive dolostones, the discontinuities are rough and planar to wavy.

The **Guelph, Goat Island, Gasport, Lions Head and Fossil Hill Formations** consist of dolostone and shaley dolostone. The Guelph Formation is porous and therefore has gas and water-bearing potential.

From the Salina Formation to the bottom of Reach 2, the RQD typically ranged from 92 to 100% and the fracture spacing was reported to be generally greater than 3 m. Based on these observations, these units are considered to be sparsely fractured and of very high quality [R15].

2.3.5.2 Reach 3 Shales

Reach 3 consists primarily of shales in the rock formations shown in Table 2-8. They are anticipated to be massive, tight formations of argillaceous rock.

Formation	**Rock Type**	**Age**
Cabot Head	Shale and shaley dolostone	Upper Ordovician
Manitoulin	Argillaceous dolostone	Upper Ordovician
Queenston	Shale and siltstone	Upper Ordovician
Georgian Bay	Shale and siltstone	Middle Ordovician
Blue Mountain	Shale	Middle Ordovician
Cobourg Collingwood Member	Shale	Middle Ordovician

Table 2-8 – Reach 3: Shale Formations

The **Cabot Head Formation** consists of fissile (capable of being split or divided in the direction of bedding planes) shale to shaley dolostone, which then transitions into the Manitoulin Formation. The **Manitoulin Formation** is a fine to coarse grained, thinly bedded dolostone with shale partings.

The **Queenston Formation** is a moderately weathered to fresh, dark red, fine to very fine grained shale with occasional to frequent fresh, green / grey, fine grained mudstone and siltstone layers. The upper beds have less than 30% siltstone interbeds and the lower beds have frequent siltstone beds. The formation is considered to be massive to blocky with some fissile sections and highly susceptible to slaking when exposed. Areas of the Queenston Formation have been known to be a source of natural gas.

The **Georgian Bay Formation** is typically green to blue-grey fissile shale with some light-grey limestone and calcareous siltstone beds. Trace in-filled fractures (halite and pyrite) as well as anhydrite and gypsum nodules are present. Petroliferous and sulphurous odours noted with depth.

The **Blue Mountain Formation** and **Cobourg Collingwood Member** are interbedded black, petroliferous shale and grey mudstone. These formations are predominately shale.

Based on borehole derived measurements, and with the exception of a few localised zones located primarily within the Queenston and Georgian Bay Formations, the rock units comprising Reach 3 can be characterised as very sparsely fractured and of excellent quality [R15].

2.3.5.3 Reach 4 Limestones

Reach 4 consists primarily of argillaceous limestones in the rock formations shown in Table 2-9.

Formation	Rock Type	Age
Cobourg Lower Member	Light to dark brownish-grey, mottled, massive appearance, very fine to crystalline, hard, dense, limestone and argillaceous limestone with abundant fossils.	Middle Ordovician
Sherman Fall	Upper – grey-brown, coarse-grained, shaley limestone. Lower – interbedded grey argillaceous limestone and dark grey calcareous shale.	Middle Ordovician
Kirkfield	Tan to dark grey, fine-grained, calcareous, irregular bedded limestone with dark shale layers.	Middle Ordovician
Coboconk	Light grey, fine-grained, bioturbated limestone.	Middle Ordovician
Gull River	Medium grey, fine- to very-fine-grained (lithographic) limestone / mudstone with dark grey shale laminations, fossiliferous.	Middle Ordovician

Table 2-9 – Reach 4: Limestone Formations

The **Cobourg Lower Member** (the repository host layer) is described as a very fine-grained to coarse-grained, bluish-grey to light to dark brownish grey mottled, thin to medium bedded, hard argillaceous limestone with abundant fossils. The bedding is typically defined by thin shaley or argillaceous partings. Thin shale interbeds are also locally common. A petroliferous odour is noted in this unit. Based on borehole-derived measurements at the Bruce nuclear site, the Cobourg Lower Member is characterized as very sparsely fractured and of excellent quality [R15].

The **Sherman Fall Formation** is described as fine- to coarse-grained, thin to medium bedded argillaceous limestone with abundant dark grey / green shale stringers, laminae, partings and layers. The limestone is somewhat more coarse-grained towards the top of the formation, and the shales become more abundant with depth through the formation. This unit possesses minor zones of lower quality than the rock units above and below [R15].

The **Kirkfield Formation** consists of grey, fine- to medium-grained argillaceous, fossiliferous limestone interbedded with dark grey-green irregular to planar bedded shale. The shale layers that locally constitute up to 20 to 40% by volume of the rock [R1]. A petroliferous odour is noted for this unit.

The **Coboconk Formation** is described as grey to tan-grey, mostly fine-grained with subordinate medium- and coarse-grained beds, fossiliferous, bioturbated limestone with irregular mottled bituminous shale laminae. Locally contains horizons of brown and black chert nodules and rare calcite-filled vugs. Formation is petroliferous and oozes hydrocarbons.

The **Gull River Formation** is light grey to grey, very fine-grained to medium-grained, locally bioturbated and fossiliferous limestone with brown to black bituminous shale laminae, beds and stringers. Stylolites are locally common and the formation is commonly petroliferous and oozes hydrocarbons.

2.4 Hydrogeologic Conditions

The following sections provide an overview of the hydrogeologic conditions that are relevant to the design of the DGR shafts and underground repository. More detailed information about the hydrogeologic conditions is available in [R15].

Unit (Reach)	Physical Properties		
	Rock Type	Thickness (m)	Horizontal Hydraulic Conductivity (K_H) (m/s)
1) Drift (1)	Overburden	20.0	8×10^{-10}
2) Lucas (2a)	Dolostone	10.4	1×10^{-06}
3) Amherstburg (2a)	Dolostone	44.6	1×10^{-06} to 1×10^{-07}
4) Bois Blanc (2a)	Cherty dolostone	49.0	1×10^{-07}
5) Bass islands (2a)	Dolostone	45.3	1×10^{-04} to 1×10^{-05}
6) Salina (2a)			
7) G Unit (2a)	Shaley dolostone with anhydrite	9.3	1×10^{-11}
8) F unit (2b)	Dolomitic shale with anhydrite	44.4	5×10^{-14}
9) E Unit (2b)	Dolostone with dolomitic shale	20.0	2×10^{-13}
10) D Unit (2b)	Anhydritic dolostone	1.6	2×10^{-13}
11) C Unit (2b)	Dolomitic shale and shale	15.7	4×10^{-13}
12) B Unit (2b)	Dolostone with anhydrite	30.9	4×10^{-13}
13) B Anhydrite (2b)	Anhydrite	1.9	3×10^{-13}
14) A-2 Carbonate (2b)	Dolostone	26.6	3×10^{-10}
15) A-2 Evaporite (2b)	Anhydritic dolostone	5.8	3×10^{-13}
16) A-1 Carbonate (2b)	Dolostone with minor anhydrite	41.5	2×10^{-07} upper 4 m; 5×10^{-13} below
17) A-1 Evaporite (2b)	Anhydritic dolostone	3.5	3×10^{-13}
18) A-0 Unit (2b)	Bituminous dolostone	4.0	5×10^{-13}
19) Guelph (2b)	Sucrosic dolostone	4.1	3×10^{-08}
20) Goat Island (2b)	Dolostone	18.8	2×10^{-12}
21) Gasport (2b)	Dolomitic limestone	6.9	2×10^{-12}
22) Lions Head (2b)	Dolostone	4.4	5×10^{-12}
23) Fossil Hill (2b)	Dolostone	2.3	5×10^{-12}
24) Cabot Head (3)	Shale	23.8	9×10^{-14}
25) Manitoulin (3)	Argillaceous dolostone	12.9	9×10^{-14}
26) Queenston (3)	Red shale	70.4	2×10^{-14}
27) Georgian Bay (3)	Grey shale and siltstone	90.9	3×10^{-14}
28) Blue Mountain (3)	Grey shale	42.7	5×10^{-14}
29) Collingwood (3)	Grey shale	7.9	2×10^{-14}
30) Cobourg (4)	Argillaceous limestone	28.6	2×10^{-14}
31) Sherman Fall (4)	Shaley and argillaceous limestones	28.0	1×10^{-14}

Table 2-10 – Thicknesses and Hydraulic Properties of Rock Units at DGR Site
(Unit Thickness – refer to [R26]; Hydraulic Conductivities are for DGR-1/2 – refer to [R15])

2.4.1 Hydraulic Conductivity

Hydraulic conductivity of the surficial deposits and bedrock below the Bruce nuclear site extend over several orders of magnitude (Table 2-10). Highest permeabilities generally occur in the surficial deposits and shallow bedrocks close to the surface, and decrease with increasing depth below ground surface.

Reach 1, the surficial deposits, is characterised by horizontal hydraulic conductivities (K_H) in the order $8x10^{-10}$ m/s with zones of higher K_H.

Reach 2a is comprised of the shallow bedrock layers to a depth of approximately 179 mBGS. Permeabilities in this reach are on the order of $1x10^{-6}$ to $1x10^{-7}$ m/s. There is a zone of high hydraulic conductivity ($1x10^{-4}$ m/s) located in the Bass Islands Formation, within this reach, at 124-144 mBGS.

Reach 2b includes shales and dolostones and cover a wide range of permeabilities. The highest hydraulic conductivity within this reach was recorded in the Guelph Formation and Salina A1 Unit ($3.1x10^{-8}$ and $2.8x10^{-8}$ m/s, respectively), while the lowest hydraulic conductivity was observed in the lower Salina units ($9.7x10^{-13}$ m/s).

Reach 3, comprised primarily of shales is a reach of very low permeability, ranging from $1x10^{-11}$ m/s in the Blue Mountain Formation, to $9.6x10^{-12}$ m/s in the Collingwood Formation.

Much like Reach 3, Reach 4 represents a zone of very low permeability. The limestones of this unit range from $1x10^{-11}$ m/s in the Kirkfield Formation to $9.6x10^{-12}$ m/s in the Cobourg Lower Member (the location of the proposed DGR).

2.4.2 Groundwater Flow Regime

Based on information from previous site investigations it is known that there is a downward hydraulic gradient through the overburden to the underlying bedrock. Groundwater levels within Reach 2a are slightly above 176 mASL, the level of Lake Huron. Groundwater flow in the upper portions of Reach 2a is westward towards Lake Huron. In the vicinity of the proposed location for the DGR, groundwater is found in the shallow bedrock at 9 to 12 m below ground surface, or approximately 184 to 180 mASL, and in the overburden 1 to 2 m below ground surface, or approximately 192 to 190 mASL [R1].

2.4.3 Groundwater Quality

Groundwater quality within Reach 1 and the upper portion of Reach 2a (Amherstburg, Bois Blanc and Bass Islands formations) is typical of that found within limestone and dolostone terrain. In these locations, groundwater has the following characteristics: fresh, hard, neutral to slightly alkaline pH, calcium, magnesium, bicarbonate and sulphate mineralised. Total dissolved solids (TDS) in this area range from 0.5 to 1.6 g/L generally increasing with depth. This fresh water within these bedrock formations is representative of water that has evolved from infiltration or precipitation over time and actively circulates within these areas.

In the deeper shales and limestones of Reaches 3 and 4, the pore water is highly saline, with the highest observed salinities occurring in the Georgian Bay Formation and the Shadow Lake Formation, which are above and below the repository level, respectively. Results are summarised for several of the pore water constituents in Table 2-11.

Sample	Na g/kg H_2O	Cl g/kg H_2O	Br g/kg H_2O	SI(halite)	Ionic strength M
DGR-2 473.19	49.2	229	3.0	-0.22	8.4
DGR-2 482.69	42.7	185	2.2	-0.56	6.7
DGR-2 491.83	52.1	204	2.6	-0.29	8.7
DGR-2 510.12	51.9	229	2.4	-0.15	9.6
DGR-2 523.08	191	439	3.3	1.72	22.5
DGR-2 562.92	108	215	1.0	0.41	16.9
DGR-2 581.32	56.6	225	1.8	-0.23	7.8
DGR-2 609.39	71.3	257	3.3	0.05	9.0
DGR-2 662.09	50.3	164	1.0	-0.63	6.1
DGR-2 663.46	49.6	154	0.8	-0.68	5.8
DGR-2 674.73	54.8	169	2.0	-0.56	6.2
DGR-2 738.00	59.4	167	1.7	-0.57	5.8
DGR-2 770.60	69.3	173	2.4	-0.14	10.5
DGR-2 796.54	54.5	135	1.2	-0.77	5.6
DGR-2 813.70	50.5	162	1.3	-0.50	8.0
DGR-2 830.05	142	306	2.5	0.59	10.8
DGR-2 840.06	42.0	145	1.6	-0.78	5.4
DGR-2 846.31	39.5	133	1.3	-0.86	5.1
DGR-2 852.39	45.0	166	1.5	-0.63	6.0
DGR-2 855.89	45.1	177	2.0	-0.56	6.5
DGR-2 861.90	64.5	203	2.4	-0.24	7.4

Note: Shaded rows indicate samples where halite dissolution is inferred to have disturbed the aqueous leachate concentrations, and therefore these chloride and sodium concentrations are meaningless.

Table 2-11 - Summary of Pore Water Measurements from DGR-2 Borehole [R28]

The pore water is more saline than modern-day seawater. For example, typical seawater has a sodium concentration of about 10.8 g/kg of water. By comparison, sodium concentrations reported for the samples at repository level are around 50 g/kg of water, a factor approximately five times higher than in seawater. Typical chloride concentrations in seawater are about 19.5 g/kg of water, whereas the pore water concentrations for the repository level samples are about 160 g/kg of water, a concentration which is higher than typical seawater by a factor of approximately eight. These waters are representative of ambient waters that have been present in these formations over geological timeframes.

Pore water investigations were carried out on drill core samples from borehole DGR-2 [R28]. A number of analyses were carried out as part of these investigations including:

- Mineralogical analyses.
- Inorganic and organic carbon and total sulphur.
- Clay mineralogy.

In high-salinity systems the water content is significantly less than the pore water content as the pore water of the brine includes the water plus the solutes.

Sulphate minerals were only detected in samples from the Queenston Formation. There was no evidence of chloride minerals found by optical microscopy. The clay mineralogy of a selected subset of rock samples indicated that the dominant clay mineral in all of the samples was illite followed by chlorite.

Aqueous extract solutions were found to be highly mineralised with total dissolved salts ranging from 500 mg/kg to 21500 mg/kg. Combined with the low porosity of most of the samples, this indicates that the in-situ pore water is a high ionic strength. Most of the extract solutions of the investigated samples are of the general chemical Na-Ca-Mg-Cl type except for a small number of samples that were of the Na-Ca-Mg-Cl-SO_4 type from the Georgian Bay, Coboconk and Gull River Formations.

Sulphate concentrations were found to increase with depth to the centre of the Georgian Bay Formation and at deeper levels the sulphate is much lower. There was evidence that there was significant sulphate uptake in the aqueous extracts resulting in gypsum saturation (lower Queenston and upper Georgian Bay Formations) and anhydrite super-saturation in all samples.

Sodium concentrations in the aqueous extracts appear to be representative of the pore water concentrations, but may be overestimated due to potential contributions from ion exchange.

2.5 Geotechnical Conditions

For the purposes of developing the preliminary design of the DGR, both a review of test data from the DGR series boreholes and a desk study were performed. On the basis of these reviews, the engineering behaviour of the soil and rock units in response to shaft and lateral excavation has been evaluated.

The information from the GSCP investigations has advanced the understanding about units of engineering interest to the underground facilities (in particular the emplacement rooms and access tunnels), including the Cobourg Collingwood Member from Reach 3 as well as the Cobourg Lower Member and Sherman Fall Formation from Reach 4. More detailed information regarding the geotechnical interpretations at the repository horizon can be found in [R14].

A desk study review was also performed which examined previous engineering studies, available historical borehole logs and case study information from relevant works in the same geologic formations that will be encountered during construction of the DGR. Relevant studies from southern Ontario and the northern United States were reviewed and compared using a similar set of criteria in order to generate a set of common findings for each of the engineering reaches at the Bruce nuclear site. The projects and investigations that were reviewed (shown in Table 2-12) were organised into studies of significance for each geological reach, with special attention paid to their significance to the DGR project. A map of each location can also be seen in Figure 2-11. For a summary of all works, sources of data and major findings, the reader is referred to [R29].

Rock Unit	Engineering Work	Significance to DGR
Dolostones (Reach 2)	Bruce B NGS Intake Tunnel	- rock mass properties - rock support - groundwater seepage and grouting
	Ontario Hydro US Boreholes	- rock mass properties - rock support
	Goderich Mine Access Shaft	- rock mass properties - rock support - groundwater seepage and grouting - gas hazard - further shaft development - long term maintenance
	Drumbo Mine Access Shaft	- rock mass properties - rock support - groundwater seepage and grouting
	Ojibway Mine Access Shaft	- rock mass properties - groundwater seepage and grouting
Shales (Reach 3)	Niagara River Hydroelectric Development	- rock mass properties - rock support
	Lakeview Generating Station Geotechnical Investigations	- rock mass properties
Limestones (Reach 4)	Darlington Intake Tunnel	- rock mass properties - stress conditions - rock support
	Wesleyville Access Tunnel	- rock mass properties - stress conditions - rock support
Other	Norton-Barberton Mine	- rock mass properties - stress conditions - ground support - groundwater seepage and grouting - long term maintenance

Table 2-12 – Summary of Engineering Works According to Reach [R29]

Figure 2-11 – Map Showing Case Study Locations [R29]

The key lessons learnt from the review of these projects and investigations that are relevant to the DGR project are presented in the following sections.

2.5.1 Reach 1 Overburden

The total overburden thickness is expected to range from approximately 7.5 to 20 m over the DGR site. The overburden consists of primarily glacial and shoreline (lacustrine) deposits and will likely include the following units (listed in order of increasing depth):

- Sand and Gravel – dense to very dense, fine to medium sand, with coarse sand to medium gravel.
- Weathered Till – compact to very dense silt to fine sand, with some coarse sand to medium angular gravel and occasional cobbles.

- Unweathered Till – dense to very dense fine sand and silt, with some coarse sand to medium angular gravel and occasional angular cobbles.
- Basal Gravel – present at the weathered bedrock surface.

2.5.1.1 Reach 1 Anticipated Engineering Behaviour

For Reach 1, representative glacial till composition as well as Standard Penetration Test (SPT) values have been summarised in Table 2-13 and Table 2-14 respectively.

Material	Range (%)
Sand / gravel	30-50
Silt	38-52
Clay	11-18

Table 2-13 – Reach 1: Representative Till Composition [R1]

Material	N-Value Range (blows/ft)	N-Value Average (blows/ft)	Relative Density
Sand	15 to over 100	40	0.6 – 0.8 (dense)
Weathered Till	20 to over 100	50-60	0.8 (very dense)
Unweathered Till	30 to over 100	60-70	0.8 (very dense)

Table 2-14 – Reach 1: Representative SPT Results [R1]

At the DGR shaft locations, the overburden is expected to consist of 2-3 m layers of granular fill and basal gravel overlying and underlying 15 m of sandy silt till [R15]. The till is expected to be cohesive and hard based on the blow counts reported in Table 2-14.

While the overburden is classified as an aquitard [R15], the basal gravel unit and sand layers will have elevated horizontal hydraulic conductivities and essentially infinite recharge potential given the close proximity to Lake Huron. Being below the water table, these soil units will exhibit flowing behaviour and transmit significant volumes of groundwater if not improved in advance of excavation. Ground treatment will need to be used prior to shaft sinking to ensure the excavation remains dry.

2.5.2 Reach 2 Dolostones

Geomechanical properties for the dolostone and shaley dolostone rock formations within Reach 2 have been collected from geomechanical and hydrogeological testing completed during NWMO's GSCP. These values are summarised in Table 2-15. Data from a variety of similar engineering works have also been examined and are shown in Table 2-16.

Formation	Rock Type	Unit Weight (kN/m^3)	Uniaxial Compressive Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Sample Size
Lucas	Dolostone	26.2	98.5 (39.0)	49.9 (1.1)	0.25 (0.06)	2
Amherstburg	Dolostone	25.6	96.9 (-)	28.3 (-)	0.12 (-)	1
Bois Blanc	Dolostone	25.4	94.2 (31.1)	36.8 (9.0)	0.18 (0.04)	3
Bass Islands	Dolostone	27.1	43.4 (12.4)	13.8 (5.8)	0.29 (0.05)	2
Salina F Unit	Shale and Dolostone	25.4	30.8 (14.4)	12.0 (4.8)	0.23 (0.04)	3
Salina C Unit	Shale	23.5	20.2 (9.2)	9.2 (0.5)	0.17 (0.11)	3
Salina B Unit	Dolostone	24.9	7.7 (3.6)	2.5 (2.2)	0.33 (0.15)	4
Salina A2 Carbonate	Dolostone	26.0	60.3 (25.2)	23.0 (8.3)	0.19 (0.14)	3
Salina A1 Carbonate	Dolostone	26.3	116.7 (2.6)	39.7 (9.6)	0.16 (0.03)	2
Salina A1 Evaporite	Dolostone	28.5	195.8 (-)	42.1 (-)	0.36 (-)	1
Salina A0 Unit	Dolostone	27.0	197.6 (45.5)	63.4 (2.9)	0.43 (0.02)	3
Guelph	Dolostone	24.2	60.4 (32.9)	27.8 (12.9)	0.32 (0.08)	3
Goat Island	Dolostone	26.0	148.3 (42.9)	37.0 (5.3)	0.37 (0.05)	3

Table 2-15 – Reach 2: Mean Geomechanical Properties from Site-Specific Data
(Note: Standard deviation shown in parentheses. See [R21] [R24] [R25] [R30])

Formation	Rock Type	Uniaxial Compressive Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Tensile Strength (MPa)
Amherstburg	Dolostone	60 (12-136)	45 (9-117)	-	-
Salina	Dolostone	100 (85-120)	35 (30-40)	0.25 (0.25-0.30)	5 (4.0-7.5)
Salina	Shale	35	8 (8-10)	0.35	1.5 (1.0-2.6)
Salina	Gypsum	30 (25-35)	8	0.35	1.5 (1.1-2.7)

Table 2-16 – Reach 2: Regional Geomechanical Properties [R1]
(Note: Expected range of data shown in parentheses)

Reach 2 has been subdivided into two sub-reaches on the basis of hydrogeologic conditions and the expected quality of the rock mass. As shown in Section 2.4, the hydraulic conductivities in the upper dolostone units (above a depth of approximately 185 m) are significantly higher than those of the lower units. As such, the more permeable dolostone units have been denoted Reach 2a. Below this depth, the Silurian age dolostones and Ordovician age shale and limestone bedrock formations (approximately 430 to 500 million years old) are expected to be highly predictable and of uniformly low permeability (with the exception of the upper 4 m of the Salina A1 carbonate unit and the Guelph Formation). These units have been denoted Reach 2b.

In general, the dominant engineering behaviour for Reach 2a is expected to consist of relatively large groundwater inflows due to high permeability and recharge potential of the rock formations. Therefore, extensive pre-excavation freezing or grouting measures will likely be required to limit groundwater inflows during shaft excavation. Grouting measures will also be required in the permeable units in Reach 2b.

Additional information regarding the geomechanical and hydrogeological properties of these rock formations can be found in documents prepared as part of NWMO’s GSCP [R21] [R23] [R24] [R25] [R30].

2.5.2.1 Reach 2 Anticipated Engineering Behaviour

On the basis of information obtained from NWMO’s GSCP and other projects in the same rock units, the dominant engineering behaviour characteristics for Reach 2 have been interpreted to be:

- High permeability and storativity that will yield high water inflows during shaft sinking. This will likely require extensive pre-excavation freezing or grouting measures in Reach 2a. Grouting in Reach 2b will also likely be required but to a significantly lesser extent than in Reach 2a.
- Highly saline ground water / pore fluid may be present in Reach 2b, which presents corrosion risks.
- Potential for hydrogen sulphide and methane.
- High horizontal in-situ stresses (relative to rock strength) are likely in Reach 2b. The stresses may be less in Reach 2a due to fracturing of the rock mass.

2.5.3 Reach 3 Shales

Geomechanical properties for the shale rock formations within Reach 3 have been collected from geomechanical and hydrogeological testing completed during NWMO’s GSCP. These values are summarised in Table 2-17 and Table 2-18. Data from a variety of similar engineering works have also been examined and are shown in Table 2-19.

The time dependent deformation (swell / squeeze) behaviour under relief of high horizontal in-situ stresses of the Queenston Formation has been well documented. In shales, swelling is caused by three factors – the presence of clay minerals, stress relaxation and the addition of fresh water. Because of the prevalence for time-dependent deformation (TDD), numerous swell tests have been performed on the Queenston Formation. Briefly, the results of swelling tests have confirmed that swelling is orthotropic, strains in the vertical direction are higher than twice those in the horizontal direction, swelling potential increases with time and swelling deformation may last for a long time. Vertical swelling at the proposed DGR facility will be constrained due to the mass of rock above.

Formation	Rock Type	Unit Weight (kN/m^3)	Uniaxial Compressive Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Sample Size
Cabot Head	Shale	25.7	12.6 (-)	3.8 (-)	0.18 (-)	1
Manitoulin	Dolostone and Shale	26.4	70.7 (16.0)	22.3 (9.9)	0.27 (0.05)	3
Queenston	Shale	26.4	48.0 (14.6)	15.3 (7.8)	0.31 (0.09)	14
Georgian Bay	Shale	26.1	40.8 (35.4)	11.5 (12.3)	0.32 (0.25)	11
Blue Mountain	Shale	25.6	21.7 (1.5)	5.2 (0.5)	0.37 (0.46)	3
Cobourg Collingwood Member	Shale	25.9	107.0 (40.0)	30.0 (8.0)	0.22 (0.13)	5

Table 2-17 – Reach 3: Mean Geomechanical Properties from Site-Specific Data
(Note: Standard deviation shown in parentheses. See [R21] [R24] [R25] [R30])

Formation	Brazilian Tensile Strength (MPa)	Sample Size
Queenston	-4.0 (2.2)	6
Georgian Bay	-4.8 (2.8)	10
Blue Mountain	-1.6 (0.6)	9
Cobourg Collingwood Member	-6.3 (1.2)	4

Table 2-18 – Reach 3: Mean Brazilian Tensile Strength from Site-Specific Data
(Note: Standard deviation shown in parentheses. See [R21] [R24])

Formation	Rock Type	Uniaxial Compressive Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Tensile Strength (MPa)	Horizontal To Vertical In-situ Stress Ratio (K_0)
Queenston	Shale	40 (33-46)	12 (6-23)	0.30 (0.10-0.44)	3 (2.0-4.6)	(2-4)
Georgian Bay	Shale	36 (11-97)	20 (11-41)	0.20 (0.10-0.20)	-	(2-20)

Table 2-19 – Reach 3: Regional Geomechanical Properties [R1]
(Note: Expected range of data shown in parentheses)

Recent swelling results from test performed on samples obtained from the DGR-2 borehole investigation [R31] indicate that isotropic swelling potential was measured on samples immersed in fresh water and no swelling was measured for samples immersed in synthetic formation (saline) water. The swelling potentials that were measured in fresh water are less than typical measurements made elsewhere – but only slightly so (0.19% versus 0.3% for Queenston shale). Since fresh water will condense during construction and may migrate during shaft sinking from the upper reaches of the shaft to the Reach 3 shales, monitoring of time dependent deformation (swell / squeeze) behaviour may be necessary to assess the magnitude of this effect.

During DGR-5 logging, a total of seven joints were observed in the Reach 3 shales (Georgian Bay Formation, Blue Mountain Formation and Cobourg Collingwood Member), which could be divided into two different VSJ sets. These joints, shown in Table 2-20, were noted as smooth, planar to undulating, tight to very tight, with some having halite or calcite coatings.

	No. of Occurrences	True Dip Direction	True Dip	Roughness	Aperture
Joint Set #1	5	210	84	Smooth, planar to undulating	Tight to very tight
Joint Set #2	2	130 / 310	88	Smooth, planar to undulating	Tight

Table 2-20 – Sub-Vertical Joint Sets Observed During DGR-5 Logging [R14]

Additional information regarding the geomechanical and hydrogeological properties of these rock formations can be found in documents prepared as part of NWMO's GSCP ([R21], [R23], [R24], [R25] and [R30]).

2.5.3.1 Reach 3 Anticipated Engineering Behaviour

On the basis of information obtained from NWMO's GSCP and other projects in the same rock units, the dominant engineering behaviour characteristics for Reach 3 has been interpreted to be:

- Extremely low permeability, therefore significant water inflow during mining is unlikely.
- The base of the Reach 3 shales are believed to have both methane and hydrogen sulphide off-gassing potential. As these are known petroliferous formations, flowing gas is a possibility (particularly in the Georgian Bay and Queenston formations). In unventilated conditions, the maximum safe concentration limit for these gases could be reached in a matter or hours or days.

- TDD due to swelling, squeezing and creep effects may occur upon relief of initial stresses (excavation) and introduction of fresh water from upper rock layers (shunt flow along shaft extrados).
- High horizontal in-situ stresses (relative to rock strength) with ratio of the principal horizontal stress to the principal vertical stress of two or greater.
- High susceptibility to slaking upon exposure.
- Highly saline pore fluid, which is a potential corrosion risk.
- Low tensile strength along bedding planes.
- Highly fissile (i.e. capable of being split or divided in the direction of bedding planes).

2.5.4 Reach 4 Limestones

The DGR access tunnels and emplacement rooms will be constructed in Reach 4 and, specifically, the Cobourg Lower Member. The following sections describe the anticipated behaviour of this unit. Table 2-21 and Table 2-22 provide representative geomechanical behaviour parameters for the Cobourg Lower Member and Sherman Fall Formation from Reach 4.

	Unit Weight (kN/m^3)	Uniaxial Compressive Strength (MPa) *	Elastic Modulus (GPa)	Poisson's Ratio	Brazilian Tensile Strength, T (MPa)
Average	26.4	119 111	49.4	0.29	-6.4
Standard Deviation	0.20	24 24	16.9	0.09	1.7
Minimum	26.0	58 58	17.4	0.02	-8.9
Maximum	27.1	166 166	86.6	0.59	-3.7
Sample Size	34	54 34	132	127	9

Table 2-21 – Reach 4: Cobourg Lower Member Strength Parameters [R14]

*Note: Upper value reflects inclusion of point load test data (PLT), while lower value reflects Unconfined Compressive Strength (UCS) tests only. In future, only UCS test data should be used.

	Unit Weight (kN/m^3)	Uniaxial Compressive Strength (MPa)	Elastic Modulus (GPa)	Poisson's Ratio	Brazilian Tensile Strength, T (MPa)
Average	26.4	49	30.9	0.24	-4.9
Standard Deviation	0.22	16	18.0	0.12	1.6
Minimum	26.1	32	4.8	0.03	-8.1
Maximum	26.7	75	73.1	0.47	-3.2
Sample Size	8	8	22	19	7

Table 2-22 – Reach 4: Sherman Fall Strength Parameters [R14]

More information regarding Reach 4 characterisation is given in [R14].

2.5.4.1 Cobourg Lower Member Geometry

The formation contacts depth / elevation data taken from the stratigraphic columns indicate that the sedimentary bedding structure of the rock dips to the west-south-west as would be anticipated from the regional geology given the location of the DGR site west of the Algonquin Arch. With consideration for the formations of direct interest to the DGR facilities, it can be seen that the formation contacts at the top of the Cobourg Collingwood Member, the Cobourg Lower Member and the Sherman Fall Formation are lower in boreholes DGR-3 and DGR-4 than in DGR-2. Treating these contacts as planar features, the contact elevations in the three borings can be used to determine the average dip of the sedimentary structure in the immediate vicinity of the DGR. This was accomplished though the development of a 3D model using data shown in Table 2-23. The calculated strike and dip values for these contacts are presented in Table 2-24.

Borehole	Surface Elevation (mamsl)	Depth to Top of Cobourg Lower Member (m)	Depth to Bottom of Cobourg Lower Member (m)	Thickness of Cobourg Lower Member (m)
DGR-2	185.84	659.5	688.1	28.6
DGR-3	187.35	673.0	700.8	27.8
DGR-4	181.60	661.5	689.0	27.5

Table 2-23 – Borehole Spatial Orientation Used to Generate 3D Formation Model
(NAD83 UTM Z17N) [R14]

	Strike		Dip (degrees)		Dip (percent)	
Formation	**Value**	**Std Dev**	**Value**	**Std Dev**	**Value**	**Std Dev**
Cobourg Collingwood Member	166.3	0.3	0.6	0.0	1.1%	0.1%
Cobourg Lower Member	164.7	2.5	0.6	0.0	1.1%	0.0%
Sherman Fall	162.5	0.5	0.6	0.0	1.1%	0.1%
Average	164.5	1.9	0.6	0.0	1.1%	0.0%

Table 2-24 – Summary of Strike and Dip Values of Formation Contacts at Repository Level [R14]
(Note: Dip Direction is 90 Degrees Clockwise from the Strike.)

Regionally, dip values are reported to be relatively flat at 0.3 to 0.5 degrees. Formations at the DGR site appear to have a local dip of approximately 0.6 degrees or 1.1 percent at an azimuth of 255° (nominally west-south-west), which is slightly steeper than the reported regional average [R14].

The formation contacts depth / elevation data taken from the stratigraphic columns also indicate that the thicknesses of the three formations of interest for the underground facilities are relatively constant across the site. Based on formation contacts logged in the three deep borings (DGR-2, -3 and -4), the differences in maximum and minimum thickness observed in each boring for each of the three formations varies by no more than 1 m.

2.5.4.2 Cobourg Lower Member Cross Anisotropic Behaviour

Due to the process of deposition, sedimentary rock mass characteristics are often very different in the horizontal direction (through a single bedding unit) and the vertical direction (which crosses several bedding units). Understanding the directional variation of strength and stiffness parameters is important in properly characterising the rock mass and predicting failure mechanisms.

Through a review of limited DGR site specific test data and data collected during the construction of the Darlington NGS cooling water intake tunnel, the following interpretations can be made regarding the cross-anisotropic behaviour of the Cobourg Lower Member:

- The Unconfined Compressive Strength (UCS) in the vertical direction is not expected to be significantly different than that in the horizontal plane. At the Darlington NGS cooling water intake tunnel, an average UCS of 87 MPa was recorded for the horizontal direction while a UCS of 110 MPa was recorded for the vertical. This is an increase of 26%. As the strength is expected to be less in the horizontal direction, it is recommended that a reduced strength be used when modelling roof and floor failure as horizontal UCS will play a much larger role in determining failure characteristics.
- With respect to stiffness, both the Darlington NGS and Bruce nuclear site data indicate that the horizontal stiffness will be approximately 20 percent higher than the vertical. This is a relatively minor increase that will not have a significant impact on design of the facility or the failure characteristics.
- While no direct tensile strength test data was obtained, a reduction in vertical tensile strength from Brazilian testing is anticipated given that the limestone layers are separated by thin shale partings.

It is important to note that some of the cross anisotropic deformation test specimens for the DGR site were described as “not properly cored,” and separated along open bedding planes during retrieval. As scale effects were not incorporated, caution is recommended when using these measurements [R24].

2.5.4.3 Cobourg Lower Member Bedding

The dominant structural feature of Reach 4 is the bedding. The bedding in the rock is typically defined by the presence of shaley partings and layers; however, both the geoscientific and geomechanical logging noted that the upper part of the Cobourg Lower Member generally has non-distinct bedding planes with the bedding becoming more distinct towards the base.

During vertical coring it was observed that core runs (3.05 m) were sometimes recovered as intact 3.05 m lengths, indicating that in-situ the rock would be anticipated to behave as a very thick bedded to massive rock. Subsequent to core recovery however, the rock was observed to separate with handling and time (to a lesser extent) along shaley partings in the limestones and along internal layers within the thicker shale.

On the basis of the geomechanical logging in the Cobourg Lower Member separations along the shaley partings (planes of weakness) are anticipated to have an average vertical spacing of 0.7 m. Incipient planes of weakness are anticipated to be more closely spaced in the overlying Collingwood Member and the underlying Sherman Fall Formation, both of which have abundant shale interbeds.

2.5.4.4 Cobourg Lower Member Vertical and Sub-vertical Joints

During geomechanical logging of borings DGR-3 and DGR-4 there were no observations of near-vertical to vertical joints in the Cobourg or Sherman Fall Formations, although there were a few observations of moderately inclined (dips 35° or less) joints.

Over the horizontal distances spanned by the inclined DGR-5 and DGR-6 boreholes no vertical or sub-vertical joints were observed.

Based on the available observations of rock core and the reported regional information on joint orientations, the Cobourg Lower Member is interpreted to have widely spaced steeply dipping joints that, for the scale of the engineering works, will not be of significance to rock mass behaviour. It is anticipated that a few steeply dipping joints, oriented approximately orthogonal to each other and the bedding, may be encountered in the repository excavations with an anticipated average spacing of 10 m or more. This combination of joint orientations coupled with the bedding in the rock mass may result in block or wedge formation that may require localised support.

2.5.4.5 Cobourg Lower Member Time Dependent Deformation

Experience at the Wesleyville and Darlington sites indicate that time dependent deformations are possible in the Cobourg Formation. Given the limited shale content of the Cobourg Lower Member at the DGR site and the low minor amount of deformation recorded at Darlington, TDD is not believed to be of engineering significance to the planned excavations or rock support.

2.5.4.6 Cobourg Lower Member Assumed Engineering Behaviour

The observations made during coring and sampling have been related to the anticipated geomechanical behaviour of the DGR excavations:

1. Projecting the inclination of the dip for vertical and sub-vertical joints in overlying units over the depth of the height of the Cobourg Lower Member suggests that the spacing of such joints would likely be in the tens of metres. In this context, the spacing of such joints relative to the engineering scale of the pillars would mean that such features would likely not control the behaviour of the rock pillar as previously thought. Such features when encountered should be considered a localised structural feature to be addressed by supplemental rock support.

2. The Cobourg Lower Member rock mass is considered to be intact, massive rock separated by discrete incipient planes of weakness.

3. The rock mass certainly appears to be massive due to the excellent coring and sampling program underway at the Bruce nuclear site. However, during the logging observations conducted during DGR-3, it was evident that horizontal bedding and planes of weakness did exist from the relatively intact appearing core lengths. While such features are to be expected from any sedimentary unit, it is their spacing and characteristics that is of importance from a geomechanical perspective.

4. It should be expected that the rock mass behaviour of the DGR emplacement rooms and access tunnels in response to excavation will be dominated by the behaviour of sub-horizontal bedding planes and other zones of weakness oriented in the plane of deposition.

5. If not supported in a timely manner the rock mass may separate along horizontal planes (either at bedding planes or between planes through intact rock) in the roof and floor areas.
6. Between bedding planes and zones of weakness (shale interbeds), the rock mass should behave as intact rock. The strength of the intact rock layers can be predicted using intact rock strength and deformation parameters obtained from laboratory tests.
7. Intact rock mass strength parameters should be scaled from intact sample values to reflect the larger size of bedding units.

For additional information on the behaviour of the Cobourg Lower Member, refer to the Geotechnical Interpretive Report [R14].

Based upon these observations, it is reasonable to assume there is a substantial difference between the performance of the horizontal planes of weakness and the limestone. Pillar, roof and floor behaviour would likely be dominated by the planes of weakness, meaning the extent of failure would be governed by the depth of these features. As the planes of weakness are typically defined by thin, smooth shale layers, the vertical tensile strength will be much smaller than that of the intact limestone, indicating that slabbing will be a concern in the roof. Reference case strength parameters for the Cobourg Lower Member incipient planes of weakness are presented in Table 2-25.

Parameter	Expected Value
Cohesion, c (MPa)	0.3
Tensile Strength (MPa)	0.6
Friction Angle, Φ (degrees)	40
Normal Stiffness, K_n (GPa/m)	250
Shear Stiffness, K_s (GPa/m)	25

Table 2-25 –Parameters for Incipient Planes of Weakness in the Cobourg Lower Member [R14]

Between the planes of weakness, the Cobourg Lower Member would behave as a massive, intact rock in a moderate stress environment. The high competency of the rock suggests that brittle failure (crushing) would likely exist in the wall of the emplacement room pillars and roof of the panel access tunnels.

2.5.4.7 Cobourg Lower Member Gas Hazard Potential

There is a potential for gas occurrence in the rock formations at the repository level. Regionally it is known that hydrocarbons occur in the subsurface within certain formations, including portions of the Devonian, Silurian, Ordovician and Cambrian [R14]. Known reservoirs of hydrocarbons occur at considerable distance from the DGR site, principally in south-west and eastern Ontario.

On the basis of the nature of the rock units, historical experience, precedent underground construction experience in the same rock units and observations during borehole investigations, it is concluded that there is potential for the presence of hazardous gases in the rock units at the DGR site. As such, the following notes regarding this gas hazard are made:

- For the purposes of design, the Cobourg Collingwood Member and Cobourg Lower Member are believed to have minor methane and hydrogen sulphide off-gassing potential. In unventilated conditions, the maximum safe concentration limit for these gases could be reached in a matter of several months.
- As the Cobourg Lower Member is a tight unit and there is limited potential for inflow, there are limited pathways for hazardous gas to travel through the rock mass. As such, only a small gas risk is posed to the repository as long as appropriate ventilation is used.
- During shaft sinking and lateral development, appropriate hazardous gas (including methane and hydrogen sulphide) monitoring equipment should be used. During the construction and operations phases, monitoring should be completed at regular intervals (to be determined). The frequency of monitoring can be reduced based on observed conditions.
- Based on preliminary site characterisation, it is expected that radon gas and its products of decay do not pose a significant risk to the DGR. Upon commencement of excavation of the DGR level and at regular intervals (to be determined), radiological surveys should be undertaken to assess any potential for Radon concerns.
- Assessment of the gas hazard at the DGR should continue over the next stages of design to better define the gas distribution and quantify gas concentration and mixture composition. If additional analyses are required, these could be completed during drilling of shaft pilot holes.

2.5.5 Geomechanical Spatial Variation

For the purposes of design, no lateral and vertical trends exist in the currently available geomechanical data across the aerial and depth ranges of the DGR emplacement rooms and access tunnels. This means that for each of the geomechanical properties of interest to the geomechanical modelling, the available data can be aggregated and each obtained test value can be treated as a data point from the same population of data to develop sample population parameter statistics.

Given the weak trend observed showing a decreasing UCS with depth, an observational design approach will be adopted during construction where rock support can be escalated in response to observed trends in the rock mass conditions.

Based upon the UCS spot test results, when strength is measured at a particular location, the distribution of strength values at that point will be less than the distribution across the repository. As such, the spot test value is considered to be more representative of the strength at that specific location.

2.5.6 In-Situ Stress Conditions

There are limited available data to describe the state of in-situ stress at and in the vicinity of the DGR site. In particular, no site-specific information is available because in-situ stress testing in boreholes at depths in the order of 600 to 700 mBGS within sedimentary rock are unlikely to yield reliable data. There is, however, some guidance available as to appropriate values to use for design of the repository facilities. Stress magnitudes considered in this section refer to the vertical (σ_v) as well as the major horizontal (σ_H) and minor horizontal (σ_h) principal stresses.

As part of the geoscientific characterization at the site, indirect means of inferring or constraining stress orientation and magnitude were used. This involved determining the presence or absence of breakouts and drilling induced fractures in the deep DGR borings. If present, they would typically manifest as pairs of diametrically-opposite features in the borehole wall that extend along the borehole axis. Such features tend to align with the principal horizontal stresses in the ground.

No occurrences of breakouts or drilling induced fractures were observed based on review of the borehole images, but the presence of ellipticity in the boreholes was noted [R34]. The elongation is consistently in the north-west to south-east direction, leading to the conclusion that the principal horizontal stress direction is north-east to south-west. This is consistent with other studies, such as the World Stress Map (Figure 2-12) [R32] and the compilation of results reported in [R33]. The data reported for north-eastern North America in the World Stress Map project database shows a dominant north-east to east-north-east orientation for the maximum principal horizontal stress. [R33] notes the presence of high horizontal in-situ stresses in the area of southern Ontario and the Great Lakes region of the northern United States, based on available measurements as deep as 5000 mBGS, and report the ratio of major principal horizontal in-situ stress to vertical stress ($K_{oH} = \sigma_H / \sigma_v$) to be between 2.0 to 2.5 and the ratio of minor principal horizontal in-situ stress to vertical stress ($K_{oh} = \sigma_h / \sigma_v$) to be approximately 1.5.

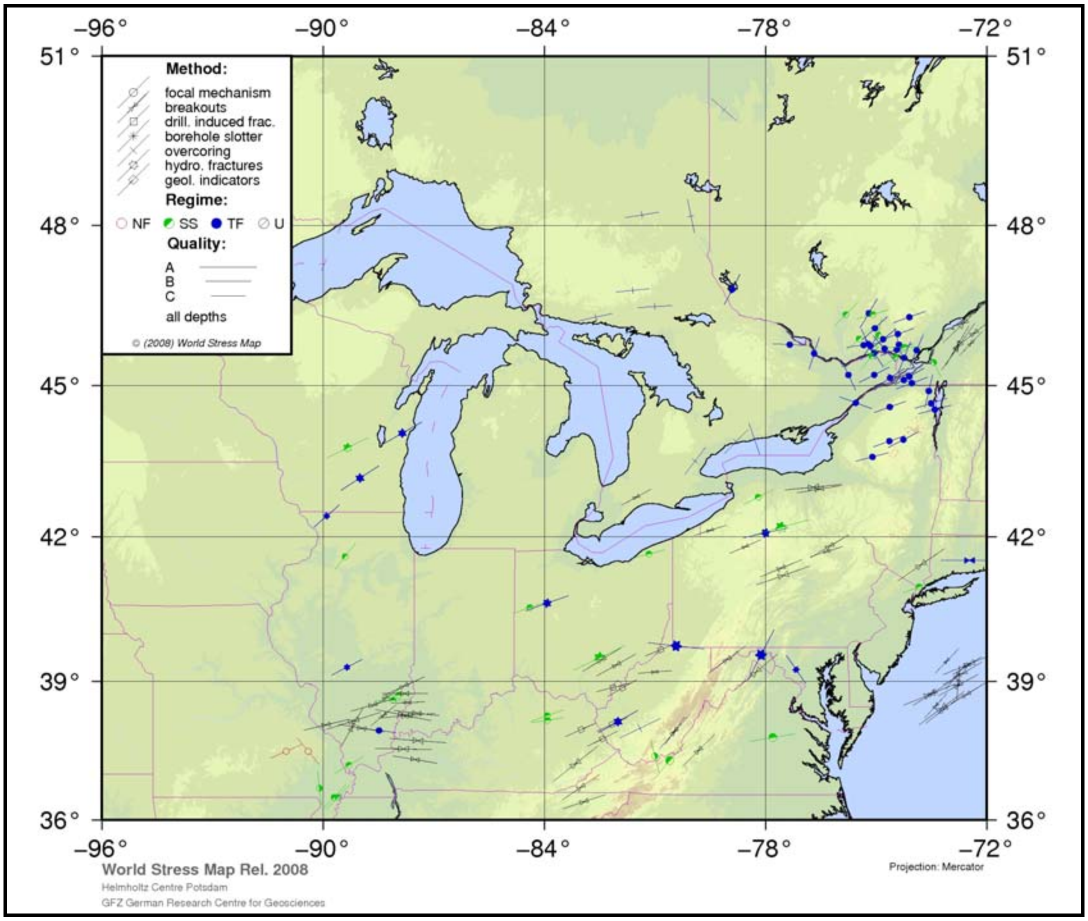


Figure 2-12 – Stress Map of Eastern N. America including Ontario and North-eastern United States
(Extracted from the World Stress Map Project Database 2008 [R32])

For the purpose of this design, a major principal horizontal in-situ stress (σ_H) direction of nominally east-north-east (067.5 degrees) is assumed, with a potential variation between north-east and east. Considering the principal stress ratios reported by others, it is recommended that a range of 2.0 to 2.5 be considered for K_{oH} and 1.0 to 1.5 be considered for K_{oh}, with expected ratios of 2.0 and 1.0 respectively [R33] [R34].

To confirm assumptions regarding the in-situ stress conditions, on which the underground design is based, it is considered essential that confirmatory geotechnical investigations including in-situ stress testing be conducted at repository level prior to performance of excavations associated with the main lateral development of the DGR. Further information on in-situ stress analysis at the proposed DGR site can be found in [R34].

2.5.7 Seismicity

Information in this section is provided from [R35]. For more information, the reader is referred to this document.

South-western Ontario and the Bruce region lie within the tectonically stable interior of the North American continent. The stable interior region of North America is characterized by low rates of seismicity. Figure 2-13 shows all known earthquakes in the region up to December 2008. This figure shows that the Bruce region experiences sparse seismic activity which is an indication of the lack of regional seismogenic features or active faults. Most recorded events have magnitude less than m_N 3 (m_N is local magnitude scale used in Bruce monitoring network), with rare occurrences of larger events within a 150 km radius from Bruce facility. Only one event over magnitude of 1.2 was recorded within 50 km of the site in Lake Huron in September 2008. There are 25 events detected in this region since 1952 with the maximum magnitude of 4.2 measured at 15 km north of Meaford. The historical record is believed to be relatively complete for events of about $m_N > 3.5$ since the early part of this century. It has become more complete at lower magnitudes over the last 10 years with the increase of station density in the region.

Figure 2-13 also includes the current locations of seismographic stations. To improve the local pattern of low-level seismicity (m_N = 1 to 3), three highly sensitive borehole seismometer stations were installed within 50 km radius of Bruce facilities in 2007. Another objective of this new array is to capture microseismic events in the immediate area for the delineation of seismogenic features deep in the bedrock. Despite the lowering of the monitoring threshold to $m_N > 1$, the m_N 1.2 event at 34 km away from Bruce site is the only recording since the implementation of the new array. Historically, there are three other events which occur within this location.

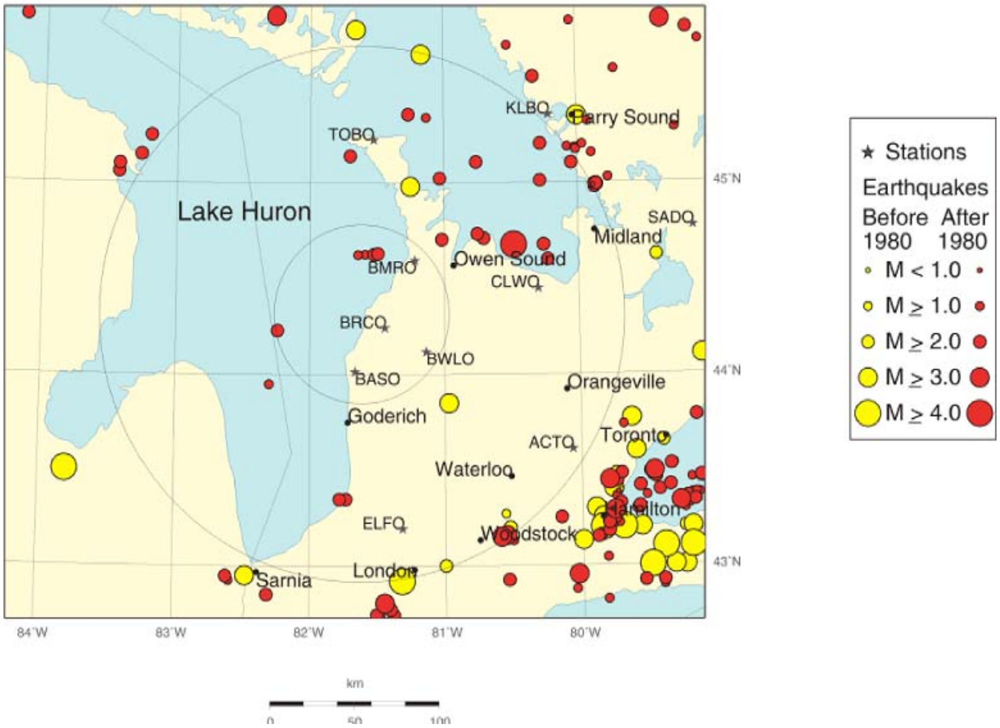


Figure 2-13 – Seismicity in the Bruce region to December 2008
All events plotted in local magnitude (M = m_N). Circles around Bruce site represent 50 km and 150 km radii

Earthquakes in eastern Canada typically occur at depths of 5 to 20 km in the Precambrian basement, on faults that have no surface expression. Furthermore, these faults were formed hundreds of millions of years ago, and may bear little relation to current seismic activity. In the Bruce region, the seismic activity would generally be occurring in the underlying Precambrian basement, which begins at a depth of about 860 m beneath the Bruce site (based on site characterization borehole DGR-2). For the 76 events with known focal depth, the average depth is 7 km. The depth distribution is as follows:

- 38% of the events occurred at depths less than 5 km;
- 43% occurred in the depth range from 5 to 10 km;
- 16% were at depths of 10 to 15 km;
- 2% were at depths of 15 to 20 km.

This is consistent with the earthquake focal depth distribution determined for western Lake Ontario and Niagara seismic zones. Hence, about 80% of the seismicity is distributed randomly over the top 10 km, with the remainder gradually tapering off with depth. Maximum focal depths are likely to be about 25 to 30 km, based on the deepest known events within the eastern North American crust (such as the 1988 Saguenay earthquake, at 28 km). With respect to the more shallow Paleozoic rocks that will host the DGR, there are no known surficial expressions or evidence of large scale faulting in the Bruce Region to support the presence of any shallow earthquake activity.

A recent study of seismicity rates in the Canadian craton reports a Canadian craton rate of M > 6 events of <0.001 pa per 106 km^2 with a variability (standard deviation) of about a factor of three. This density of seismicity (where density is the rate of activity per unit area) is applicable to the Bruce region. This rate could potentially be altered under future glaciation cycles which lead to vertical stress changes that may temporarily increase seismicity rates – but the rate is clearly very low in any case.

A preliminary seismic hazard analysis (SHA) was performed for the Bruce region to estimate bedrock ground motions that are expected for probabilities of 10^{-3} to 10^{-5} per annum. The peak ground accelerations obtained from the SHA are summarised in Table 2-26. The table also presents the results of a 4 x 10^{-3} probability (1/2,500 per annum) event determined from this study and that defined in 2005 National Building Code of Canada (NBC) [R36].

Event (Probability of exceeding p.a.)		**Peak Ground Acceleration**	
		(cm/s^2)	**(% g)**
1 / 1,000		22	2.2
1 / 2,500	Present study	60	6.1
	NBC 2005	44	4.5
1 / 100,000		243	24.8

Table 2-26 – Summary of Seismic Hazard Analysis Result

3. Waste Package Inventory

The waste package inventory information that is presented in this section is based on Appendix D. Appendix D data was, in turn, compiled from, reviewed and, if found necessary, moderated from information contained in the OPG Report "Reference Low and Intermediate Level Waste Inventory for the Deep Geologic Repository" [R4][1]. The DGR inventory will consist of all of OPG's operational and refurbishment L&ILW. This includes both existing stored wastes at the WWMF as well as L&ILW arising from future nuclear reactor operations and refurbishment projects. The total projected emplaced waste package inventory volume is approximately 200,000 m^3 with a total of about 50,000 packages. The uncertainties associated with this projection are discussed in the aforementioned OPG Waste Inventory Report.

All waste packages delivered to the DGR will be required to meet the Preliminary Waste Acceptance Criteria (WAC) [R37].

The WAC includes a requirement that each waste package falls below two specific dose rate limits:

- 2.0 mSv/h at contact with the accessible exterior surface.
- 0.1 mSv/h at 1 metre from the exterior surface.

It is expected that most of the waste packages that are retrieved from WWMF storage can be transferred "as is" to the DGR. The major exceptions will be the ILW, which will require shielding to protect workers during transfer operations, and a portion of LLW containers, which require overpacking. In addition some of the large object wastes, such as the Steam Generators, will be sectioned into smaller segments to allow transport within the Main Shaft cage. The volumes and characteristics of the waste package inventory as presented in this document have taken into account the aforementioned assumptions about shielding, overpacks and segmentation.

The L&ILW inventory can be divided into six categories or groups based on size, mass and handling features. These categories are used for logistics simulation, developing waste package transfer methods, and determining emplacement room sizing and layouts. The LLW and ILW categories are stated in Table 3-1 and Table 3-2 respectively. More details of the anticipated dimensions, volumes and masses are given in Table 3-4. The groups are further detailed in terms of type, transfer methods, handling requirements and dose rates in Appendix D.

Table 3-3 summarises the titles and handling methodology for the different waste package categories or groups. These groups are assigned alpha-numeric names in this table.

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[1] OPG periodically updates their projections of total amount L&ILW that would require disposal. A new projection is expected and may contain some differences relative to the August 2008 projection (on which this design is based). However, NWMO has advised that there are no significant changes that would affect the DGR design; in other words it is expected that the number of packages, package types, emplaced volumes will be essentially the same.

In addition, the L&ILW package inventory is divided by the date the waste is generated. Waste placed into the WWMF prior to this date is termed "pre in-service" and will thus require retrieval prior to transfer into the DGR. New waste arising after the start of DGR operations is termed "post in-service". The L&ILW generated by the nuclear stations will generally be delivered to the WVRB at the WWMF for processing, packing and staging before transfer to the DGR in a disposal-ready form. The one major exception would be fresh Resin Liners (Group E), which could be delivered directly to the DGR WPRB from the nuclear generating stations where they will be made DGR-ready by placing them in sacrificial concrete shields if required by the dose rates of the individual liners.

Waste Category	Group	Container Type	Overpack	Container Code[2]
Operational Wastes	A1	Ash Bin (Old) - bottom ash (AIBO2)	Yes	BINOPK
	A1	Ash Bin (New) - bottom ash (AIBN)	Yes	BINOPK
	A1	Drum Rack - baghouse ash (DRACK)	Yes	BINOPK
	A1	Ash Bin (new) - baghouse ash (AIBN)	Yes	BINOPK
	A2	Compactor Box		B25
	A3	Bale Rack		BRACK
	A1 / A4	Drum Rack - non-processible drums	~10%	BINOPK/ DRACK
	A5	Drum Bin		DBIN
	A6	Non-Pro Bin (47" high)		NPB47
	A7	Non-Pro Bin		NPB4
	A1	Low Level Resin Box (90") (RB90)	Yes	BINOPK
	A8	Low Level Resin Pallet Tank		RTK
	A1	ALW Sludge Box (NPBSB)	Yes	BINOPK
	B1	Shield Plug Container		SPC
	B2	Heat Exchanger		HX
	F4	Encapsulated Tile Hole		ETH
Reactor Refurbishment Wastes	F1	Steam Generators - Bruce A		SGSGMT
	F2	Steam Generators - Bruce B		SGSGMT
	F3	Steam Generators - Pickering B		SGSGMT

Table 3-1 – LLW Package Types by Groups

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[2] Container code represents the final package to be accepted by the DGR.

Waste Category	Group	Container Type	Shield Used	Container Code[3]
Operational Wastes	C1, E1	Resin Liner	No	RL
	C2	Resin Liner in Overpack	No	RLOPK
	F5	Resin Liner Shells from Quadricells	Disposable	-
	E2, F6	Resin Liner - Shield 1	Disposable	RLSHLD1
	E3, F7	Resin Liner - Shield 2	Disposable	RLSHLD2
	E4, F8	Resin Liner - Shield 3	Disposable	RLSHLD3
	D1	IC-2 Liner	Re-useable	THLIC2
	D2	IC-18 T-H-E Liner	Re-useable	THLIC18
	C3	ILW Shield	Disposable	ILWSHLD
	C4	Tile Hole Liner	No	THLSTG3
Reactor Refurbishment Wastes	F9	Retube Waste (Pressure Tubes)	Disposable	RWC(PT)
	F10	Retube Waste (End Fittings)	Disposable	RWC(EF)

Table 3-2 – ILW Package Types by Groups

Group Name	Group Title	DGR Handling Method
A	Bin-Type Waste	Rail Carts and Light Duty Forklifts
B	Heavy Non-Forklift	Rail Carts and Cranes
C	Light ILW	Rail Cart and Light Duty Forklifts
D	T-H-E	Custom T-H-E Handler and Horizontal Emplacement Machine (HEM)
E	Fresh Resin Liners	Rail Cart, Overhead Crane, Light and Heavy Duty Forklifts [4]
F	Heavy Forkliftable	Rail Cart and Heavy Duty Forklifts

Table 3-3 - Summary of Waste Package Groups

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[3] Container code represents the final package to be accepted by the DGR.

[4] Special handling procedures will be required when fresh Resin Liners from nuclear stations are received at the WPRB.

Waste Category	Group	Waste Package Type	Number		Dimensions (m)			Emplaced Volume	Mass [each] (kg)								
			Items	*Waste Packages*	*L*	*W (or dia)*	*H*	*(m^3)*	Contents (Avg.)	Contents (Max.)	Grout	Container	Shield	Pallet or Lifting Frame	Overpack	Total (Average)	Total (Maximum)
LLW Operational Wastes	A1	Ash Bin (Old) - bottom ash (Overpacked)		269	2.54	1.78	1.88	2,286	2,269	2,836		681			1,591	4,541	5,108
	A1	Ash Bin (New) - bottom ash (Overpacked)		816	2.54	1.78	1.88	6,936	1,224	1,530		380			1,591	3,195	3,501
	A1	Drum Rack - baghouse ash (Overpacked)		47	2.54	1.78	1.88	399	1,340	1,675		150			1,591	3,081	3,416
	A1	Ash Bin (new) - baghouse ash (Overpacked)		134	2.54	1.78	1.88	1,139	1,224	1,530		380			1,591	3,195	3,501
	A2	Compactor Box		5,298	1.84	1.12	1.3	14,194	2,236	2,795		486				2,722	3,281
	A3	Bale Rack		1,491	2.29	1.22	1.2	4,999	1,450	1,813		150				1,600	1,963
	A1	Drum Rack - non-processible drums (Overpacked)		296	2.54	1.78	1.88	2,516	1,340	1,675		150			1,591	3,081	3,416
	A4	Drum Rack - non-processible drums		2,663	2.29	1.22	1.2	8,928	1,340	1,675		150				1,490	1,825
	A5	Drum Bin		3,317	1.96	1.32	1.03	8,839	1,160	1,450		290				1,450	1,740
	A6	Non-Pro Bin (47" high NPB47)		15,349	1.96	1.32	1.19	47,256	1,100	1,375		360				1,460	1,735
	A7	Non-Pro Bin (NPB4)		4,978	2.29	1.22	1.47	20,444	726	908		340				1,066	1,248
	A1	Low Level Resin Box (90") (Overpacked)		45	2.54	1.78	1.88	382	2,475	3,094		1,180			1,591	5,246	5,865
	A8	Low Level Resin Pallet Tank		2,126	1.24	1.24	1.68	5,492	1,680	2,100		320			TBD	2,000	2,420
	A1	ALW Sludge Box (Overpacked)		1,534	2.54	1.78	1.88	13,039	1,440	1,800		380			1,591	3,411	3,771
	B1	Shield Plug Container		9	3	1.8	1.8	87	13,653			4,990	6,940			25,583	28,100
	B2	Heat Exchanger	66	82	4.57	2		1,177			TBD					TBD	30,000
	F4	Encapsulated Tile Hole		66	4.6	1.5		537								25,000	27,500
Reactor Refurbishment Wastes	F1	Steam Generators - Bruce A	32	128	2.37 - 4.12	2.40 - 2. 60		1,868								30,407	35,040
	F2	Steam Generators - Bruce B	32	192	2.27 - 2.99	2.50 - 3.60		3,457						970		33,662	34,970
	F3	Steam Generators - Pickering	48	192	3.17 - 4.46	1.80 - 2.50		2,349								26,362	27,440
ILW Operational Wastes	C1	Resin Liner, Unshielded, No Overpack, Pre In-Service Date		288	1.915	1.915	2.15	2,271		3,750		795		670			5,215
	C2	Resin Liner, Unshielded, Overpacked, Pre In-Service Date		92	1.915	1.915	2.15	725		3,750		795		670	1,455		6,670
	E1	Resin Liner, Unshielded, Post In-Service Date		212	1.915	1.915	2.15	1,672		3,750		795		670			5,215
	F5	Resin Liner Shell from Quadricell in Sacrificial Pallet	120	60	2.62	2.62	5.01	2,063		7,500		1,590	17,760	1,800		28,650	
	E2	Resin Liner - Shield 1, Post In-Service Date	86	43	4.25	2.2		695		7,500		1,590	17,760				26,850
	E3	Resin Liner - Shield 2, Post In-Service Date	227	114	4.45	2.4		2,295		7,500		1,590	27,060				36,150
	E4	Resin Liner - Shield 3, Post In-Service Date		538	2.74	2.53		7,411		3,750		795	24,420				28,965
	F6	Resin Liner - Shield 1, Pre In-Service Date, No Overpacks	121	61	4.25	2.2		985		7,500		1,590	17,760				26,850
	F7	Resin Liner - Shield 2, Pre In-Service Date, No Overpacks	700	350	4.45	2.4		7,046		7,500		1,590	27,060				36,150
	F8	Resin Liner - Shield 3, Pre In-Service Date, No Overpack		21	2.74	2.53		289		3,750		795	24,420				28,965
	F6	Resin Liner - Shield 1, Pre In-Service Date, With Overpacks	77	39	4.25	2.2		630		7,500		1,590	17,760		2,910		29,760
	F8	Resin Liner - Shield 3, Pre In-Service Date, With Overpack		231	2.74	2.53		3,182		3,750		795	24,420		1,455		30,420
	D1	IC-2 Liner		20	7.6	0.61		44	3,500	3,850	696	1,000	27,146			32,342	32,692
	D2	IC-18 T-H-E Liner		444	10.7	0.55		1,129	2,200	2,420	792	1,400	27,146			31,538	31,758
	C3	ILW Shield		7,383	1.7	1		9,858	275				2,015			2,290	2,290
	C4	Tile Hole Liner in Sacrificial Rack	201	101	3.453	1.52	0.8	424	3,100	3,500		900		565		4,565	4,965
Reactor Refurbishment	F8	Retube Waste (Pressure Tubes)		458	1.85	1.85	2.25	3,527	2,500				26,600			29,100	35,000
	F10	Retube Waste (End Fittings)		918	1.7	3.35	1.92	10,038	4,300				29,200			33,500	35,000
TOTALS		**LLW**						**146,324**									
		ILW						**54,284**									

Notes: -For source data and assumptions for all data in this table, see individual Waste Package Group Sections in Appendix D.
-L refers to heights for the cylindrical packages that stand on their ends:
Encapsulated Tile Holes,Steam Generator segments (except Bruce B Steam drum segments), Resin Liners and Resin Liner Shields
Mass values marked as "TBD" are to be determined in future engineering. Total mass do not include any allowance for the "TBD" component.

Table 3-4 – Summary of DGR Emplaced Packages' Volume and Mass

3.1 Group A – Bin-Type Waste

Group A containers consist of low level wastes in bin-type containers. It is assumed that all of the Ash Bins (Old), Ash Bins (New), Drum Racks - baghouse ash, Ash Bins (New) - baghouse ash, Low Level Resin Boxes (90"), ALW (Active Liquid Waste) Sludge Boxes and 296 (or about 10%) of the Drum Racks - non-processible drums are to be overpacked in the standard container overpack (BINOPK). For planning purposes, there are anticipated to be a total of 3,141 overpacked bin-type packages. Shielded overpack containers may be used if the dose rates of the packages would exceed the WAC limits in a non-shielded overpack container. Alternatively, special procedures may used to move these higher dose rate packages if their dose rates are not too high and if the total number of packages is relatively small.

Group A containers also include Low Level Resin Pallet Tanks which include plastic containers for the resin. It is likely that steel plates will have to be added to these containers to meet the non-flammable container requirement in the DGR WAC [R37]. The mass of these plates is not included in the mass shown in Table 3-4.

See Appendix D for more detail regarding Group A packages.

3.2 Group B – Heavy Non-Forklift

The Group B packages are relatively heavy and are not appropriate for handling using a forklift.

3.2.1 Shield Plug Containers

The nine Shield Plug Containers represent the smallest quantity of any of the waste package types within the inventory. They are reasonably large and heavy, at approximately 26 tonnes. They are not stackable and must be handled using a crane. The removable shielding and specialised lifting hardware, if required, will be installed at the WWMF during retrieval from storage.

These specialised containers utilise removable shielding panels which will be replaced during the package retrieval process at the WWMF. The mass of these panels is included in the total mass shown in Table 3-4.

The Shield Plug Containers will be retrieved last from storage, to allow additional decay and further reduction in dose rates to allow safe transfer into DGR without excessive amounts of shielding. It should be noted that these containers are currently stored with the integral shielding materials removed. These materials would be replaced before transporting the package.

3.2.2 Heat Exchangers and Heat Exchanger Segments

Prior to transfer from the WWMF, the Heat Exchangers may need to have protuberances (e.g. nozzles, supports) cut off and any openings so created welded closed with a seal plate. This will be done to improve the stacking qualities of these items in the underground emplacement room. All off-cuts can be disposed in low level disposal bins providing dose rates are within the WAC. In preparation for transfer at the WWMF, lifting lugs will be affixed to the exterior of the heat exchangers to allow them to be lifted by crane.

For planning purposes, it has been assumed that all Heat Exchangers will have the same dimensions with the most common size from the Pickering NGS (2.0 m diameter by 4.57 m long) being taken as representative. It has also been assumed that 25 % of the Heat Exchangers will exceed the shaft cage dimensional limitations and they will, thus, be grouted to stabilise the contents and cut into sections. This sectioning process is anticipated to be similar to that used for the Steam Generator Segments, which is described in more detail in Section 3.6.4.

3.3 Group C – Light ILW

The packages in Group C are similar in size and handling features as Group A, but are ILW waste and fewer in number.

3.3.1 Unshielded Resin Liners (Pre In-Service Date)

Resin Liners are vessels of carbon steel, stainless steel or carbon steel in stainless steel overpacks used to store spent ion exchange resins. These resins are considered ILW and normally require shielding to allow safe handling.

A portion of the pre-in-service-date Resin Liners will likely have dose rates such that they can be safely handled without shielding. When the mobile crane is used to retrieve one of these liners out of an in-ground container, it will be lowered into an awaiting sacrificial pallet. A light duty forklift will then be used to load them onto the flat-bed trailer used to transfer them to the DGR.

The remaining Resin Liners currently in in-ground storage and future Resin Liner packages that require shielding will be placed in one of three shield types. The shield types are described in Section 3.6.2.

3.3.2 Tile Hole Liners

The Tile Hole Liners are a steel tube, which has dimensions of 3.0 m long by 0.61 m in diameter. At the time of retrieval, grout will be added to these liners to stabilise the contents and to provide a shielding effect. (However, some liners may have been grouted at time waste was originally placed in liners). These packages have similar contents to the T-H-E Liners described in Section 3.4; however, radioactive decay in these older packages is expected to negate the requirement to further shield them. The mass of the grouted liner will be approximately 2.0 tonnes.

The Tile Hole Liner is equipped with lifting brackets, which will be used to lift the container from the tile hole with a mobile crane. Because of the liners' narrow profile, they will be placed horizontally on racks at the WWMF. Each of the stackable racks will hold two liners. One filled rack will constitute one DGR-ready waste package.

3.3.3 ILW Shield

After the start of DGR operations, OPG has assumed that the waste materials previously destined for the in-ground T-H-E Liners would then be placed in ILW Shields. These shields, which have yet to be designed in detail, are anticipated to be relatively compact in size and lightweight; at 1.0 m diameter by 1.7 m high with a full mass of 2.29 tonnes. Integral forklift pockets will allow the light duty forklift to be utilised for handling.

3.4 Group D – Tile Hole Equivalent (T-H-E) Liners

Long cylindrical carbon-steel metal tubes containing filter elements and vessels, disposable ion exchange columns, core components and other miscellaneous wastes are currently stored in-ground inside IC-2s and IC-18s[5]. These tubes, or liners, are called Tile Hole Equivalent (T-H-E) Liners. The IC-2 holes contain one T-H-E Liner and the IC-18 holes contain seven liners. The forecast inventory of T-H-E Liners is defined in Table 3-5. Each T-H-E liner constitutes one waste package. However, these T-H-E Liners will require shielding during transport to and within the DGR. A reusable steel shield called a Transfer Bell will be used for this purpose.

Name	Liner Diameter (m)	Liner Length (m)	Liner Quantity	Number of Liners per Tile Hole
IC-2	0.6	7.6	20	1
IC-18	0.55	10.7	444	7

Table 3-5 – T-H-E Liner Inventory

The same Transfer Bell design would be used to transfer both the IC-2 and IC-18 T-H-E Liners (see Figure 3-1). Retrieval of the T-H-E Liners will begin with the process of grout stabilisation. Specially developed techniques will be used to fill the interstitial void space with a low-density grout. This grout will act to stabilise the contents and provide some shielding. The mass of the Transfer Bell loaded with a grouted T-H-E Liner is anticipated to be a maximum of 32.7 tonnes.

A mobile crane would be used to position the Transfer Bell over the in-ground container. Once in position over the T-H-E Liner to be retrieved, a grapple will be lowered through the hollow Transfer Bell and into the collar of the liner. Once remote inspection has been used to ensure the grapple is properly secured, the crane will pull the liner out of the in-ground container and up into the Transfer Bell and the open end at the bottom of the Transfer Bell would be closed. The Transfer Bell, with the T-H-E Liner inside, will be rotated to the horizontal position and secured in a custom-made cradle on a flat-bed truck. The loaded bell would then be transported by this truck to the WPRB.

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[5] These In-Ground Containers (ICs) are vertical, lined excavations at WWMF that are used to store ILW and use the shielding effects of the surrounding till. They are used to store either Resin Liners or T-H-E Liners.

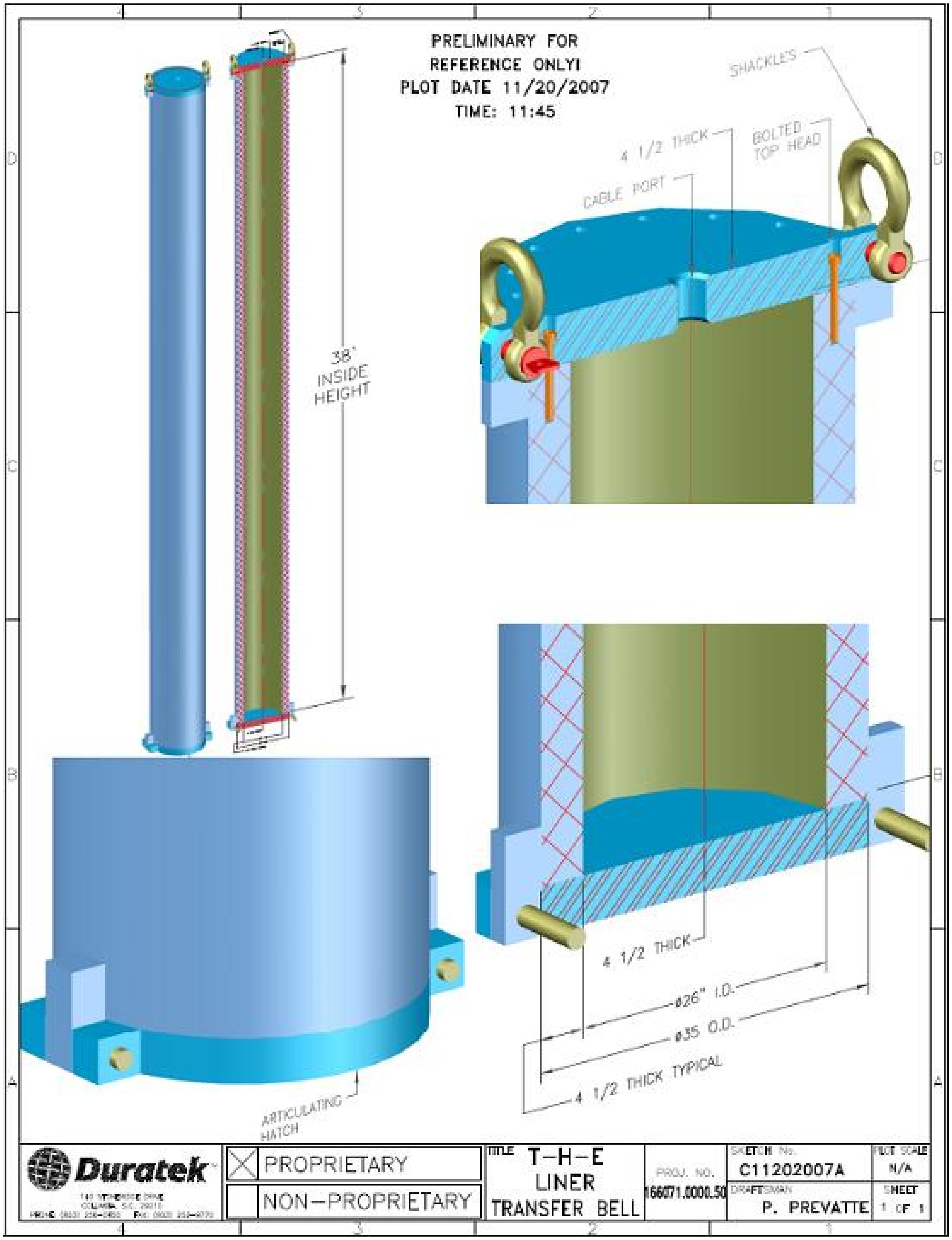

Figure 3-1 – Re-usable Steel Transfer Bell for T-H-E Liners

3.5 Group E – Resin Liners (Post In-Service Date)

The Group E wastes consist only of Resin Liners that are generated post in-service date by the nuclear stations and are assumed to be delivered directly to the WPRB. This is unlike other wastes generated at the stations, which will be sent through the WWMF for receiving, processing and repackaging if required, and inspection to ensure they are DGR-ready. Thus, special handling requirements at the WPRB are required for these packages, as described in Section 6.1.6.

It is anticipated that some of these fresh Resin Liners will require shielding and others will not. At the WPRB, those liners not requiring shielding will be placed into sacrificial pallets and those that do require shielding will be placed in the appropriate shield. The predicted quantities are summarised in Table 3-6. For Shield 1 and Shield 2, two Resin Liners inside the new sacrificial shield will comprise one waste package for transfer into the DGR.

Resin Liner Shield Requirements – Post In-Service Date	Percentage	Number of Liners	Number of Packages
No shielding required	19.9%	212	212
Shield 1 - 250 mm Concrete (2 liners per shield)	8.1%	86	43
Shield 2 - 350 mm Concrete (2 liners per shield)	21.4%	227	114
Shield 3 - 350 mm Concrete with 40 mm Steel Insert (1 liner per shield)	50.6%	538	538
Total		**1,063**	**907**

Table 3-6 - Projected Shielding Requirements for Post In-Service Date Resin Liners

Note that 62 of highest-dose Resin Liners are predicted to exceed DGR WAC dose rate limits [R37] in the Shield 3. One option for dealing with these Resin Liners is to store them for a longer time period to allow additional decay and then transfer to the DGR in a shield. The other option may be to transfer these liners in a Shield 3, but using special procedures under the supervision of a health physicist.

3.6 Group F – Heavy Forkliftable Waste Packages

The Group F packages are large, heavy, and can be handled using a heavy duty forklift.

3.6.1 Encapsulated Tile Holes

Encapsulated Tile Holes (ETH) are LLW, 4.6 m tall by 1.5 m in diameter with a mass of 25 tonnes. For the purposes of this study, it assumed that all ETH packages are comprised of an outer cylindrical steel pipe (9.5 mm thick walls) that encapsulates the waste-filled tile hole that was once in the ground. The contents of the tile hole have already been stabilised with grout and the annular space between the steel pipe and the tile hole is also filled with grout. Concrete is used to seal the base of the steel pipe.

The ETH package has features that allow lifting by forklift. The forklift pockets are an integral part of the outer steel shell. The ETH may be transferred to the DGR by flatbed truck or heavy duty forklift. The ETH package will be in a vertical orientation throughout the entire transfer process.

3.6.2 Shielded Resin Liner Shields (Pre In-Service Date)

In order to safely handle most of the Resin Liners and protect workers they must be placed in shields. For the Resin Liners stored in in-ground containers, new shields will need to be procured. The dose rates on Resin Liners will vary and thus shielding requirements will also vary. The expected dose rates on Resin Liners were examined and a suite of standard shield designs was developed. All shields will be appropriate for handling using a heavy duty forklift.

The “Shield 1” is a 250 mm thick, cylindrical concrete shield, which can accommodate two stacked Resin Liners. This shield will effectively handle 404 of the Resin Liners yielding a dose limit on the exterior of the shield of less than the WAC limits.

Where a Shield 1 does not provide sufficient shielding for the given dose rate of a Resin Liner, a Shield 2 or a Shield 3 may be used. For the Shield 2, a 350 mm thick concrete shield is employed with the ability to stack two liners inside. A total of 700 Resin Liners (amounting to 42 % of the total Resin Liner inventory) are anticipated to use this shield. It should be noted that the maximum mass of this package will be 36.15 tonnes, which exceeds the WAC limit of 35 tonnes. However, the cage payload limit will be 44 tonnes and, therefore, an exception to this design criterion will be allowed to obviate the need for a large number of additional single liner packages. Some Resin Liners in stainless steel overpacks are anticipated to require the level of shielding provided by Shield 2. However, to stay below cage payload limits these heavier Resin Liners will be allocated to the lighter single-liner capacity Shield 3.

The highest dose rate liners retrieved and the aforementioned Resin Liners in overpacks (252 or 15 % of the pre in-service date inventory) will be placed in a shorter 350 mm thick concrete shield with a 40 mm thick steel insert (“Shield 3”). To limit the total mass to ensure that the hoist payload is not exceeded, only one liner will be contained in each of these shields.

The shells from Quadricells are existing shields that were used before in-ground storage of these packages was employed. The concrete shells contain two Resin Liners and are assumed to be disposal-ready. These concrete shells are similar to a Shield 1, but are 4.6 m tall. Lifting eyes will be installed in the shell container lid and the shell container will be lifted by the crane and placed on a sacrificial pallet on a low bed trailer adjacent to the Quadricell. These shells in their sacrificial pallet while being transported underground are the defining package for the height of many of the excavations.

IC-12’s are used to store four Resin Liners and IC-18’s are used to store six Resin Liners. For the Resin Liners that require shielding, an overhead / mobile crane will recover them from the IC’s and place them into the shields, with either a single or two liners placed in a vertical stack inside each shield. The shield, which will have embedded forklift pockets cast into the concrete, will be placed on a flat-bed trailer. The package will be inspected to ensure it meets the DGR WAC and an Integrated Waste Tracking System (IWTS) barcode will be attached. After it has been confirmed that it is DGR-ready, the shield will then be transported to the DGR.

A summary of the projected pre in-service date Resin Liner shielding requirements is provided in Table 3-7.

Resin Liner Shield Requirements – Post In-Service Date	**Percentage**	**Number of Liners**	**Number of Packages**
No shielding required	23.0%	380	380
Resin Liners in Quadricell Shells – 250 mm Concrete	7.3%	120	60
Shield 1 - 250 mm Concrete (2 liners per shield)	12.0%	198	99
Shield 2 - 350 mm Concrete (2 liners per shield)	42.4%	700	350
Shield 3 - 350 mm Concrete with 40 mm Steel Insert (1 liner per shield)	15.3%	252	252
Total		**1,650**	**1,141**

Table 3-7 - Projected Shielding Requirements for Pre In-Service Date Resin Liners

3.6.3 Retube Waste Containers

Retube wastes are associated with the reactor refurbishment process. To date, two types of shielding containers have been used for the re-tube wastes from Bruce A reactors: one, designated for volume reduced components (pressure tube, calandria tubes and calandria tube inserts); and one slightly narrower and longer package, designated for uncut end-fittings. The stackable containers are a steel-concrete-steel construction with a maximum full mass of 35 tonnes.

3.6.4 Steam Generator Segments

The Steam Generators are too large and too heavy to transfer whole into the DGR. Thus, they will be segmented in their storage building or in a nearby building, that would be specifically built for the processing of these Steam Generators and other large objects prior to transfer to the DGR.

Each Steam Generator will be filled with low-density grout to stabilise the internal parts, then cut into sections using a diamond wire saw. Each segment will be sealed with a plate welded to each cut end. These plates will serve a dual purpose of increasing the shielding of the grouted segment, and providing a flat surface to aid stacking in the emplacement rooms. Forklift pockets and other elements to aid stability during stacking will be welded onto one seal plate on each segment to facilitate safe lifting and transfer of these segments.

The internal dimensions of the conveyance are the defining restraints for the size of large segmented sections of the Steam Generators. Table 3-8 illustrates the relationship of the conveyance dimensions to the size of the segmented sections, and the position that the pieces must be in to fit inside the conveyance.

The masses and dimensions account for the attachment of steel plates to seal the cut ends and forklift pockets. The dimensions shown in Figure 3-2, Figure 3-3 and Figure 3-4 are the basic cut lengths and do not include the sealing plates and forklift pockets.

Item	**Length (m)**	**Height (m)**	**Width (m)**	**Mass (tonnes)**	**Positioning in Conveyance (see Notes)**
Conveyance Limits	5.20	13.50	2.65	35.0	Note 1
Pickering Head	Ø 1.80	3.17	Ø 1.80	25.5	Horizontal
Pickering Main	Ø 1.80	3.74	Ø 1.80	26.3	Horizontal
Pickering Steam Drum	Ø 2.50	4.46	Ø 2.50	27.4	Horizontal
Bruce A Head	Ø 2.60	2.37	Ø 2.60	33.7	Horizontal
Bruce A Main	Ø 2.40	3.01	Ø 2.40	26.4	Horizontal
Bruce A Tail	Ø 2.40	4.12	Ø 2.40	35.0	Horizontal
Bruce B Head	Ø 2.50	2.27	Ø 2.50	35.0	Horizontal
Bruce B Main	Ø 2.50	2.99	Ø 2.50	30.5	Horizontal
Bruce B Steam Drum	Ø 3.60	Ø 3.60	2.66[6]	34.9[7]	Vertical

Table 3-8 – Steam Generator Dimensions / Mass Summary

Notes for Table 3-8:

- The conveyance (cage) limits represent the dimensional envelope available for waste packages, including transfer carts, supports, cradles and rigging. The actual internal cage dimensions are 200 mm larger on the two plan axes and 500 mm larger on the height. These allowances allow for manoeuvring loads into and out of the conveyance safely.
- A vertical position means the sealed, flat surfaces of the segmented piece are vertical.
- A horizontal position means the sealed, flat surfaces are horizontal.
- "Ø" indicates diameter.
- Masses include grout, end plates (2.311 tonnes each) and forklift pockets (500 kg/set), and dimensions include sizes of end plates (65 mm each) and forklift pockets (100 mm), where relevant.
- A sacrificial saddle will be attached to each Bruce B Steam Drum segment in order to allow them to be transported and emplaced while standing on their round side. This saddle is assumed to fit within the outermost dimensions of the segment, resulting in a package that is no larger in width, length or height.

The base of the 'horizontal' segments will be fitted with forklift pockets, which will be designed to not only withstand the loads imposed during lifting and handling, but also the loads due to stacking of segments in the emplacement rooms. This category represents all but the 64 Bruce B steam drum segments. These pockets will be welded to the bottom seal plate in the fabrication workshop before the seal plate is installed, in order to minimise radiological exposure. The assembly will be stress-relieved and machined if necessary to remove any distortion caused during workshop fabrication and before it is welded to the segment.

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[6] Note that this dimension is slightly larger than the nominal operating envelope of the cage. However, this is not considered problematic as adequate clearance is still available for this limited number of items.

[7] Includes the mass of the sacrificial support frame.

The ‘vertical’ segment orientation is shown in Figure 6-2, which depicts a three dimensional view of a ‘vertical’ segment positioned in the shaft conveyance.

Segments from the different Steam Generators are described as follows:

3.6.4.1 Pickering Steam Generators

Each Steam Generator will be cut into four segments. All the segments, including the wide steam drum can be placed with their cut faces flat on the floor of the cage, which makes for simpler and quicker handling of these items.

The head end and main sections will be divided into three segments all having a diameter of 1.8 m. The steam drum will form a single segment of diameter 2.5 m. The proposed sectioning is shown in Figure 3-2 with dimensions given in Table 3-8. There are 48 Pickering Steam Generators yielding 192 segments.

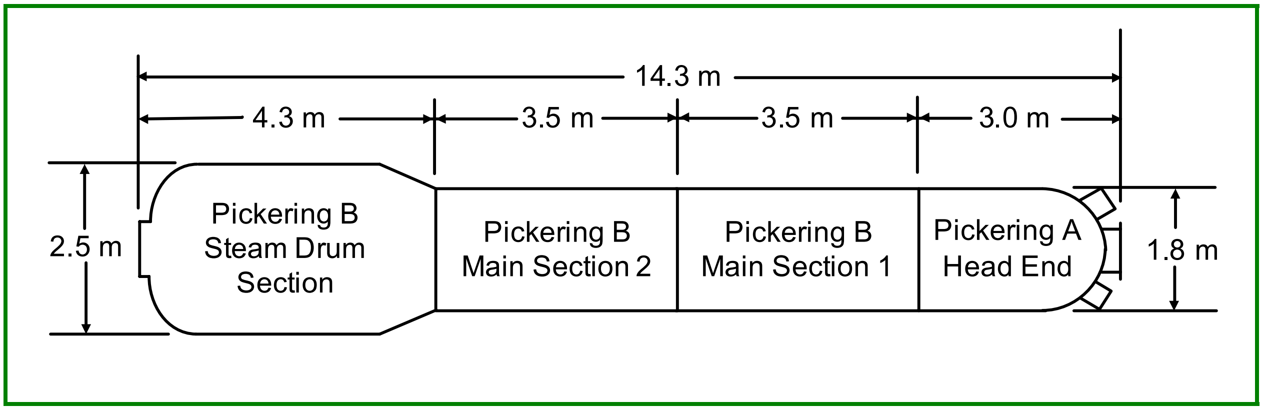

Figure 3-2 – Steam Generator Segments for Pickering

3.6.4.2 Bruce ‘A’ Steam Generators

These Steam Generators will be cut into four pieces. All the segments will be transported in the cage with the cut faces flat on the cage floor.

The head end has a slightly larger diameter (estimated at approximately 2.6 m) than the main and tail sections. The head end of the Steam Generator will become one of the segments. The tail end and main sections will be divided into three segments all having a diameter of 2.4 m. The proposed sectioning is shown in Figure 3-3 with dimensions given in Table 3-8. There are 32 Bruce A Steam Generators yielding a total of 128 segments.

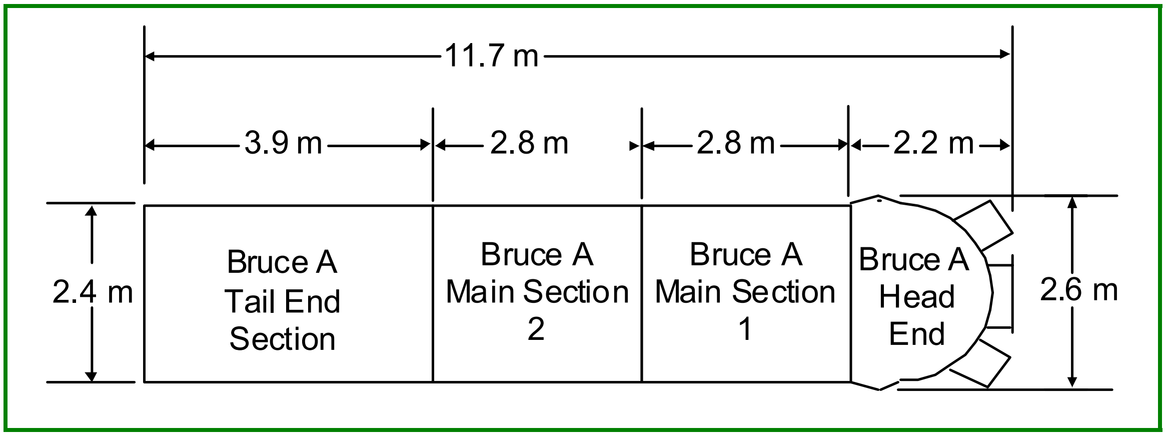

Figure 3-3 – Steam Generator Segments for Bruce 'A'

3.6.4.3 Bruce 'B' Steam Generators

Bruce 'B' has the largest Steam Generators, and will require cutting into six segments. The head and main sections have a diameter of 2.5 m and will be cut into one and three segments respectively. These segments will be able to be transported in the shaft cage flat on their cut faces. The steam drum will be cut into two (2) segments with a large diameter of 3.6 m, making those segments the only ones that will not fit in the hoist cage with the cut edge horizontal. When inserted into the cage in a vertical orientation (i.e. on their round side), they represent the widest package. There are 32 Bruce B Steam Generators yielding 192 segments, of which 64 will be large diameter steam drum segments. These steam drum segments will have seal plates installed in addition to a saddle frame that will allow the segment to be forklift handled and rest in a stable manner on its round side. The forklift pockets will be perpendicular to the seal plates, allowing the minimum distance from the centre of gravity to the forklift mast.

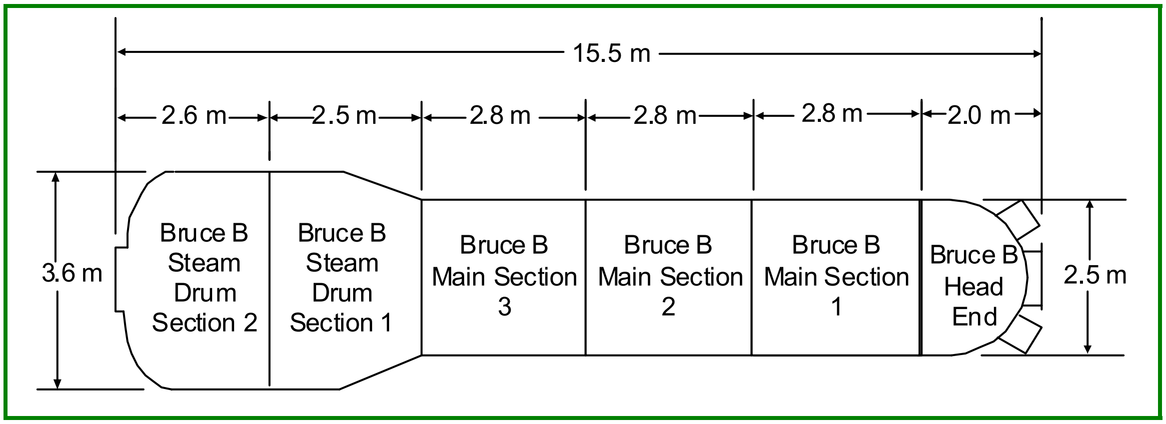

Figure 3-4 – Steam Generator Segments for Bruce 'B'

4. General Arrangement of DGR Facility

4.1 Description of Facility

The DGR consists of above and below ground structures and excavations. Key features of the DGR infrastructure include:

- Surface:
    - WPRB, which will receive waste packages and where the packages are loaded onto rail carts for transfer underground.
    - The Main Shaft, which will provide access to the underground repository for transfer of waste packages, personnel, equipment, materials and downcast ventilation.
    - The Ventilation Shaft, which will act as a second egress and convey the air discharged from the repository.
    - The Waste Rock piles, where all the underground rock excavated during construction of the DGR will be stored.
- Underground:
    - Shaft stations and waste-package off-loading and staging area.
    - A services area with safety refuges, administrative and maintenance rooms.
    - A ramp to access the waste rock loading pocket and the two shaft bottoms from the DGR level.
    - Tunnels to access two panels of emplacement rooms, which will be arranged as single-ended rooms parallel to each other and to the expected direction of the principle horizontal stress of the rock mass.

The preliminary layout of the surface facilities and the link to the WWMF are depicted in Figure 4-1.

The surface structures will all be grouped in relatively close proximity, which facilitates operations and maintenance activities and provides a compact footprint. In addition to the Main and Ventilation Shaft Headframes, there will be various other structures. The large WPRB will receive all radioactive waste packages and transfer these to the Main Shaft cage for transport underground. This building will directly adjoin the headframe and additionally provides the access to the Main Shaft collar for personnel and equipment. A maintenance workshop and store for essential shaft related spares and materials will be attached to the WPRB. An office, control room and Amenities Building will also form part of the Main Shaft complex for administrative purposes, control and monitoring of the DGR, and receiving visitors to the DGR. The hoists for the Main Shaft will of the Koepe friction type, which are mounted within the concrete headframe.

At the Ventilation Shaft, a collar house will be attached to the headframe. As well as having an important function during shaft sinking, the collar house will provide shaft maintenance facilities and an airlock function to ensure that recirculation of exhaust air cannot occur. Unlike the Main Shaft, the Ventilation Shaft is equipped with a double drum, ground-mounted hoist. A separate hoist house is located to the east of the headframe.

The other main features of the surface infrastructure are the Intake Fans and propane heaters, which feed air to ventilate the DGR into the downcast Main Shaft, the Exhaust Fans at the exit from the upcast Ventilation Shaft, an electrical substation, which provides power to the entire facility, both surface and underground, and an emergency generator to provide power in the event of an outage of the Hydro-One supply grid.

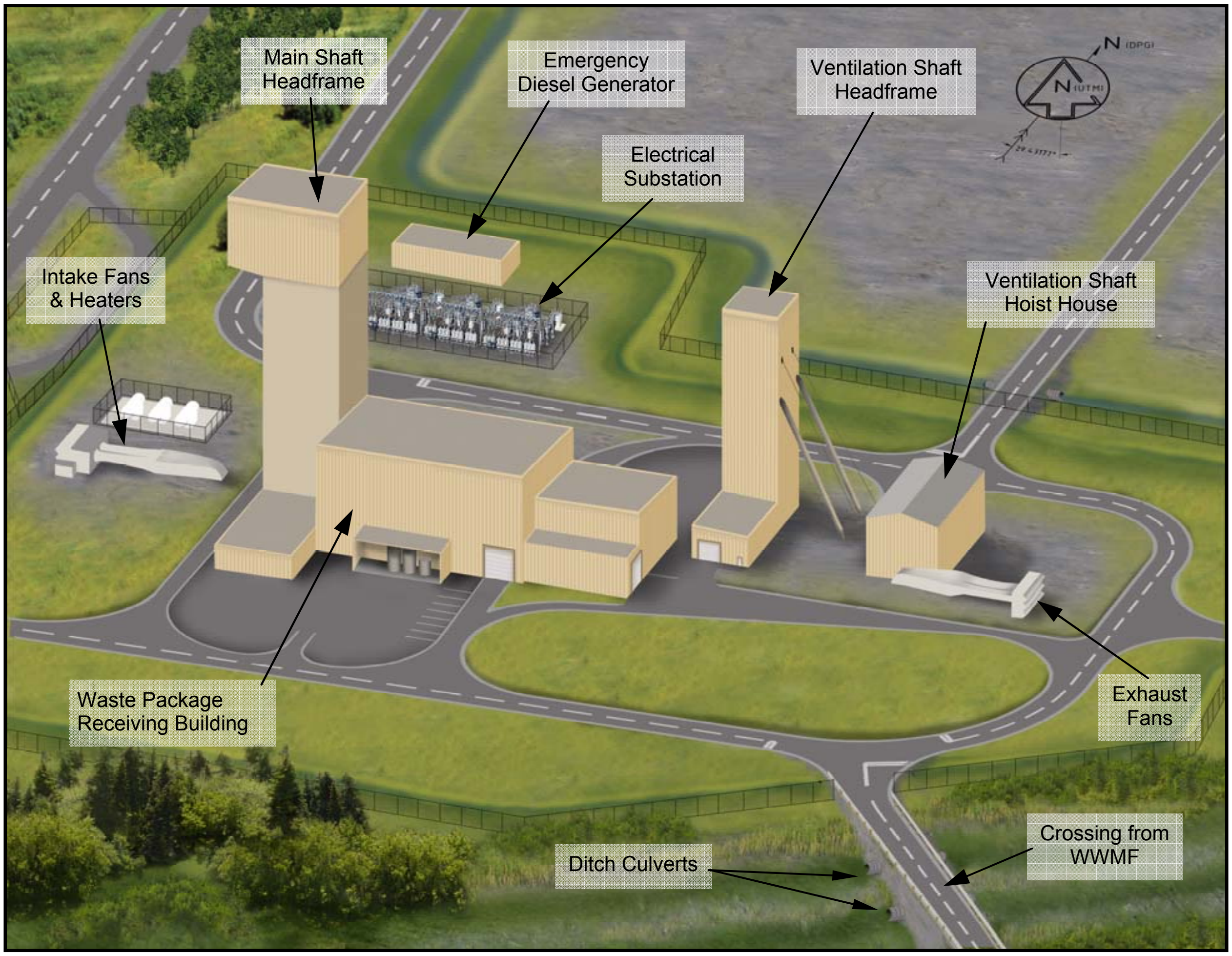

Figure 4-1 – Isometric View of DGR Surface from SE

Detailed descriptions of the structures and surface features of the DGR, together with their functions are given in Section 4.2. The shaft headframes and hoisting systems are described in Sections 4.3.2, 4.3.3, 4.3.5, 4.4.2, 4.4.3 and 4.4.5, and the surface aspects of the ventilation system can be found in Section 5.

The repository access shafts and the underground layouts are described in Sections 4.3, 4.4 and 4.5.

Figure 4-2 depicts an isometric view of the underground arrangements on the DGR level at approximately 686 m below shaft collar level. The collars for both shafts are currently assumed to be at an elevation of 186 mASL. The final elevation for the shaft collars will be evaluated once a study of storm-event water levels, being performed by NWMO, is completed.

Two panels of waste emplacement rooms will be located to the east of the access shafts. The emplacement rooms will all be approximately the same length (250 m) and will be arranged parallel to the assumed direction of the major principal horizontal in-situ stress (ENE).

A services area will be constructed around the two shafts and will contain refuge stations to ensure personnel safety in the event of any underground incidents such as fire or spills, sanitary facilities, an office and lunch room, maintenance workshop, wash bay and refuelling stations for underground mobile equipment, geotechnical laboratory and stores.

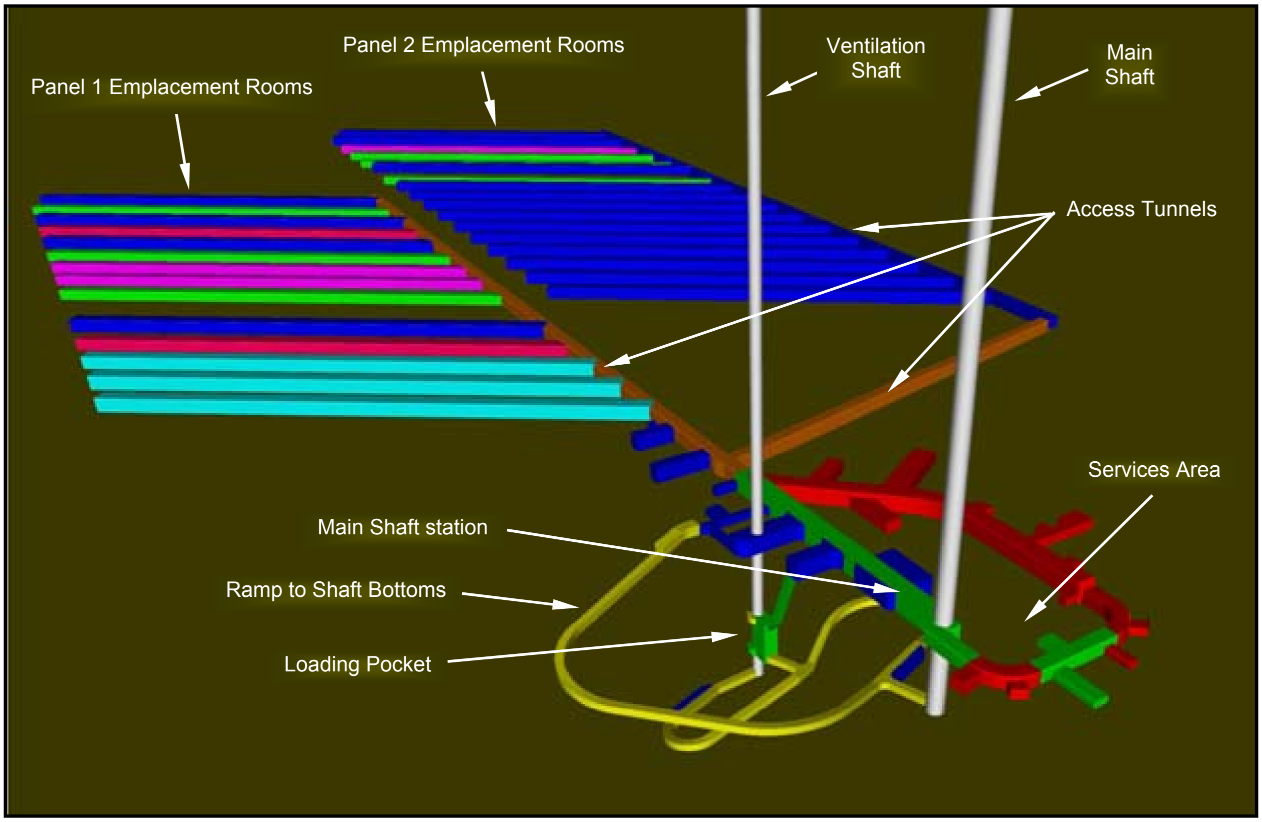

Figure 4-2 – Isometric View of Underground DGR Level

An electrical substation for high voltage switchgear and communications and instrumentation room for low voltage and all instrumentation, monitoring and control equipment will be located close to the Main Shaft, which will distribute power throughout the underground facility and marshal all instrumentation and communication signals. A Secondary Control Room (SCR) will be set-up at Refuge Station 1 in the underground Shaft and Services Area for troubleshooting and in case communications with the main surface control room are disrupted (See Section 8.9.2).

4.2 Surface Infrastructure & Buildings

Table 4-1 provides a summary of approximate sizes of the buildings in the Shaft Surface Facilities Area (SSFA) as shown in drawing H333000-WP403-10-042-0001.

Length (m)	Width (m)	Surface Facility Building / Major Component
15	15	Main Shaft Headframe
11	10	Ventilation Shaft Headframe
21	13	Ventilation Shaft Hoist House
15	10	Ventilation Shaft Collar House
60	25	Waste Package Receiving Building
15	13	Offices & Main Control Room
15	13	Amenities Building
9	10	Air Compressor Plant
11	7	Heater House
22	7	Electrical Room
41	31	Electrical Substation
20	10	Emergency Diesel Generator
20	12	Propane Storage Platform

Table 4-1 – List of SSFA Buildings during Operations

The following sections describe the WPRB and various other ancillary buildings around the Main Shaft Headframe. The two headframe structures and various structures and equipment directly associated with hoisting are described in Sections 4.3.1 to 4.3.5 and 4.4.1 to 4.4.5 inclusive.

4.2.1 Surface Facilities

4.2.1.1 Waste Package Receiving Building

The WPRB will receive the waste packages from the WWMF or nuclear power stations and stage them for transfer onto the Main Shaft cage. The WPRB is connected to the Main Shaft Headframe. The main WPRB plan area is 987.5 m^2 (39.5 m long by 25 m wide) with a height of approximately 20 m, constructed as an insulated and clad steel frame structure. The WPRB includes the following features:

- Waste package staging and secondary inspection area.
- Unloading bay and truck dock.
- Offices and control room.
- Radiological detection equipment for worker safety and to prevent the spread of contamination.
- A 20 m x 19.5 m maintenance and storage area, with space for T-H-E Handler and spare rail carts, is attached to the main WPRB area.
- Covered storage area for empty Resin Liner Shields and a Trillium platform (see Section 10.4.5).

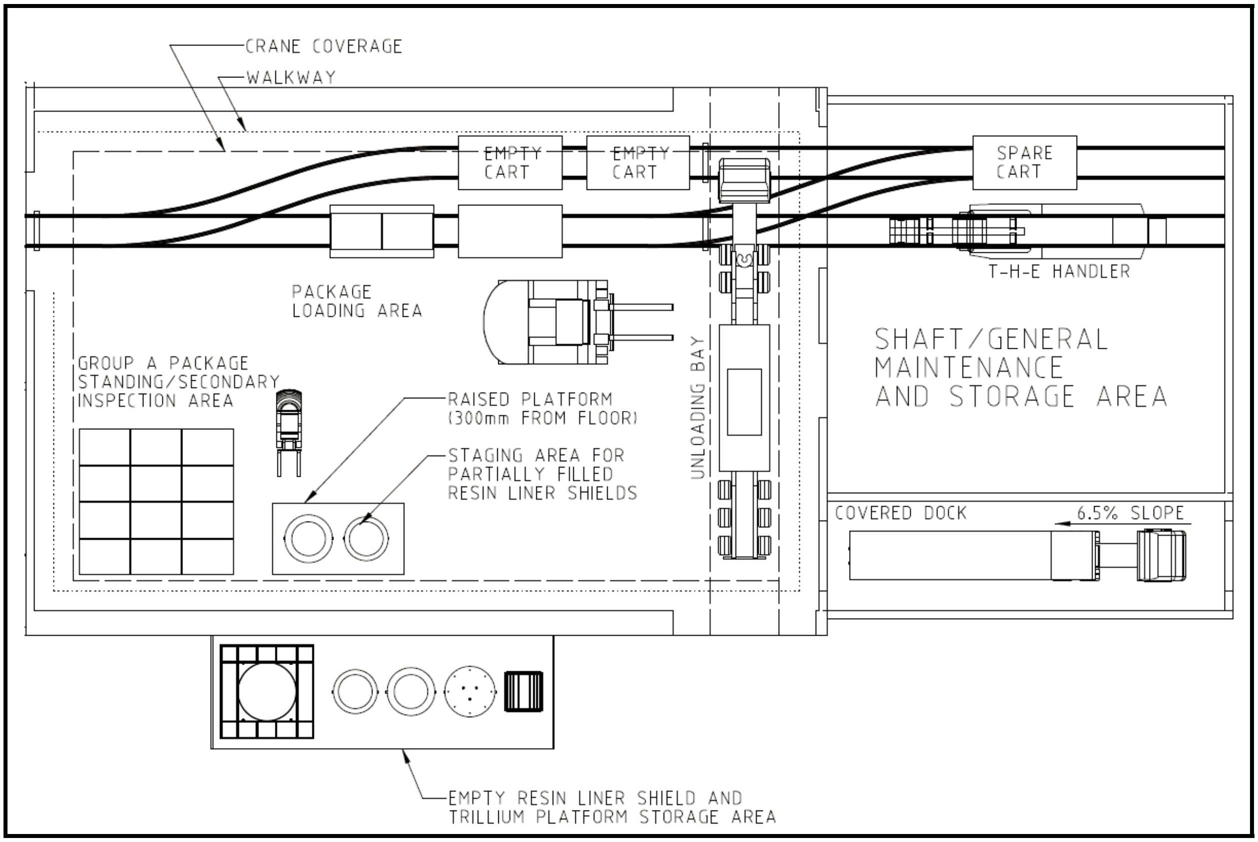

Figure 4-3 – Showing WPRB Layout

4.2.1.1.1 Package Staging and Secondary Inspection

The main open area of the WPRB will have a package staging area with room for 24 Group A packages stacked two high with a minimum 50 mm gap between packages. The staging area is based on the minimum number of bin-type packages anticipated to be transferred during a shift.

There will be an area outside of the WPRB, enclosed (on three sides), for empty Resin Liner Shields, Resin Liner sacrificial pallets and a Trillium platform (see Section 10.4.5).

4.2.1.1.2 Shaft / General Maintenance and Storage Area

The shaft general maintenance and storage area will be used for minor repairs and preventative maintenance tasks for the shaft components and equipment used within the WPRB. The area would be part of the steel clad building with access from within the WPRB.

4.2.1.1.3 Waste Package Unloading

A drive-through off-loading bay will be located on the end of the WPRB away from the shaft. Trucks will enter parallel to the common wall with the maintenance area adjacent to the end wall of the WPRB and exit the building through the opposite side. The enclosed off-loading bay will facilitate operation throughout the winter months and provide some control by ensuring egress from the WPRB is via specific doors with monitor points.

A covered dock for off-loading trailer-mounted ISO containers and end-loaded covered trucks will be located perpendicular to the loading bay and beside the maintenance area.

The main WPRB area will have rail embedded in the floor up to the shaft to facilitate cage loading and a side switched area, which will have a two cart capacity. It will be accessible via standard size hydraulic powered rail switch. The two parallel tracks will be extended out through a rollup door into the maintenance and general storage area. This area will serve as a location to store spare rail carts and the T-H-E Handler. A second switch is included along this double tracked area so that the empty carts can be moved to the package loading area without approaching the shaft. If it is desired to store the T-H-E Handler at the wall of the maintenance area, the switch orientation shown in drawing H333000-WP406-20-042-0005 can be mirrored to allow this.

Two power reels will be placed to provide power and control signals to the self-propelled rail carts.

4.2.1.2 Office and Main Control Room

The Office and Main Control Room (MCR) will be a steel framed, insulated and clad structure and will be attached to the south side of the Main Shaft Headframe. The office area will be used by the operations staff, which could include an engineer, shaft controller and planner, cage tender, mechanic, electrician and instrumentation / controls technician. For the layout of the above buildings, see drawing H333000-WP406-20-042-0005.

The control room, forming a part of the office area, will be equipped with computing, control, and monitoring equipment to marshal all signals and data transmitted from underground. The hoisting system status display and production logs of all equipment, facilities and systems will also be available. Two individual washrooms will be located within the office and control room space.

The shaft controller / planner would use the data received to monitor the shaft operation and the flow of waste packages to the WPRB and into the DGR.

4.2.1.3 Amenities Building

The Amenities Building will have a small bank of lockers for DGR visitors. There will also be a decontamination area (i.e. a shower) that would be used in the unlikely event that a person is exposed to loose radioactive material. A small parking area will be provided outside the Amenities Building to accommodate movements by DGR staff (e.g. managers, supervisors and maintenance staff) and vehicles transporting visitors. Other facilities provided include a Training / Visitor Area, Lamp Room and Monitoring Area, Storage and Janitor Room.

The approximate size of the building will be 14 m x 15 m x 3 m high. It is anticipated that the building will be an insulated and clad steel structure. .

4.2.1.4 Electrical Substation

The Electrical Substation will provide power to both surface and underground facilities during construction and operation.

The substation equipment will not be covered (i.e. not inside a building), but will be enclosed by fencing. The approximate footprint of the substation area will be 41 m x 31 m.

The substation will be located in close proximity to the Main Shaft Headframe as is reasonably practical.

4.2.1.5 Electrical Room

The Electrical Room (switch room) will be the main electrical distribution point for all low voltage (600 V) loads required on surface. It will contain all motor control centres (MCC) for all drives on surface with exception of the high voltage feeds required for the hoists and any other drive rated greater than 600 V. The approximate size will be 22 m x 7 m x 5.5 m high.

The Electrical Room will be adjacent to the Main Shaft Headframe and WPRB with direct access from the WPRB. The building will be steel-framed metal clad construction with access and aisle requirements per electrical code.

4.2.1.6 Emergency Diesel Generator

An Emergency Diesel Generator will provide emergency back-up power in event of substation failure or utility supply disruption. The approximate size of the generator area will be 16 m x 20 m.

The generator area will not be covered (i.e. not in a building) however there will be some enclosures for weather sensitive equipment. The area will be enclosed by fencing.

4.2.1.7 Propane Storage

Propane will be used to heat the air for underground infrastructure. The ventilation air will be heated on the surface in the Heater House during the winter months before entering the Main Shaft and forced underground.

Three 50,000 litre propane tanks will be provided to supply liquid propane for ventilation air heating during process operation.

Propane will be delivered regularly to each tank by propane tanker truck. The filling station will be located off of the DGR site boundary so that delivery personnel will not need to enter the DGR facility.

The propane tank area will be enclosed by a fence with a minimum height of 1.8 m. Both the propane tank area (within the DGR site) and the filling station (external to the DGR site) will be enclosed by separate lockable gates and appropriate protective berming will be provided.

The propane tank farm will be protected against damage from traffic by bollards placed around the perimeter.

4.2.1.8 Heater House

The function of the surface heaters is to raise the ambient temperature being drawn in by the Intake Fans to a temperature such that services within the Main Shaft and headframe are not subject to adverse temperature conditions.

The heaters in the Heater House will be designed to be propane fuelled direct fired burners. The heaters will be designed for the lowest extreme air temperature measured in the area.

The approximate footprint of the Heater House area is 7 m x 10 m.

4.2.1.9 Air Compressor Plant

The Air Compressor Plant building is located close to Main Shaft to provide compressed air for surface and underground maintenance and the underground refuge stations. The compressors will be housed inside an acoustic enclosure in order to reduce the environmental noise level. Intake and cooling louvers will be provided as required.

The compressor building will be of steel framed metal clad construction. The approximate footprint of the Compressor Building is 9 m x 10 m.

4.2.2 Connection to WWMF

A crossing is required to provide direct access between WWMF and the DGR over the abandoned railway. The proposed crossing features the connecting two-lane road situated on a fill embankment over the existing ditches and railway. Concrete-surrounded corrugated-galvanised steel elliptical culverts (approximately 3 m wide, 2 m high) will be used to accommodate the existing water flow in the railway ditches. This is an economical solution, which accommodates the existing water flow in the ditches and provides a short, direct connection to the WWMF.

A 20 m width embankment is recommended to accommodate wide road lanes (4 m minimum), shoulders (1.5 m minimum), walking area (2 m on each side), and adequate space for snow storage (1.5 m minimum) during winter operations, and concrete barrier (1 m) on both sides of the road. In selecting the embankment width, consideration was given to the fact that this crossing represents the only access (other than the emergency accesses) to the DGR facility.

Excavated material from shaft sinking and lateral development will be used as embankment fill material. The current assumed location and general layout of the crossing is included in drawing H333000-WP403-10-042-0003.

4.2.3 Waste Rock Management Area

Waste rock generated as a result of excavation of the shafts and at the repository level will be managed on the DGR site in a WRMA. About 832,000 m^3 of rock that is excavated during the construction of the DGR will be managed over the long-term at the WRMA. This volume excludes the soil and rock material that will be temporarily stored within the WRMA, but eventually re-used in the construction of berms and roadways. The general arrangement, environmental protection measures to be employed during construction and operation, and construction and operational environmental monitoring programs for the WRMA are described in further detail below.

The quantities of rock materials to be excavated for (i) the shafts (both Main and Ventilation); (ii) the emplacement rooms; and (iii) the underground Shaft and Services Area, ancillary rooms and access tunnels are given by material type in Table 4-2. Material volumes were determined from calculations associated with development of the Main and Ventilation Shafts and underground repository layouts, as described in Section 9.3, and the observed thickness of formations from the DGR-1, 2, 3 and 4 boreholes (see stratigraphic columns in Figure 2-8).

Material Type	**Volume (m^3) ***	
	In-Situ	**Bulked**
Reach 1 (Overburden)	1,400	2,000
Reach 2 (Dolostone and Shale)	34,300	48,000
Reach 3 (Shale)	21,200	29,700
Reach 4 (Limestone)	594,200	831,900
Total (excludes Overburden)	**649,700**	**909,600**

Table 4-2 – Estimated Quantities of Excavated Materials by Reach

4.2.3.1 Location and Size

The WRMA will be located adjacent to the surface facilities (refer to drawing H333000-WP404-10-042-0001). There are constraints to site development within the DGR Site Boundary, which have been incorporated into the design of the WRMA [R38].

In order to provide for (i) temporary management of overburden materials, shales and dolostones, and (ii) long-term management of argillaceous limestones, the rock piles will require a total area of approximately 11 ha, while the overall footprint of the WRMA, including the storm water management system will be approximately 17 ha. This area, along with the surface facilities, will be fenced during construction to isolate the WRMA from the nearby WWMF and other facilities on the Bruce nuclear site.

The size of the WRMA is based on a total rock and overburden volume from repository development and is divided into two areas: an area for the temporary storage of overburden, dolostones and shales, and another larger area for the long-term management of argillaceous limestone. Therefore, it is assumed that the materials in the temporary storage area will be re-used on site prior to the completion of lateral development. As a result, the footprint of the argillaceous limestone management pile overlaps with that of the dolostones (see drawings H333000-WP404-10-042-0001 and H333000-WP404-10-042-0003).

Temporary and long-term waste rock management piles are described in Table 4-3. Waste rock management piles have been designed with 2.5 : 1 slopes to ensure stability. In order to prevent ponding of water on the top of the argillaceous limestone pile, the top of the pile will be graded (refer to drawing H333000-WP404-10-042-0003).

Material Type	Temporary/ Long-term	Material Quantity (m^3)	Surface Area (ha)	Height (m)
Overburden	Temporary	2,000	0.3	10
Dolostones	Temporary	41,200	0.8	10
Shales (includes Reaches 2 and 3)	Temporary	36,500	0.6	10
Argillaceous Limestone	Long-term	831,900	8.7	15

Table 4-3 – Waste Rock Management Requirements by Material Type

As overburden materials can be easily eroded, a silt fence barrier will be placed around the temporary overburden pile to contain any silt laden run-off during storm events, thereby minimising loss of materials. If the final excavated overburden is to be left in place for a period of greater than one year, it will be vegetated to minimise erosion. However, it is anticipated that overburden materials will be re-used in less than one year.

4.2.3.2 Site Preparation

Much of the site is currently open scrubland, with some woodland, while a portion of the WRMA is currently used for disposal of excess clean soil material from excavation activities at other OPG facilities. Currently a 44 kV single-pole power line crosses a portion of the WRMA. This would need to be relocated prior to the start of construction activities.

Clearing and grubbing will be required within the site to clear existing vegetation. Clearing and grubbing will be timed to avoid environmentally sensitive periods (i.e., outside of the breeding bird season, generally mid-May through July). Clearing and grubbing will be staged to ensure that the period of time in which soils are exposed is minimised. Wood materials will be chipped and re-used on site in landscaping activities. Some cleared and grubbed materials will require disposal (i.e., stumps); this will either be stored on the DGR site, or elsewhere on the Bruce nuclear site according to appropriate best management procedures.

Following clearing and grubbing, the site will be graded to ensure effective storm water management, as described further in Section 4.2.3.4. The site grading plan for the WRMA will take advantage of existing topography and soils. It is currently assumed that it will not be necessary to import soils to construct a liner at the site. However, the need for a liner should be reassessed when more comprehensive site data are available from the WRMA.

Prior to deposition of waste rock materials, the storm water management system in the WRMA will be constructed (refer to drawing H333000-WP404-10-042-0001).

4.2.3.3 Material Handling and Access

It is assumed that the waste rock will be transported to the WRMA from the shafts by rock trucks. Once materials are placed onto the respective piles, earth moving equipment will be used to effectively shape the piles to ensure slope stability. Gravel access roads have been provided within the WRMA for movement of materials and equipment [R38]. Primary access to the WRMA will be provided through the shaft service area, and secondary access will be provided from the Interconnecting Road (refer to drawing H333000-WP404-10-042-0003).

4.2.3.4 Storm Water Management

Storm water from the WRMA will be managed to control for potential contamination. Storm water run-off will be collected in a network of trapezoidal drainage ditches, around the perimeter of the WRMA, and directed to a storm water management pond.

The WRMA storm water management system will also receive storm water run-off from the developed area around the two shafts, as well as any water that will be pumped to the surface from the underground shaft sumps (refer to drawing H333000-WP404-10-042-0001). Water from both sources will flow through a grit, sediment, and oil water separator, such as a stormceptor, before being discharged into a WRMA perimeter drainage ditch.

The results of rainfall run-off analysis from the aforementioned areas are summarised for the 6 hour, 25 mm and the 1:100 year events in Table 4-4. The resulting run-off coefficients are tabulated. As the SSFA would be predominantly paved, the run-off coefficient is correspondingly higher than for the unpaved WRMA.

DGR Area	Area (ha)	Storm water Management Parameters	Storm Event	
			6 hour, 25 mm	1:100 Year
Waste Rock Management Area (WRMA)	17.0	Rainfall (m^3)	4,250	24,620
		Run-off (m^3)	2,848	20,188
		Run-off Coefficient	0.67	0.82
Shaft Surface Facilities Area (SSFA)	5.6	Rainfall (m^3)	1,400	8,148
		Run-off (m^3)	1,134	7,741
		Run-off Coefficient	0.81	0.95

Table 4-4 – Rainfall Run-off Volumes over the study Areas

It is anticipated that run-off from the WRMA will contain fines from both exposed rock and the soil during its temporary storage on-site. As the excavated rock material is from a natural source and has not likely been impacted by contamination, the waste rock would likely be considered as ‘inert fill’ according to Ontario Regulation 347 [R39]. It is expected that the storm water run-off from the waste rock will be acceptable for discharge to the natural environment. However, storm water management is still required within the WRMA to control Total Suspended Solids (TSS) / turbidity as required by the Ontario Ministry of Environment (MOE) prior to discharge.

Drainage ditches to be constructed around the WRMA will be a minimum of 3 m wide (at base) and 1 m deep trapezoidal ditches that will be vegetated to minimise erosion, around the perimeter of the WRMA (see drawings H333000-WP404-10-042-0001 and H333000-WP404-10-042-0005). The drainage network will direct run-off to a storm water management pond, designed for removal of TSS. The pond will be located along an existing drainage channel in the northern portion of the WRMA (refer to drawing H333000-WP404-10-042-0002).

The storm water management pond consists of:

- A retention area for settling of particles (to a size of approximately 0.02 mm).
- An extended storage area for larger storm events.
- A natural material (liner) with a protective cover (granular material).

The storm water management system has been designed with capacity to:

- Retain the 6 hour, 25 mm storm for a period of 24 hours, and
- Safely pass the 1 : 100 year storm event, as required in the Storm water Management Planning and Design Manual [R40] without overtopping of the dyke and erosion of the outlet system.

Water from the storm water management pond will then be discharged via a quantity controlled output into the existing drainage ditch network, which drains north via three culverts and into a drainage ditch that eventually discharges into Lake Huron (see drawings H333000-WP404-10-042-0001 and H333000-WP404-10-042-0002). It is assumed that this drainage ditch and other ditches and discharges located downstream are capable of controlling and conveying water from the storm water management pond. This will be confirmed during the next phase of engineering. Effluent from the management pond will be periodically tested to confirm compliance with applicable discharge requirements (see Section 4.2.3.10.2).

In order to stop water discharge from the management pond in the unexpected event that contaminants in discharge water exceed acceptable limits or general discharge needs to be halted due to downstream issues, a gate will be installed on the outlet. This gate can be controlled either manually or remotely; at this time it is assumed that the gate will be manually controlled. It is assumed that the gate will normally remain in an open position.

4.2.3.5 Visual Impact

A setback or buffer of 200 m from the Interconnecting Road has been included in the design of the long-term waste rock pile (limestone). Visual screening (i.e. berm and / or trees) will be installed. Trees are recommended around the WRMA due to the preferred aesthetics and reduced surface area requirements of trees, as opposed to berms. It is anticipated that several of the buffer areas are likely already treed and these trees will also contribute to dust management. Planting of trees will also partially offset those cleared in order to construct the WRMA.

4.2.3.6 Capping of Excavated Materials

If the temporary storage of shales is required for a period of longer than one year, then the shale pile will be capped to minimise the potential for erosion of these materials while also limiting infiltration into the pile. If required, shales will be capped using standardised capping procedures for landfills as identified in Ontario Regulation 232 / 98 [R41]. This includes a minimum of 0.6 m of cover materials, such as clays, as well as a minimum of 150 mm of topsoil or other material capable of sustaining plant growth. Topsoil would then be seeded using local vegetation species capable of providing abundant growth with limited care, such as quick-growing grasses. Overburden materials stripped / excavated from the project area are likely to be suitable for use in capping.

Capping is not currently in consideration for the long-term management of argillaceous limestone. The potential for erosion from the limestone pile is not considered to be significant.

4.2.3.7 Protection of Existing Sensitive Environmental Features

The design of the WRMA considered various environmental constraints. Since a portion of the proposed DGR lands are located within the catchments for Stream C (see Figure 2-1), an important coldwater fish habitat within the site that is protected under the Fisheries Act [R42], an important constraint was to avoid discharges to this watershed. To avoid potential effects to Stream C, all storm water run-off from the WRMA is captured within the storm water management system, which outlets into the existing drainage network that leads directly to Lake Huron (refer to drawing H333000-WP404-10-042-0001).

Potential habitat for two species of burrowing crayfish (*Fallicambarus fodiens* and *Orconectes immunis*) has been identified on the DGR site [R43]. Neither species are identified under the federal Species at Risk Act or the provincial Endangered Species Act, 2007, and both are considered to have apparently secure populations within the province [R44]. However, the occurrence of *F.* fodiens is considered as uncommon within the province by a specialist in the field [R45]. Since burrowing crayfish habitat would be protected under the Fisheries Act [R42], the waste rock pile has been designed to avoid the areas identified with the highest potential for use by burrowing crayfish. In addition, a minimum 30 m vegetated buffer has been placed around the potential crayfish habitat to enhance protection of this feature. If buffer areas are not currently vegetated, they will be planted using species native to Bruce County, and will use local genetic stock where practical. These actions should help lessen potential effects on crayfish habitat, which will be evaluated as part of the environmental studies for the DGR project.

As part of the field studies for the environmental impact study of the proposed DGR project, vegetation and wildlife surveys were completed at the DGR project area. With the exception of the items mentioned above, these studies did not identify any species, communities or habitats that would constrain the layout of associated surface facilities.

4.2.3.8 Fugitive Dust

Dust will be generated during the construction of the DGR. This will be of primary concern during the movement of rock from the shaft service area to the WRMA during construction. It is not anticipated that dust generation will be a significant concern during the DGR operations period, as the majority of fugitive dust should have already been displaced during wind and rain events.

Dust can result in numerous environmental problems, including annoyance, potential impacts to human health, degradation of surface water quality, and restriction of photosynthesis in plants coated in dust. Sources of dust include grading activities, road construction and vehicle movement, material conveyance, excavation, and storage piles. In order to control fugitive dust emissions from the WRMA, and mitigate potential environmental problems, several mitigation measures can be used. These can include, but are not limited to,

- Spraying of areas to be worked during dry periods.
- Stabilisation of exposed ground surfaces.
- Limiting speeds on unpaved roadways.
- Spraying of unpaved roadways with water or an appropriate suppressant approved for use in Ontario by the MOE.
- Minimising drop heights and wetting materials.
- Providing a vegetation buffer at the site boundary.

4.2.3.9 Noise Control

Noise and vibration associated with the truck movement and dumping of excavated rock materials to the WRMA may potentially result in environmental problems, including annoyance, and wildlife avoidance of an area. Noise may be generated by the operation of equipment / vehicle movement, excavation activities (i.e. blasting), and deposition of materials within the WRMA.

In order to control noise emissions, all equipment / vehicles will be equipped with muffler systems, as required, to eliminate sources of noise. These systems will be maintained throughout the duration of use on site to ensure effective noise abatement. Blasting vibrations will be monitored and limited to tolerable limits at the nearest receptors. In addition, berms or noise fences to shield sensitive receptors from noise will be employed, if necessary, to abate noise emanating from the site. Waste rock piles may also shield the surrounding areas from noise impacts, and will be included in any noise analysis.

4.2.3.10 Environmental Monitoring Program

Environmental monitoring systems have been developed for the WRMA [R38], the principal components of which are summarised below:

4.2.3.10.1 Dust Control

Daily visual inspections of the shafts (while excavations are underway), access roads within the WRMA, waste rock piles and dust control measures will be undertaken. These observations will be used to determine whether dust control measures need to be further developed and where maintenance is needed. Observations, recommendations and any mitigation measures implemented will be noted in a daily log.

In order to ensure air quality around the site meets provincial standards, an ambient air quality monitoring program will be completed during DGR construction.

If excessive ambient air quality criteria are noted during monitoring, efforts will be made to identify the source and cause, and mitigation measures will be employed, where necessary, to prevent exceeding criteria further.

Contingency plans to deal with excessive dust generated by the transfer and placement of waste rock in the WRMA will be required. Contingency plans would be activated where environmental conditions on the site have the potential to result in increased dust generation.

4.2.3.10.2 Surface Water

Prior to discharging any effluent from the storm water management pond, periodic initial testing for pH, temperature, TSS, BTEX (Benzene, Toluene, Ethylene and Xylene), chlorides, sulphides, ammonia and PHC (Petroleum Hydrocarbons) will be undertaken to confirm compliance with applicable discharge requirements. It is expected that details regarding the frequency and parameters for long term testing would be included in the Certificate of Approval from MOE for the facility.

During DGR operations, it is likely that water leaving the shaft service area (i.e. storm water run-off and shaft sump water) will need to be periodically sampled at a location inside the fence and prior to discharge in the WRMA perimeter ditch (refer to drawing H333000-WP404-10-042-0001). These samples would be analysed to determine concentration of radioactivity in water and to confirm concentrations are below acceptable limits as established by the Canadian Nuclear Safety Commission (CNSC). It may also be necessary to periodically monitor concentration of radioactivity in discharge water from the storm water management pond.

4.2.3.10.3 Groundwater

Monitoring wells will be installed within the vicinity of the storm water management pond to monitor the effectiveness of the liner. The need for additional monitoring wells to monitor groundwater quality within the DGR site will be assessed in a later phase of design. As with surface water monitoring, test parameters and testing frequency for these wells, as well as their number and location, will be assessed and finalised in the next phase of design and would be included in the Certificate of Approval from MOE for the facility.

4.3 Main Shaft

4.3.1 Hoisting Duties

The following duties are required of the Main Shaft permanent hoists:

- Transport of heavy equipment into and out of the DGR level (Main Shaft Koepe friction hoist).
- Transport of nuclear waste packages into and possibly out of the DGR level (Main Shaft Koepe friction hoist).
- Daily transport of small non-nuclear material and personnel (Auxiliary Koepe friction hoist).

The Main Koepe friction hoist can, in the event of an emergency, be used to transport personnel. At no time will nuclear waste be transported in the Main Cage while personnel are being concurrently transported in the Auxiliary Cage under normal operating conditions.

The expected duties for the two hoists are presented in this section and are determined based on the heaviest loads that will be transported in each case during operations:

- Main Koepe friction hoist: Shielded waste packages including transport rail cart up to 44.0 tonnes.
- Auxiliary Koepe friction hoist: Material transport of 1.27 tonnes.

A fundamental aspect of the hoisting systems is that the systems will be stable and safe in the event of an equipment malfunction or power failure.

4.3.2 Hoisting Systems

Both of the Koepe friction hoists are of a cage-counterweight configuration. Specifically, the two hoisting systems are comprised of the following elements:

- Main Koepe Arrangement:
  - Six-rope direct driven Main Koepe friction hoist.
  - Head rope deflection sheave cluster consisting of six sheaves on a common spindle.
  - Cage.
  - Counterweight.
  - Six head ropes.

  - Four tail ropes.
- Auxiliary Koepe Arrangement:
  - Two-rope gear driven Auxiliary Koepe friction hoist.
  - Double deck cage.
  - Counterweight.
  - Two head ropes.
  - Two tail ropes.

4.3.2.1 Main Koepe Friction Hoist Description

The hoist consists of a 4.27 m diameter, fabricated steel drum with friction inserts mounted around the circumference of the drum, in which the wire ropes will run. The friction between the ropes and these inserts transfers the driving and retarding torque to operate the hoisting system. A set of ropes is attached to the top of the cage and run over the hoist drum to the counterweight on the other side.

In order to maintain a sensible internal shaft diameter, the ropes on the counterweight side are moved horizontally by a set of deflection sheaves 12.5 m below the Koepe drum (see Figure 4-5), thus providing an angle of wrap greater than 180°. A set of tail ropes are connected to the bottom of the cage and run down to a loop below the lowest shaft station and thence back up to attach to the bottom of the counterweight. This type of hoist has a high load capacity since multiple ropes are used to share the load.

Because it is 'balanced' by hoisting the cage against the counterweight and balancing the head ropes against the tail ropes, installed motor power is reduced compared to an equivalent double-drum style hoist, which would have large out-of-balance loads at the extremities of the wind.

The hoist drum will have two integral machined steel discs on the outside of the drum cheeks, against which multiple disc brake units are mounted. In a similar manner to the control and safety systems, these multiple units will also provide redundancy and ensure that only one set of brake units on one disc will be required to safely stop the hoist in the event of failure of the complete set of brake units on the other disc. The brake controls will be fully dynamic and will ensure that emergency braking will be achieved at controlled and ramped retardation rates to avoid any shock loads being applied to the shaft conveyances and remain in compliance with the mining regulations. In the event of any power failure, the braking system will act in a fail safe manner to bring the hoist to a smooth stop. The hydraulics are equipped with accumulators to ensure that hydraulic power remains available to achieve a controlled stop of the hoist under power failure conditions.

The main mechanical and structural components of the hoist (drum shaft, drums, bearings, etc.) will be designed to provide a 100 year life using fatigue and finite element analysis as appropriate.

Koepe friction hoists are a well proven technology within the world-wide mining industry for personnel, material, and rock hoisting at hoist trip frequencies and speeds well in excess of those proposed for the DGR hoists. The key difference between a Koepe friction hoist and a double drum hoist is the use of multiple head ropes laying over a single drum instead of a single rope coiling onto each of the two drums of a double drum hoist from each of the cage conveyance and counterweight. These head ropes connect to both the cage conveyance and its counterweight in a balanced manner and work in conjunction with a set of tail ropes, which also connect in a long loop under the cage conveyance and counterweight, thereby more effectively balancing the loading, which the hoist moves by friction between the drum and head ropes. By design, the maximum out of balance load, which the hoist will see, will be half of the maximum cage payload. The minimum permitted factor of safety under the Ontario Regulation 854 Mines and Mining Plants (henceforth referred to as the Ontario Mining Regulations, OMR) [R48] for this style of hoist is 5.5 for each head rope.

The multi-head rope configuration allows the shaft conveyances to run on steel guides instead of timber guides. Under the OMR [R48], this permits the removal of safety devices on the cage conveyances (known as “safety dogs”), which cover the eventuality of a single rope conveyance suffering a rope breakage event, but require timber guides, into which they must dig in to stop a free-falling conveyance. As the DGR Main Shaft conveyances are multi-rope conveyances, the risk of all the head ropes breaking simultaneously is very remote. The ropes selected for the main cage permit breakage of up to two ropes before the minimum regulatory rope factor of safety for friction hoists is exceeded (see §228 (13) of [R48]). Ultimately, one head rope in good condition could statically support the full suspended mass of a loaded cage. Current design considerations have also retained a form of the single rope safety devices for the cage conveyance (wedge dogs), which are suitable for steel guides and are over and above the requirements of the OMR. Use of steel, rather than timber, guides in the shaft also has the benefit of removing flammable mass from the Main Shaft.

4.3.2.2 Auxiliary Koepe Friction Hoist Description

The Auxiliary Koepe friction hoist will be a two-rope configuration driven by a force ventilated induction motor through a gearbox. The ropes will make a 180° of wrap around the 1.38 m diameter Koepe drum. The drum will have dual disc brakes with spring applied, hydraulically released brakes disc callipers. The drum will be mounted between roller bearings set in fabricated pedestals. Connection between the drum shaft, gearbox and drive motor will be with gear couplings, which are torsionally rigid but accommodate small misalignments. No deflection sheaves are required for this hoist as the drum diameter is the same dimension as the rope compartment centres for the Auxiliary cage and counterweight.

The hoist is situated on a level in the Main Shaft Headframe below the deflection sheaves for the Main Koepe friction hoist. Arrangement of the head and tail ropes is similar to that of the Main Koepe friction hoist.

4.3.3 Main Shaft Hoist Houses

4.3.3.1 Main Shaft Sinking Hoist House

A double drum hoist will be installed in a 13 m x 24.4 m building, which will be 11.5 m high and constructed as an insulated and clad steel frame structure. This building will be required for the sinking phase and will house a 3.66 m diameter double hoist drum for hoisting two buckets with capacity of 8.0 tonnes each. The building will contain all the electrics and control cubical. Access will be provided by roll up doors, which will allow an 8 tonne monorail access for the installation or major overhaul of the hoist. The hoist house will be removed at the end of the sinking phase (refer to drawing H333000-WP405-020-042-0010).

4.3.3.2 Main Shaft Winch Houses

Two single hoists will be installed in two 10.0 m x 11.2 m buildings, which will be 9.1 m high and constructed as an insulated and clad steel frame structure. Two buildings will be required for the sinking phase and will each house two 2.16 m diameter single drum winches with a 3.6 m flange diameter, which will be used to hoist the 5.9 m diameter three deck shaft sinking Galloway stage. The buildings will contain all the electrics and control cubical. Access will be provided by roll up doors, which will allow an 8 tonne monorail access for the installation or major overhaul of the hoist. The Winch Houses will be removed at the end of the sinking phase. An opportunity exists in later stages of engineering to combine the two buildings into one provided the geometries of the systems remain amenable.

4.3.3.3 Main Shaft Hoist Room

The Main Shaft Hoist Room will be located at the top of the Main Shaft Headframe and have external dimensions of 15.0 m x 21.8 m with a height of 12.5 m in a configuration which is typical for headframes of this type. These dimensions will provide an overhang of approximately 6.8 m to provide access for hoisting the major components for the 4.27 m diameter Main Koepe friction hoist directly from the delivery vehicles into the hoist room during construction using a 50 tonne overhead travelling crane mounted above the Main Koepe friction hoist room in the headframe. This hoist room will also house all the controls and electrics necessary to operate the hoist along with a local hoist operating cubicle. Access to the hoist room may be provided by an elevator internal to the headframe. The exterior walls will be constructed, insulated, and steel cladded in a manner consistent with buildings located on ground level (refer to drawing H333000-WP406-20-042-0001).

4.3.4 Main Shaft Permanent Conveyances

4.3.4.1 Main Cage

For the reference case, the Main Cage will be designed for a height of 18.5 m with an external floor plan of 5.6 m long by 3.0 m wide to accommodate the largest waste package and various mobile equipment. The payloads to be transported are defined as having a maximum footprint of 2.65 m wide by 5.2 m long.

The height of the cage is determined by the longest waste package, which are the reference case IC-18 T-H-E liners at 11.8 m. They will be transported vertically in a custom Transfer Bell inside the cage and loaded into the cage using a custom rail car, the T-H-E Handler. The cage will be provided with support devices to hold the T-H-E liner at two elevations in the cage during transport to the DGR level. The T-H-E Handler will provide the necessary support during transport to the cage and while installing the package into the cage, support inside the cage will come from frames installed in the cage. A second T-H-E Handler underground will remove the Transfer Bell from the cage.

The height of the cage enables installation of three decks in the cage. This provides an option to achieve maximum hoisting efficiency when standard low mass packages (e.g. LLW bins / racks, ILW shields) are being transported.

The cage top transom will be designed to support the draw bar complete with chase blocks and sockets for the six hoisting ropes, as shown in Figure 4-4. The top transom design will ensure that it can withstand the rope slip loads under the condition of highest friction coefficient between the ropes and rope treads on the hoist drum (refer to drawing H333000-WP405-20-042-0003-02). The bottom arrangement will be designed to support the draw bar complete with chase block and socket for the four tail ropes. Payload in the single deck configuration will be 44.0 tonnes and 41.9 tonnes in the optional multi-deck configuration.

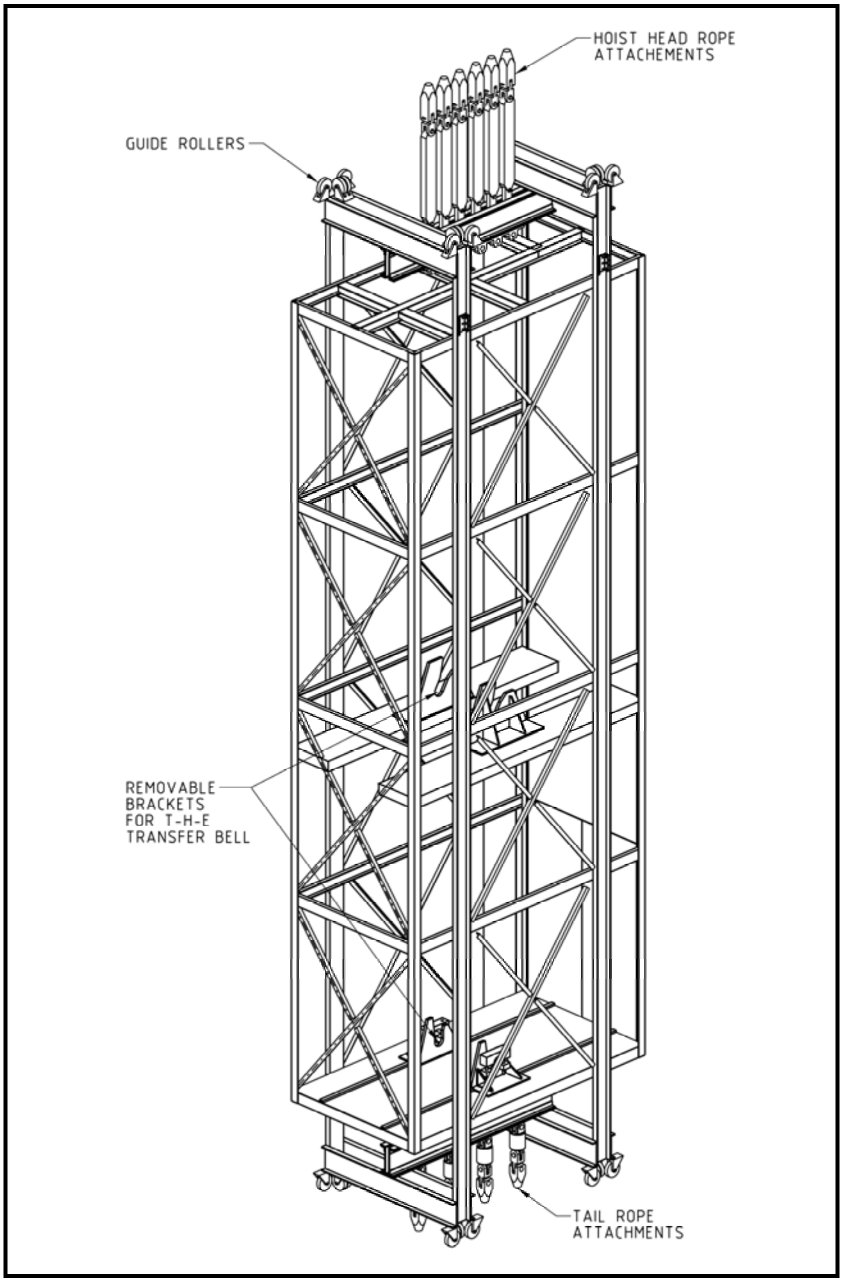

Figure 4-4 – Isometric View of Main Koepe Cage
Note: Cage side and roof steel plate cladding not shown for clarity

4.3.4.2 Main Cage Counterweight

The main cage counterweight will have a design envelope of 9.4 m long x 2.2 m wide by 1.0 m deep. It will contain 332 ballast plates spread over four levels and weighing a total of approximately 33.3 tonnes. The top transom will cater for the six head ropes and the bottom transom will allow four tail ropes to be attached via their respective attachments. The arrangement of the counterweight is shown in drawing H333000-WP405-20-042-0004.

4.3.4.3 Auxiliary Cage

The auxiliary two deck cage will be approximately 5.7 m high with an internal floor plan of approximately 1.0 m by 1.34 m to transport personnel to the DGR level. Each deck will transport six people at a mass of 90 kg per person. The cage will be clad with perforated plate and each deck will have lockable folding access doors. The cage top transom will be designed to support the draw bar complete with sockets, hydraulic adjusting links and chase blocks for the two hoisting ropes. The top transom design will ensure that it can withstand the rope slip loads under the condition of highest friction coefficient between the ropes and rope treads on the hoist drum. The bottom transom will be designed to support the draw bar complete with socket and swivel for the two tail ropes. A general arrangement of this cage with detailed dimensioning is given in drawing H333000-WP405-20-042-0005.

4.3.4.4 Auxiliary Cage Counterweight

The counterweight for the Auxiliary cage has been designed to be 3.75 m tall with a floor plan of 1.0 m by 0.23 m. The conveyance will be designed to carry a series of ballast plates split over two decks. The counterweight top transom will be designed to support the draw bar complete with sockets for the two hoisting ropes. As with the Auxiliary cage, the top transom design will ensure that it can withstand the highest rope slip loads. The bottom transom will be designed to support the draw bar complete with socket and swivel for the two tail ropes. Drawing H333000-WP405-35-042-0001 shows the configuration of the counterweight, with detailed dimensions.

4.3.5 Headframe

The Main Shaft Headframe will be a 62.5 m high reinforced concrete structure with a plan area of 225 m^2 (15 m x 15 m). This headframe will contain a tower mounted, 4.27 m diameter Koepe friction hoist which will be installed in the permanent condition as shown in Figure 4-5. The headframe design is such that every effort has been made to ensure that, with a planned maintenance system in place, the structure will not require any major refurbishments for the 100 year design life of the DGR. This does not, however, remove the responsibility of ensuring regular maintenance on the structure is carried out. The concrete structure is the best method of providing the necessary structural support for this heavy duty Koepe friction hoist and is ideally suited to provide insulation of the equipment and personnel working within the headframe during the winter conditions (drawings H333000-WP406-20-042-0001 and H333000-WP406-20-042-0002 present details of the permanent layout).

The headframe design will incorporate sinking and permanent requirements and the design is such that the change over from the sinking to the permanent configuration will be completed with minimal modifications. The sinking layout is shown in drawing H333000-WP406-20-042-0003. A muck bay will be required for the sinking period.

The top section of the headframe consists of a 12.5 m high insulated clad steel structure containing the hoist room for this shaft; details are given in Section 4.3.3.3.

In addition to the hoist, the headframe will contain the 4.2 m diameter deflection sheaves for the Main Koepe friction hoist head ropes, the 1.38 m diameter Koepe friction hoist for the Auxiliary Cage, arresting gear for the retarding the conveyance in the event of overwind and monorail beams for maintaining and installing the conveyances. Stairs and intermediate floors and platforms have been provided for access and maintenance requirements and provision has be made for an internal elevator to service the various floors in the headframe. Refer to Figure 4-6 for arresting details, which show an identical system in a shaft bottom configuration. The conveyance, if travelling beyond its prescribed travel limits and failing to be stopped by travel limit switches mounted in the shaft, will impact upon the arrestor frame and force the frame to move along its fixed guides thus deforming the arrestor strips. The kinetic energy of the moving conveyance is converted into strain energy by deformation of the arrestor strips, thereby stopping the conveyance in a controlled manner.

To prevent cage movement as a result of hoist rope stretch when heavy loads are placed in or removed from the cage, a cage chairing system will be installed at the collar in the Main Shaft Headframe. This system will be required to keep the cage locked in position to prevent either upward or downward movement as a result of changing stretch in the hoist head ropes due to increase or decrease of the load within the cage during loading and off-loading. The chairs are mounted on the shaft station and will be moved into the shaft using hydraulics to lock both top and bottom of a load bearing member of the cage structure. The chairing system will be interlocked with the Main Koepe friction hoist control system to ensure that the chairs cannot be deployed until the cage has stopped in the correct position at the station and has permitted the chair system to operate. This cage locking system will minimise any differential motion between the cage floor rails and the collar rails. The rail system configuration for package transport requires closer tolerances than would be required for a rubber-tired transport system. Such systems are common in mine cage systems with and without rails and are used very effectively to provide safe conditions for heavy material movement into and out of the mine cages. A similar system will be installed at the repository level where rope stretch will be more significant due to the longer suspended length of the head ropes at this location. Figure 4-7 shows a typical chairing arrangement of the type proposed for the DGR Main Shaft, which would be designed along similar lines to a system supplied by Siemag, [R5].

Doors in the side of the headframe and a floor with extension rails at the hoist level will be installed to enable any large hoist components to be lowered to or raised from the ground on the outside of the headframe structure for replacement or major overhaul.

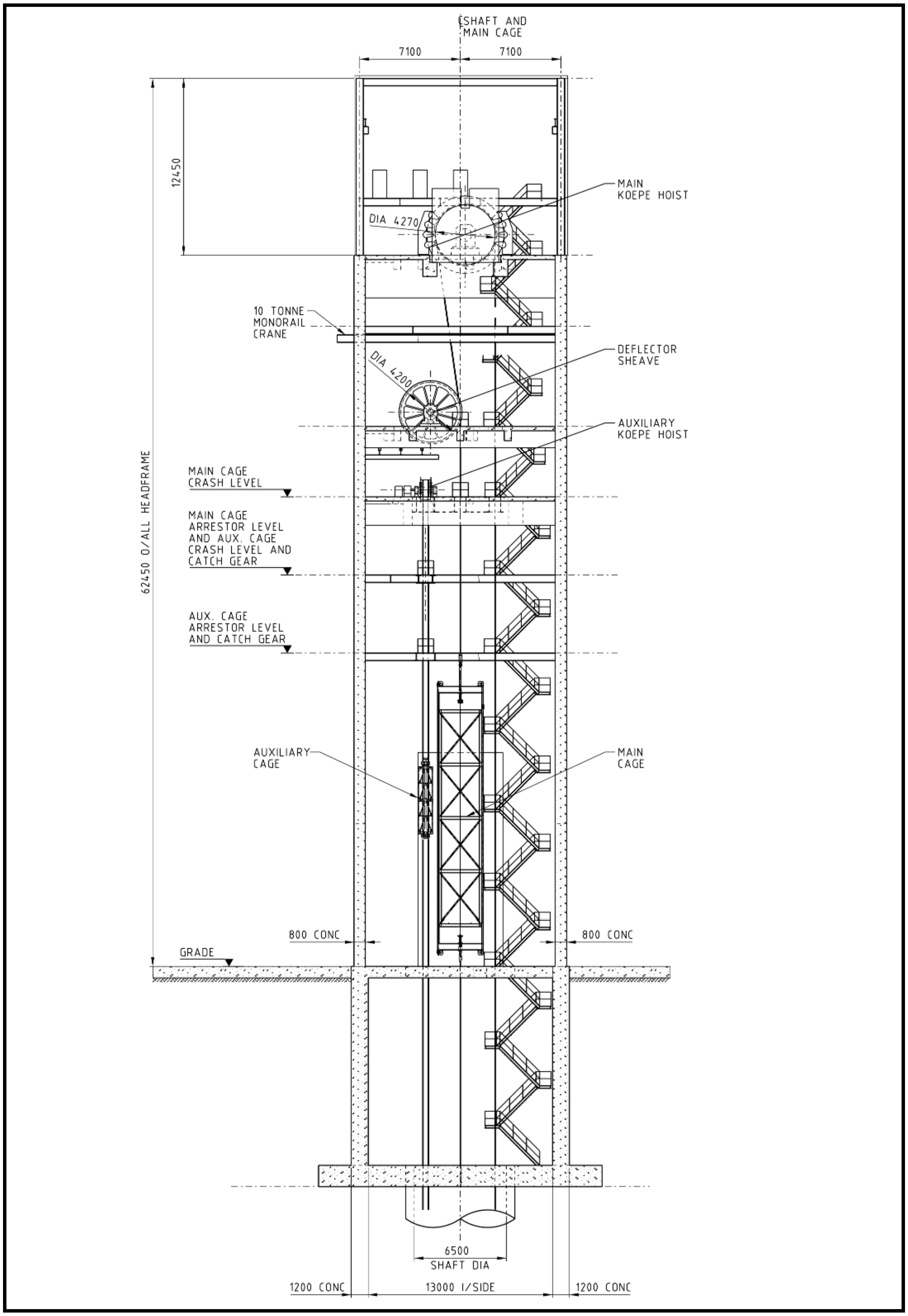

Figure 4-5 – Main Shaft Headframe

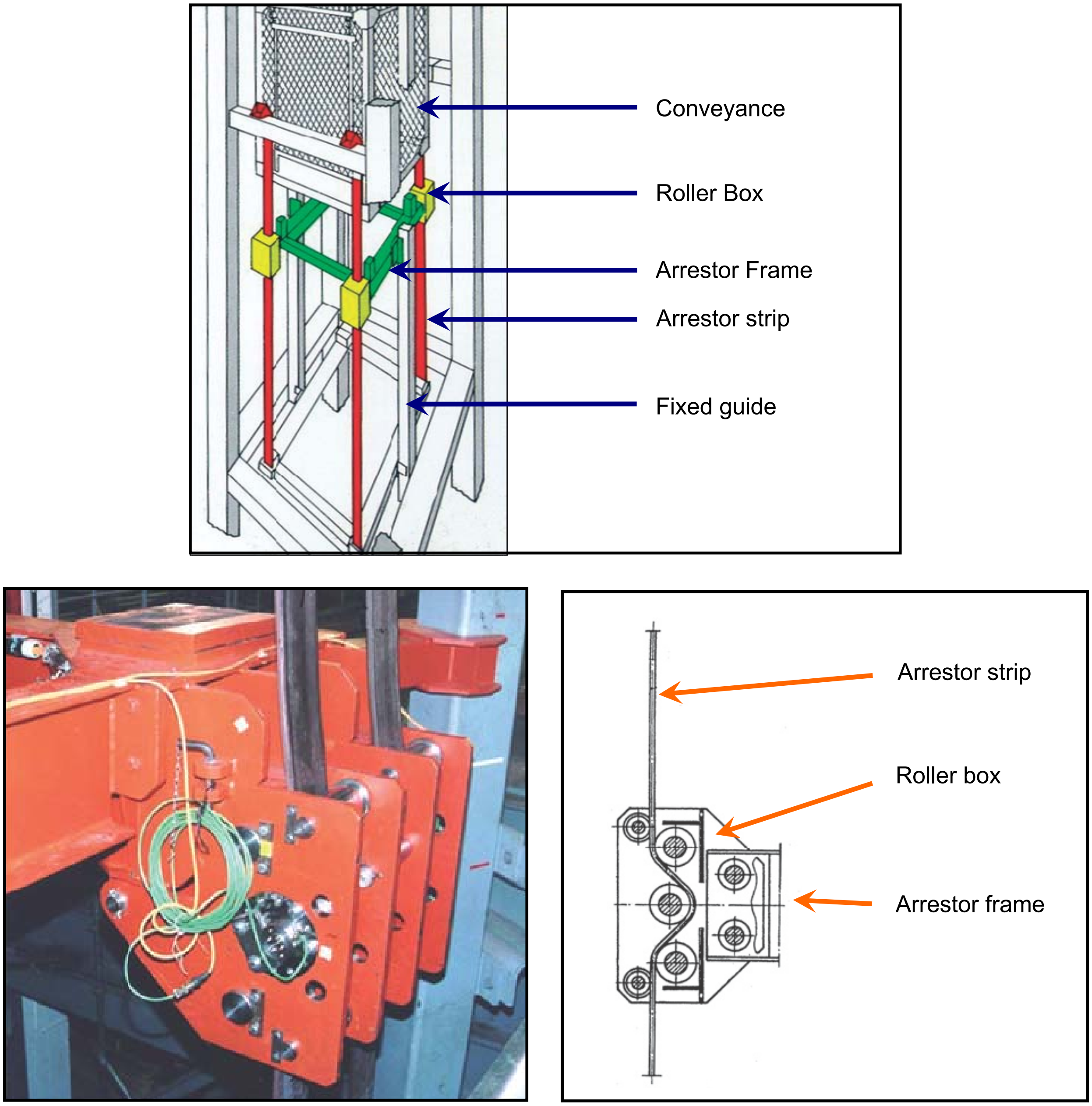

Figure 4-6 – Siemag / Selda Conveyance Arrestor

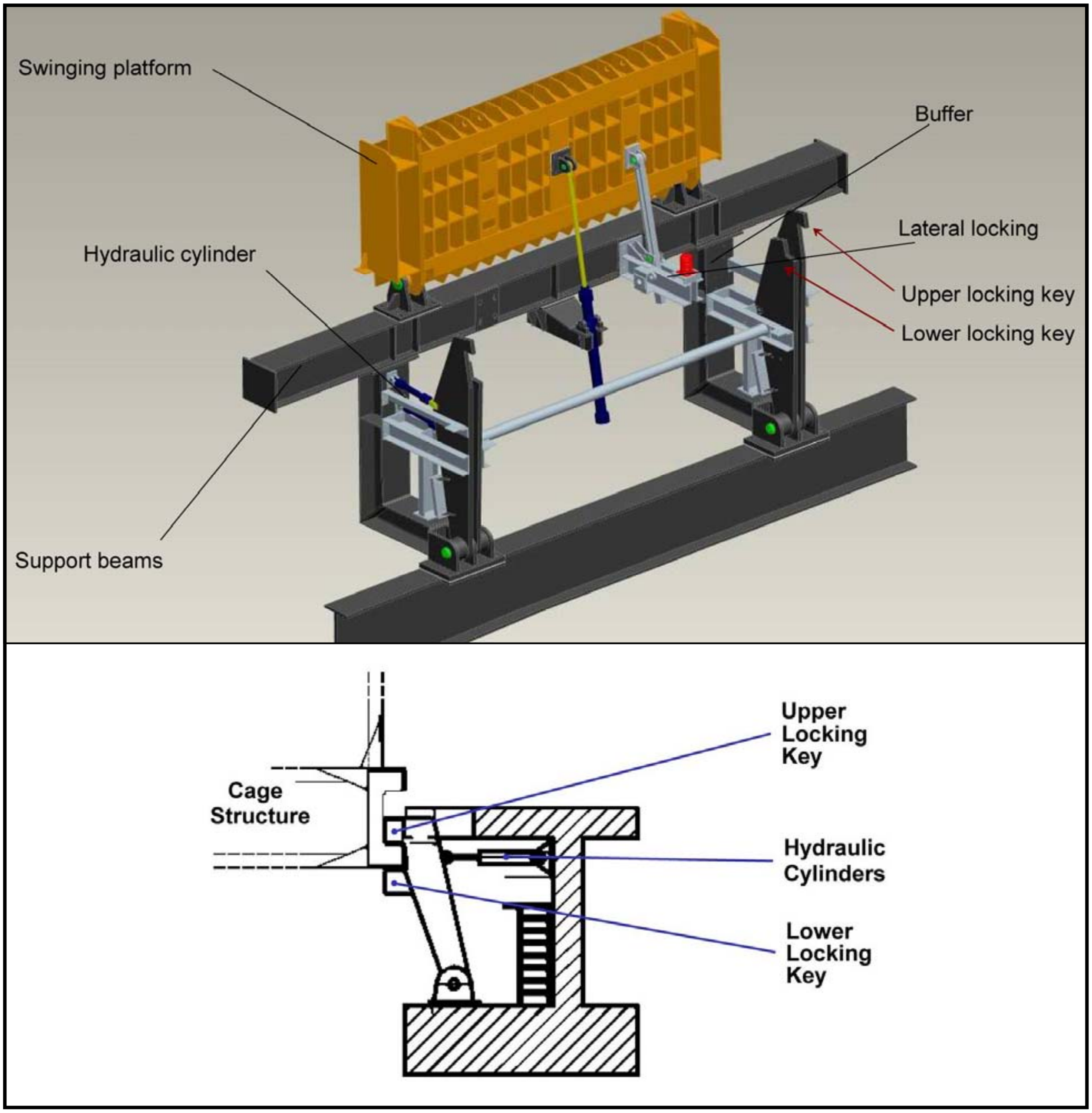

Figure 4-7 – Cage Position Locking Device (Chairs)

4.3.6 Shaft Structures

4.3.6.1 Design – Support, Water Control & Lining

4.3.6.1.1 Shaft Design Requirements

The Main and Ventilation Shafts will have a finished diameter of 6.5 m and 5.0 m, respectively. Both shafts will extend from ground surface to the repository horizon located at a depth of 686 m below the collar. To accommodate hoist overrun, loading pocket (in the Ventilation Shaft only) and sump arrangements, the total excavated shaft length for the Main Shaft and Ventilation Shaft will be approximately 719 m and 746 m, respectively.

The geotechnical-based shaft design has been based on the following requirements:

- Provide 100 year design life (with minimal maintenance requirements).
- Provide sufficient size for safe waste haulage operations.
- Provide sufficient size to accommodate efficient construction activities for the access way and the repository.
- Limit ingress of groundwater along the shaft length, control ventilation and provide utility and fire-life-safety requirements.
- Ensure the ability to reliably seal the repository access upon the completion of waste handling operations.

Due to the varied nature of the stratigraphy at the site, the shaft lining and water control measures will be presented according to the four stratigraphic reaches described in Section 2.3.

Shaft sinking methods and lining systems are considered to be at a conceptual level of design and will be developed in more detail in the next phase of design.

4.3.6.1.2 Shaft Permanent Lining Design

Each of the shafts will require a final lining as a necessary component of shaft support during the operations period. These lining systems will be designed to:

- Prevent cross-formational groundwater flow from the Reach 2a dolostones into the lower units.
- Provide support for shaft conveyance guides and utilities to the DGR level.
- Replace initial support elements, which, by their nature, are designed for quick installation and short duration.
- Assure reliability of the support with minimal maintenance requirements over the 100 year design life.
- Provide swelling control and prevent degradation (slaking) of the rock in Reaches 3 and 4. A final lining with properly detailed stress relief provisions can control swelling in these units, minimise exposure of the rock to fresh water and humidity and control the slake potential of shaley rocks.

- Provide a stiff retaining structure that will limit relaxation of the rock mass.

A steel rebar-reinforced concrete liner design was selected for both shafts at the DGR for structural reasons and to control shrinkage crack widths that can introduce fresh water from Reach 2a into lower portions of the repository. For the purposes of preliminary design, the concrete will be reinforced with steel rebar (estimated at approximately 1 percent by volume radially and 0.4 percent by volume vertically).

The level of reinforcement in the liner will vary with loads on the lining and may be increased or reduced on the basis of future design analyses and observed rock mass conditions during construction with approval of the engineer.

4.3.6.1.3 Reach 1 Final Lining

Expected sinking depth through Reach 1 is approximately 18 m. A thicker lining will be installed through Reach 1 to accommodate the reinforced collar beam at the soil / rock interface and to provide support for the shaft headframe structure. See Section 9.3.1 for more details.

4.3.6.1.4 Reach 2 Final Lining

Pre-sinking ground improvement and structural design of the shaft lining system must preclude the likelihood of shaft flooding and excessive inflows from the Reach 2a dolostones to a level where such an event would not be considered credible. This will require the installation of a water-resistant, permanent lining system capable of resisting hydrostatic pressures through Reach 2a and Reach 2b prior to excavation in Reach 3. (Potential optimisation of this design is discussed in Section 4.3.6.1.6).

Such a system is often referred to as a “hydrostatic” lining. For the System Requirements [R46], a water-resistant hydrostatic lining system is felt to be appropriate. This system will allow some inflow (limited to seeps and damp patches), the accumulated levels of which will be compatible with pumping requirements. The inflows will not affect ground water levels and hence will be limited to the point that hydrostatic pressure levels will develop outside of the lining. While a fully water-tight lining could be achieved with a steel shell, such a system is not believed to be necessary to achieve the design goals for the DGR shaft lining.

The hydrostatic liner will be 600 mm thick for the Main Shaft and 500 mm thick for the smaller Ventilation Shaft. During forming, panning will be necessary to prevent groundwater inflow into the concrete and to prevent pressure build-up until the concrete has reached sufficient strength.

It is currently assumed that the hydrostatic cast-in-place reinforced concrete liner will be slip formed from the Reach 2b / 3 contact to the ground surface to provide final support and limit inflows along the length of the shaft. Slip forming in lieu of advancing the shaft lining concurrent with sinking is believed to be necessary as it provides higher quality concrete and does not create joints in the lining that can allow groundwater infiltration from units with increased hydraulic conductivity (i.e. Reach 2a units as well as the upper 4 m of the Salina A1 carbonate unit and the Guelph Formation in Reach 2b).

The likelihood of a significant quantity of groundwater movement along the interface between the concrete liner and the host rock is considered low due to the use of ground improvements performed in Reach 1 and Reach 2 (refer to Section 9.3.1). However, it is considered necessary to protect Reach 3 shales from fresh groundwater as this can cause rock mass degradation and swelling. Therefore, the following three measures are proposed to be undertaken to limit cross-formational water flow along the liner / rock interface:

1. Following completion of the concrete placement and strength gain, contact grouting should be performed through the lining to seal the aforementioned panning measures and the interface between the rock and final lining to minimise the potential for shunt flow caused by differential groundwater gradients.
2. Install a horizontal ring barrier (made of bentonite or similar material) behind the concrete liner at the Reach 2b / 3 contact zone. This ring will minimise the likelihood of any cross-formational groundwater flow during the operational period of the facility and will also ensure downward seepage of fresh groundwater does not occur along the concrete / rock interface into the Reach 3 shales. This ring will be approximately 600 mm thick outside the concrete liner and extend approximately 4 m along the shaft wall. Excavation for the ring barrier would be carried out using mechanical means. The ring is shown in Figure 4-8.
3. Prior to shaft sinking into the Reach 3 shales, curtain grouting near the dolostone / shale contact would be performed to control groundwater flow along this contact zone. This grouting is believed to be necessary to seal alternative pathways around the shaft seal ring through any fractures in the dolostones and the upper section of the Queenston Formation created during blasting.

Based on the current System Requirements [R46] and Design Criteria [R47], plain concrete is not recommended for the Reach 2 hydrostatic lining. The strength and thickness requirements necessary for a plain concrete liner to accommodate hydrostatic pressures are considered beyond what could reasonably be achieved during shaft development.

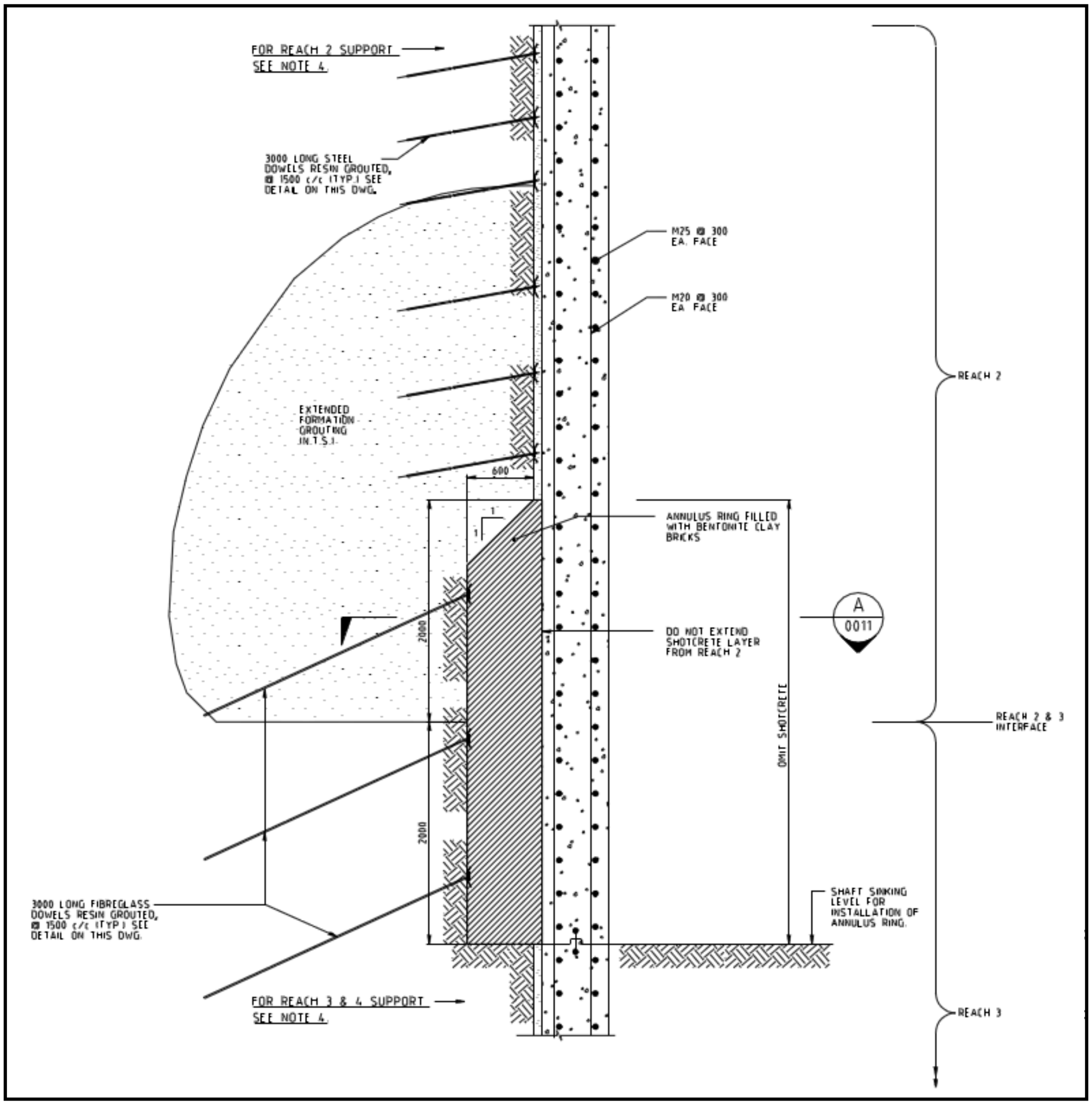

Figure 4-8 – Final Lining and Bentonite (or similar) Ring Details at Reach 2 / 3 Interface

4.3.6.1.5 Reach 3 / 4 Final Lining

The proposed final lining system for Reach 3 and Reach 4 will be similar to that used in Reach 1 and Reach 2. A reinforced concrete lining is proposed that is able to accommodate swelling pressures in the Reach 3 shales caused by time dependent deformational behaviour due to stress relief and / or the potential introduction of fresh water from Reach 2a.

A key difference relative to the Reach 1 and Reach 2 lining will be the inclusion of drainage and panning provisions. This lining type (often referred to as a "leaky lining") would not need to resist hydrostatic pressures, thus reducing the structural demands on the lining to only external rock loads and pressures, shaft appurtenance loading and other effects. Depending upon the magnitude and distribution of these loads, the reinforcing levels would likely be significantly reduced, possibly to levels where a plain concrete system may be permissible.

It is currently assumed that the lining system through Reach 3 and Reach 4 will be slip formed from the shaft bottom up to the Reach 2 / 3 contact at the conclusion of sinking. As these units are likely tight and, therefore, pose little risk of groundwater inflow, reduced concrete quality and strength requirements may be acceptable, thereby allowing consideration of drop forming as a possible lining installation method.

4.3.6.1.6 Potential Optimisation

The current design basis assumes that hydrogeologic conditions in Reach 2b necessitate the installation of a hydrostatic lining. However, if appropriate hydrogeologic conditions (i.e. sufficiently low hydraulic conductivity, limited groundwater inflow and limited recharge potential) can be verified for Reach 2b at the two shaft locations, there is the potential to move the horizontal ring barrier (currently planned for the Reach 2b / 3 contact) higher into Reach 2b, possibly as high as the Reach 2a / 2b contact zone.

In doing so, the Reach 2b final lining could be designed as a leaky lining system with drainage and panning provisions. Depending upon the magnitude and distribution of the other load effects in Reach 2b, this would likely reduce the reinforcing levels significantly from those required for a hydrostatic system; possibly to levels where a plain concrete system may be permissible. Drop forming of the lining would also be considered possible in this case.

To accomplish this, it is likely that a semi-permanent seal around the shaft would be necessary to reduce the hydraulic conductivities of the permeable units in Reach 2b (currently expected to be the upper 4 m of the Salina A1 carbonate unit and Guelph Formation). This can be achieved through curtain grouting in addition to the supplemental formation grouting during sinking (see Section 9.3.1.3).

If used, curtain grouting would be performed throughout the entire height of the expected permeable units in Reach 2b. Grout materials used for curtain grouting (usually micro-fine cementitious or chemical materials) are injected under pressure into the rock mass to create a reduced permeability zone using pre-drilled grout holes arranged in horizontal fan-shaped arrays. The grouted zone must be of sufficient size (annulus thickness around the shaft) and reduced permeability so that tolerable inflow levels through the shaft lining combined with the head loss through the grouted zone are effective in preventing build-up of hydrostatic pressures against the lining. Such grouting systems often require periodic lining maintenance and re-grouting to maintain the effectiveness of the system over the operating life of the shaft.

The need to implement these proposed groundwater control measures behind the shaft lining and the details of their design will be reviewed in the next phase of engineering.

4.3.6.1.7 Shaft Inspections

For information on proposed shaft inspections, the reader is referred to Section 10.3.2.

4.3.6.2 Design – Internal Steelwork

The shaft dimension and layout is dictated by the external dimension of the main cage which is 5.6 m long by 3.0 m wide by 18.5 m high, which has been set by the 5.0 m length of the 40 tonne forklift, (without the forks), the 2.62 m width of the Quadricell Resin Liner shells in a sacrificial forklift transport pallet, and the height of the shielded IC-18-T-H-E liner waste packages. The Main Shaft inside diameter will be 6.5 m and the shaft configuration will be split into three parallel compartments as described below:

- Main Cage compartment which is the largest and in the centre of the shaft.
- Main Cage Counterweight compartment to the south of the Main Cage compartment.
- The Auxiliary Cage and Auxiliary Cage Counterweight to the north of the Main Cage.

The Main Cage compartment will contain the cage conveyance as well as the following:

- Fibre optics and communications.
- Hoist signalling cables.
- Fire detection.

The Main Cage Counterweight compartment will contain the counterweight as well as the following:

- One 100 mm nominal diameter process water line.
- Two 150 mm nominal diameter slick lines (concrete for shaft construction only).

The Auxiliary Cage and Counterweight compartment will contain the cage and counterweight as well as the following:

- One 100 mm nominal diameter dewatering water line.
- One 150 mm nominal diameter compressed air line.
- Power feeds.

This configuration provides separation of power and communications as well as facilitates the installation of the conductors off the top of the Main Cage.

The Main Shaft will be equipped with two main steel buntons, which divide the shaft into the three compartments. Four steel guides will be fixed to the buntons for the main conveyance in the centre compartment. Stub buntons will cantilever off the main buntons in the two outer compartments, to which sets of guides will be fixed for each conveyance as shown in Figure 4-9 and drawing H333000-WP407-20-042-0001. Buntons will be 150 mm wide x 250 mm deep hollow steel sections and the guides will be 150 mm square hollow steel sections. The buntons will be fixed to the shaft concrete lining with a system of steel inserts, which are designed to allow horizontal alignment. The use of stub buntons facilitates a high quality alignment of steelwork during shaft equipping and ensures that the total material quantity is limited as far as is possible without affecting the performance of the system. These will be designed taking into account the emergency slip conditions which can exist with the conveyance. Steel guides are more durable and suitable for the heavy loads that will be hoisted. A total clearance of 12 mm is allowed between the guide and the brass slippers, which are mounted on the cage as part of the guide shoes. This clearance allows smooth riding in the shaft without becoming excessive as the brass slipper plates wear. The Main Shaft Main and Auxiliary cage designs are not required to incorporate any "safety dogs" as these conveyances are supported by at least two ropes; six ropes in the case of the Main Cage and two ropes for the Auxiliary Cage. In Ontario, such safety devices are required if the cage conveyances are suspended on a single rope. While not required under Ontario Mining Regulations as described in Section 4.3.2.1, a form of " wedge safety dogs" suitable for use on steel shaft guides has been provided for in the design in order to increase system redundancy.

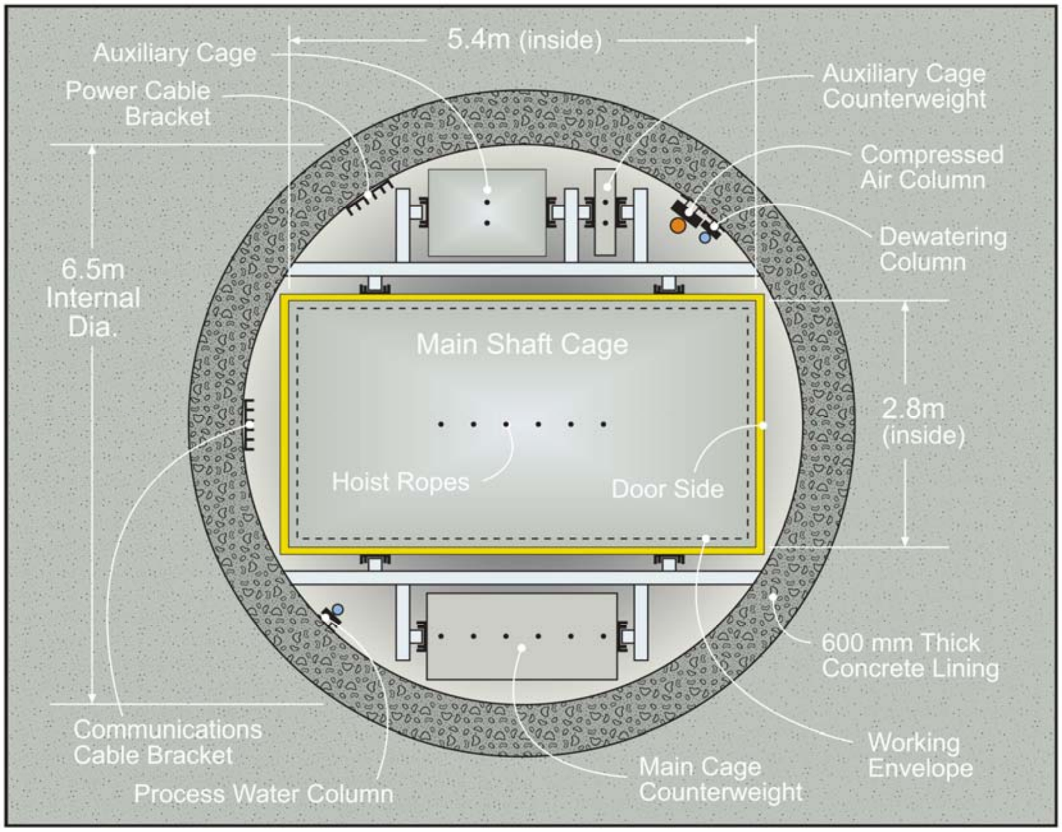

Figure 4-9 – Plan View Main Shaft

4.3.6.3 DGR Geosciences Stations

During and after construction of the Main Shaft and lateral excavations, ongoing geomechanical and geoscientific characterisation activities for the DGR site are proposed. The objectives of this work include verification of assumptions made during engineering design with respect to:

- In-situ stress conditions and rock mass behaviour.
- An observational design approach during construction where rock support can be adjusted in response to observed trends in the rock mass conditions.
- Long-term performance of the rock to support postclosure assessment.

This characterisation and verification program is described in Section 9.1.2.3. At this stage of design, the descriptions represent the interpretations performed during conceptual design desk study and will need to be developed in more detail during future phases of design.

4.3.6.4 Proposed Mid-shaft Exploratory Heading

A mid-shaft side heading is proposed in the Queenston Shale Formation at a depth of about 480 m below collar (BC) at Shaft Set 80 (refer to drawing H333000-WP407-20-042-0006). This facility would provide sufficient space and lighting for geological, hydrogeological and geotechnical testing that may be performed in the Reach 3 Ordovician shale.

4.4 Ventilation Shaft

4.4.1 Hoisting Duties

The following duties are required of the Ventilation Shaft hoist:

- Removal of waste rock during DGR level development.
- Second emergency egress for personnel.
- Provision of facility to remove waste rock in case of future expansion of the facility.

In addition, the Ventilation Shaft hoist will be used as the sinking hoist during construction of the Ventilation Shaft.

All the above duties are catered for using a double drum hoist and descriptions can be found for each of these duties in this section. The hoist has been rated based on the most onerous conditions from each of the expected operating scenarios.

A fundamental aspect of the hoisting systems is that the systems will be stable and safe in the event of an equipment malfunction or power failure.

4.4.2 Hoisting Systems

The Ventilation hoisting system will consist of the following elements:

- Ventilation Shaft hoist.
- Two ropes – one for each conveyance.
- Two conveyances.

- Two sheaves mounted in the Ventilation Shaft Headframe.

4.4.2.1 Description of Ventilation Shaft Hoist

The Ventilation Shaft hoist will be a 3.66 m double drum configuration with the two ropes passing over two sheaves mounted below the roof of the Ventilation Shaft Headframe. The hoist itself will be housed in a separate hoist house near the Ventilation Shaft Headframe. It will be driven by a direct coupled motor. The hoist consists of two separate drums mounted on a single drum shaft. Either one or both drums can be decoupled from the drum shaft through a mechanical clutch arrangement mounted on the outside of each drum. This enables the hoist to be used in a single drum configuration as required which is especially important during the construction phase of the shaft.

Each drum accommodates one rope, which is coiled on and off the drums with the rope 'dead end' being secured to the drum assembly, as compared to a Koepe friction hoist where the rope lays over the drum.

Bolted onto each drum is a brake disc onto which spring applied, hydraulically released disc brake callipers act. The brakes and clutches of the drums are interlocked electrically, hydraulically and mechanically through the hoist driver's brake and clutch levers to prevent the withdrawal of a clutch without the relevant drum's brakes being applied.

A sophisticated drive control and safety system is part of the hoist and control of the hoist can be either fully automatic or manual from a local hoist operator's console situated directly behind the hoist in the hoist house. The fully automatic feature can be used when the DGR level is being developed and waste rock is being transported from underground.

4.4.3 Ventilation Shaft Hoist Houses

4.4.3.1 Ventilation Shaft Hoist House

A double drum hoist will be installed in a nominal 13 m wide by 24.4 m long building, which will be 11.5 m high and constructed as an insulated and clad steel frame structure. This building will be required for both the sinking and permanent phase and will house the 3.66 m diameter double hoist drum for hoisting a bucket in single drum mode during sinking and either a bale with a cage or skip in one compartment and a skip in the other compartment after sinking is completed. The building will contain all the electrics and control cubicles, roll up doors for access, 8 tonne monorail for installation or major overhaul of the hoist.

4.4.3.2 Ventilation Shaft Winch Houses

Two single hoists will be installed in 10.0 m wide x 11.2 m wide building, which will be 9.1 m high and constructed as an insulated and clad steel frame structure. Two buildings will be required for the sinking phase and each building will house two 2.16 m single hoist drums with a 3.6 m flange diameter for hoisting the 4.2 m diameter three deck Galloway stage. Each building will contain all the electrical panels and control cubicles. Access will be provided by roll up doors which will allow the 8 tonne monorail access for the installation or major overhaul of the hoist. The Winch Houses will be removed at the end of the sinking phase. As with the Main Shaft Winch Houses, there is an opportunity to combine these houses if the geometries remain amenable.

4.4.4 Ventilation Shaft Conveyances

4.4.4.1 Skips for DGR Level Development

Two skips will be provided for waste rock removal during the construction of the repository. One skip body will be installed in the shaft without a bale and the other will be installed in a bale to allow the skip to be interchangeable with a cage. The skips will be bottom discharge types with a capacity 9.3 tonnes of broken rock as shown in Figure 4-10. These two skip arrangements are shown in drawings H333000-WP405-20-042-0014 and H333000-WP405-20-042-0015.

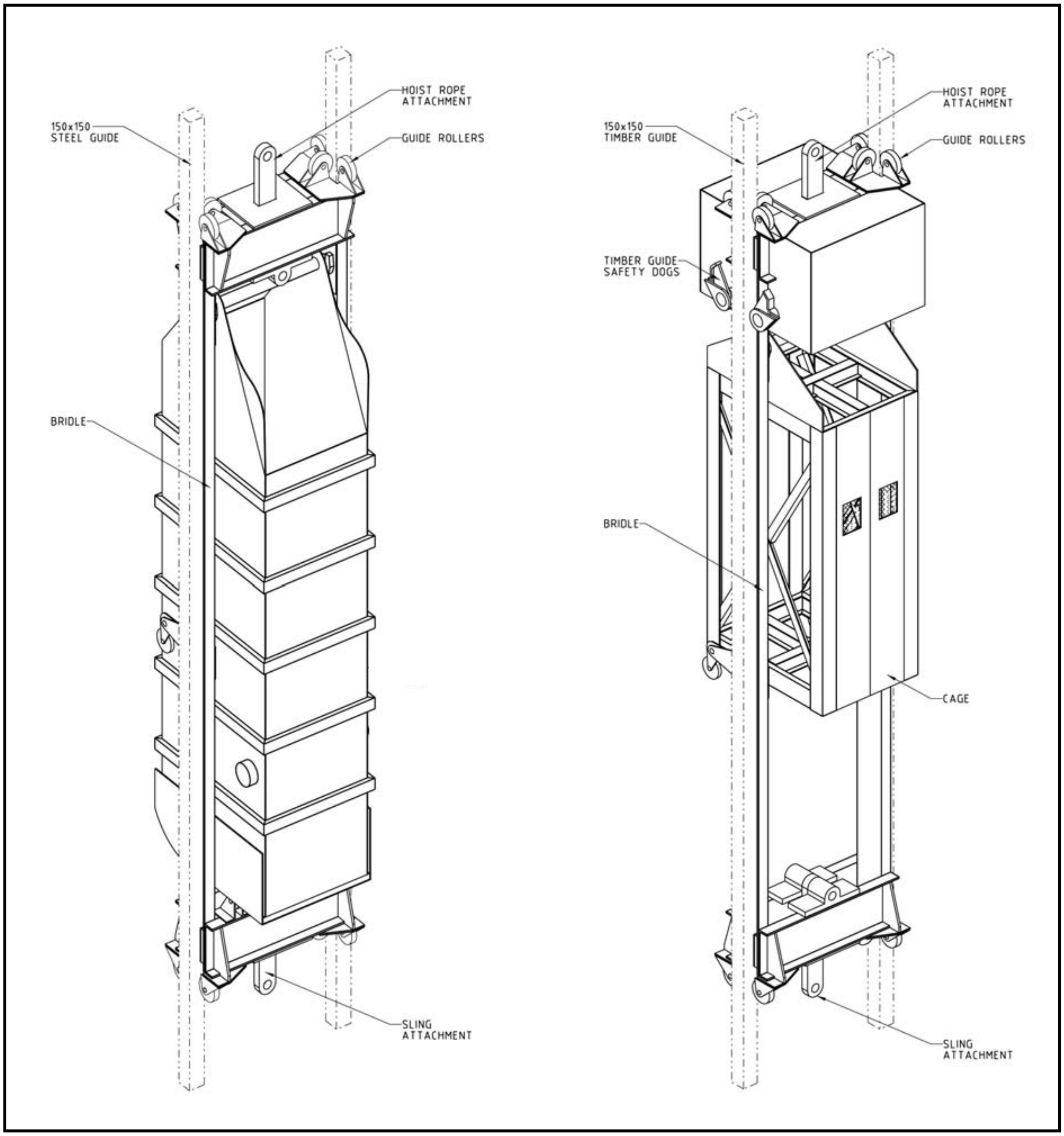

Figure 4-10 – Permanent Skip and Bale with Cage

4.4.4.2 Removable Cage

During the initial stages of level development the removable cage will be installed to provide access to the repository. Once the Main Shaft cages are available, the Ventilation Shaft removable cage will be replaced by the removable skip, thereby permitting skip-skip operation for the balance of the development period. Following completion of underground development, this cage will be reinstalled and used as a second egress to enable personnel to be evacuated from the repository. To provide a second egress during the period when two skips are in use, a suspended floor will be provided for installing in the bale skip to allow personnel transport, per § 232 (3) of the OMR [R48].

The single deck cage for seven people will be designed to fit the same bale used for this removable skip and when required the skip will be removed from the bale and the cage will be fitted. The cage will be approximately 2.8 m high with a floor plan of approximately 1.0 m wide by 1.45 m long to transport people. Details and full dimensions of the cage are given in drawing H333000-WP405-20-042-0016.

4.4.5 Headframe

The Ventilation Shaft Headframe will be a 43 m high, insulated and clad steel structure. Without the need for a large tower mounted Koepe friction hoist, this construction is more cost effective for this application with nominal plan dimensions of 10 m by 10 m. The headframe will be designed with heavier main members than would normally be used at a mine headframe to ensure that, with a planned maintenance system in place, the structure will not require any major refurbishments during the 100 year design life of the DGR. The headframe design will incorporate the sinking and permanent requirements with minimal modifications required to change over from sinking to permanent condition (drawings H333000-WP406-20-042-0006 and H333000-WP406-20-042-0008 show for the permanent and sinking layout of the headframe respectively).

The headframe will include two 3.66 m diameter sheaves, one for hoisting the bale, with either a cage or skip, and the other to hoist a skip. In addition to the sheaves, the headframe will include a tipping path and discharge chutes for the waste rock excavated during construction of the repository, the bale and skip arresting gear for retarding the conveyance in the event of overwind, monorail beams for maintaining and installing the conveyances and a muck bay on the north side of the headframe, into which the hoisted waste rock will be dumped before being loaded into trucks for transport to the WRMA. Stairs, intermediate floors and platforms have been provided for access and maintenance requirements. Figure 4-11 depicts the headframe in its permanent operations condition.

4.4.5.1 Collar House

The insulated and clad steel-framed collar house will be used for general maintenance and inspection of the shaft and conveyance hardware and ropes. The internal dimensions of the collar house will be 15 m long by 10 m wide by 5 m high. The building will contain electrical panels, lighting, roll up doors for access of the transmixer trucks, a monorail, equipment and materials required for the maintenance personnel. The building will be required to have airlocks to maintain proper functioning of the ventilation system. For the layout of the building see drawing H333000-WP406-20-042-0010.

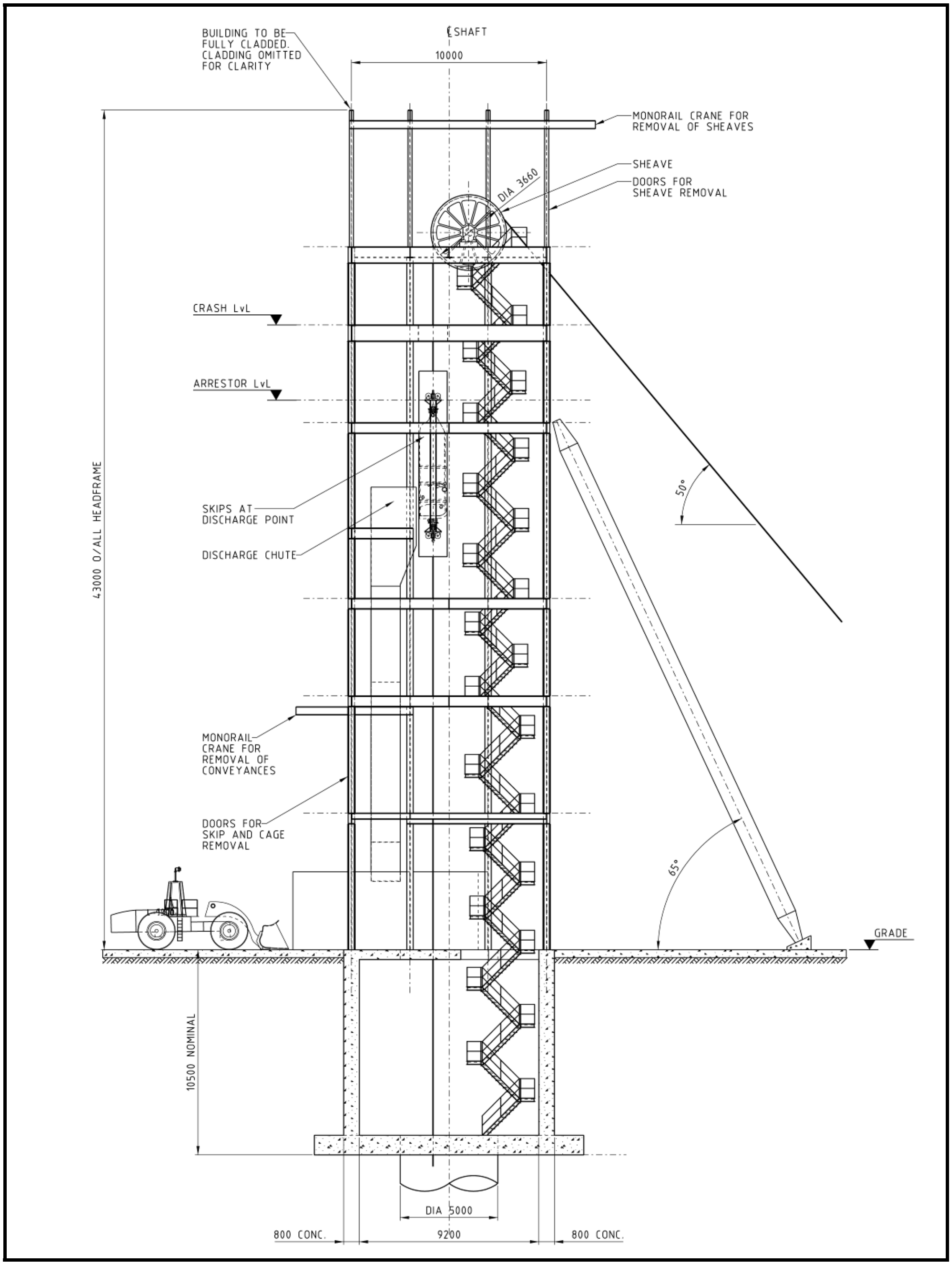

Figure 4-11 – Ventilation Shaft Headframe

4.4.6 Shaft Structures

4.4.6.1 Design – Support, Water Control & Lining

The Ventilation Shaft will have a smaller finished diameter than the Main Shaft at 5.0 m. The final concrete liner will also be thinner at 500 mm. Otherwise, the general design of the support, water control and lining will be the same as that of the Main Shaft, which is described in Section 4.3.6.1.

4.4.6.2 Design – Internal Steelwork

The Ventilation Shaft diameter has been set by ventilation air flow and construction requirements, requiring the internal finished shaft diameter to be 5 m. The shaft will be split into compartments as listed and described below:

- Cage and Skip compartment to the west.
- Empty compartment for upcast ventilation only to the east.

It should be noted that there is no vertical separator, such as a concrete brattice wall, between compartments and, therefore, upcast air will flow across the full cross-section of the shaft.

The cage and skip compartment contains either a cage and skip configuration or two skip configuration as well as the following:

- One 100 mm nominal diameter DGR dewatering water line.
- One 100 mm nominal diameter process water line.
- One 150 mm nominal diameter compressed air line.
- Power feeders.
- Fibre optics and communications.
- Hoist signalling cables.
- Fire detection.

The empty compartment will include the following:

- One 100 mm nominal diameter shaft water dewatering from shaft bottom to DGR level.
- Two 150 mm nominal diameter slick lines (concrete for construction only).

Upcast air will flow in both compartments and the design will ensure that the open area for air flow will be maximised to minimise friction as the air velocity will be higher than in the downcast Main Shaft.

The Ventilation Shaft will be equipped with one main steel bunton, which divides the shaft into two compartments. Stub buntons will cantilever off the main buntons in the north compartments to which two sets of guides will be fixed for each conveyance. Buntons will be 150 mm wide x 250 mm deep hollow steel sections and the guides will be 150 mm square timber guides for the bale / cage compartment and 150 mm square hollow steel guides for the skip compartment as shown in Figure 4-12 and drawing H333000-WP407-20-042-0002. The timber guides will be used since the cage is supported on a single rope and will, therefore, have to be equipped with safety dogs. Safety dogs are devices that are automatically deployed in the event of failure of the cage rope connection, which dig into the timber guides to stop the cage from free-falling to the shaft bottom. The buntons will be fixed to the shaft concrete lining with a system of steel inserts which are designed to allow horizontal alignment. As for the Main Shaft, the total clearance of 12 mm is allowed between the guide and the brass slippers, which are mounted on the cage guide shoes.

Additionally, the east compartment will also contain a ladderway section down from the DGR level with landings to provide a second access to the loading pocket (for rock loading of the skip). While not shown in the reference drawings in Appendix E, for safety purposes the ladderways below the repository level in both shafts will likely be carried to the shaft bottoms in subsequent design development.

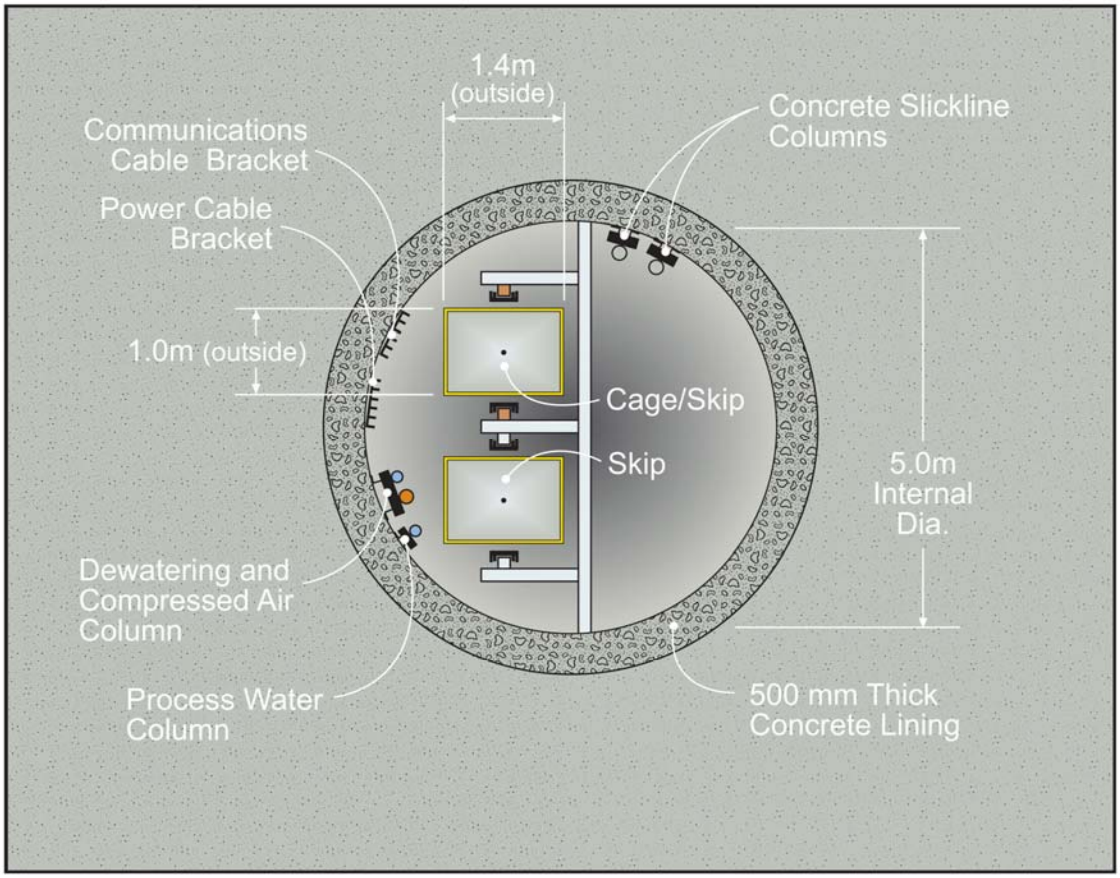

Figure 4-12 – Plan View Ventilation Shaft

4.4.6.3 DGR Level Station

At the DGR level, the Ventilation Shaft will be accessible by two routes: the ventilation tunnel leading directly to the Ventilation Shaft from the Main Access tunnel, and from the horizontal access tunnel leading to the ramp, which accesses both shaft bottoms and the loading pocket. The former, as currently designed, will be the site of three Exhaust Fans providing suction ventilation from the emplacement rooms and the maintenance workshop / fuelling area. It will be closed off by a ventilation door most of the time.

The second route on the repository level to the Ventilation Shaft will be the principal path for access and will be used not only as the route to obtain all concrete and shotcrete for the repository from the twin shaft slicklines located in the Ventilation Shaft, but also by personnel in a second egress situation. Transmixer vehicles will enter the Ventilation Shaft area off the access tunnel to the ramp and will back up into a small ramped area to receive their load from the slickline. The end of this area will also serve as sump for line slicking and flushing. The necessary compressed air and water take-offs will be present at this station and be fed from the Ventilation Shaft.

A typical shaft station arrangement of through going shaft framing steel will be constructed at the DGR level. This will provide a proper shaft station configuration set-up for the operations phase when a skip and cage will be operating in the shaft compartments to provide a second egress from the repository. During construction, however, when the shaft is used primarily for waste rock removal and two skips are in the shaft compartments, this access will be used only in the event that the Main Shaft conveyances are unavailable for timely use and a second egress need arises. Special man riding platforms will be required in the skip as will a method to get to that platform. A standard operating procedure will have to be prepared for this case.

This shaft station will also provide access to the offset ladderway up from the loading pocket and potentially also the shaft bottom. This route provides a second means of access to and from the loading pocket area and the shaft bottom to complement the ramp.

Power and communication services, which provide redundant feed to the repository, will exit the Ventilation Shaft at this level and be routed through the Ventilation Access to their respective rooms.

One of the two dewatering discharge routes from the main dewatering sump in the ramp to the shaft bottoms will enter the shaft through this station via the north access route and will provide the primary dewatering line for the repository.

A general arrangement of the Ventilation Shaft station at the DGR level may be found in drawing H333000-WP407-35-042-0002.

4.4.6.4 Loading Pocket System

During the construction of the repository, waste rock generated by the development of the repository openings will be transported to surface by two skips in the Ventilation Shaft. Waste rock will be brought to a dump point on the DGR level, with a rock sizing grizzly and rockbreaker, which is connected to the loading pocket system via a supported raise. This raise will terminate at the loading pocket at a control gate and will provide surge storage for waste rock in the raise to decouple waste transport on the DGR level and the hoisting of waste up the Ventilation Shaft.

Operation of the skip loading will be performed either locally, or remotely by the Ventilation Shaft hoist operator, and will consist of opening the control gate, passing the waste rock across a vibrating pan feeder and into a measuring box to ensure the proper weight and volume of rock are delivered to the skips. When the correct skip is in position, the door on the measuring box opens, vibrators on the measuring box are activated to assist dumping of waste rock into the skip via a feed chute, the door closes, and the skip is cleared for hoisting to surface to dump into the muck bay on the ground outside of the headframe. There will be two measuring boxes at the loading pocket, one for each skip, and a programmable logic controller (PLC) for the loading pocket will ensure that the diverter chute, located after the feeder but before the measuring boxes, will direct waste rock flow to the next skip to be loaded.

Communications between the loading pocket PLC and the hoist control system ensures that the necessary permissives are met to ensure safe and reliable operation of the system. Several of these permissives are: skip in position for loading, measuring box door status (open or closed); measure box status (weight / volume). This technology is at the heart of all underground mines using shaft hoisting systems for moving rock, is well understood, and is used on many systems worldwide hoisting tens of thousands of tonnes per day.

Because of the vertical extent of this type of facility, a ladderway will be provided internal to the loading pocket to access the several landings in this facility. As the cage in one of the Ventilation Shaft compartments will not be installed until the transition to operations (i.e. after all excavation of the DGR level has been completed), and because of the configuration of the loading pocket, cage access to this area will not be possible. Access will be provided by the ramp to the shaft bottoms and by an offset ladderway from the Ventilation Shaft station at the DGR level.

The loading pocket programming and the hoist programming will have to account for the different duties that may be needed during the life of the repository, which could include re-use of the fixed-bale skip for removal of any rock produced as a result of ground support maintenance or other circumstances.

A general arrangement of the facility may be seen in drawing H333000-WP407-20-042-0005.

4.5 Underground Repository Arrangement

The underground repository is comprised of several primary components that provide for access, support services, and the emplacement of the waste packages. As shown on Figure 4-2, these components are the:

- Main Shaft.
- Ventilation Shaft.
- Shaft and Services Area.
- Ramp to shaft bottoms.
- Panel 1 emplacement rooms.
- Panel 2 emplacement rooms.

Section 4.5.1 will provide the description of the geotechnical design of the openings: the Shaft and Services Area, access tunnels, emplacement rooms, development rock handling and the ramp to the shaft bottoms.

4.5.1 Underground Arrangement – Geotechnical Design Basis

The purpose of this section is to summarise the geotechnical design basis for DGR emplacement rooms and access tunnels. For more detailed information, the reader is referred to [R14] and [R49].

The geotechnical properties of the Cobourg Lower Member and the anticipated engineering behaviour of the rock unit are described in Section 2.5.4. Additionally, information regarding geomechanical modelling and the various assumptions used in the modelling are described in [R50].

4.5.1.1 Approach to Preclosure Geomechanical Modelling

Geomechanical modelling of excavations at the repository level during the preclosure condition were completed using Phase2 and FLAC software. The results of these analyses were used to assist in rock support design, emplacement room orientation and excavation sequences [R50]. The following description provides the assumed rock mass behaviour characteristics that were used for preclosure geomechanical modelling:

1. Constitutive Behaviour – rock mass modelled using intact rock behaviour characteristics between distinct bedding planes or incipient planes of weakness. Intact rock mass properties should consider cross-anisotropic strength behaviour.
2. Intact Rock Failure Criterion – the Diederichs compound failure criterion, which recognises spalling behaviour in low confinement stresses and reverts to the standard Hoek-Brown failure line at higher confining stresses, was used.
3. Cross-Anisotropic Strength Values for Intact Rock – vertical intact rock strength and deformation parameters determined from average values determined from DGR-2, DGR-3 and DGR-4 UCS and triaxial tests. Horizontal intact rock strength was based upon factors obtained from anisotropic, cross-core UCS test results.
4. Tensile Strength – considered to be ubiquitous across bedding planes. Was determined on the basis of average Brazilian Tensile Strength (BTS) values.
5. In-situ Stresses – ranges of 2.0 to 2.5 for K_{oH} and 1.0 to 1.5 for K_{oh} should be considered at the repository depth.
6. Jointing – bedding direction and horizontal planes of weakness will be controlled by the strength of shale interbeds and partings. Bedding and horizontal discontinuities were modelled as friction only surfaces with reduced vertical tensile capacity using self-weight for interconnecting bedding laminae.
7. Incipient Planes of Weakness – modelled discretely at 0.7 m centre to centre in the Cobourg Lower Member. Modelled ubiquitously in the Cobourg Collingwood Member and the Sherman Fall Formation.

8. Vertical / Sub-vertical Joints – considered vertical, sub-vertical and inclined joints to represent a localised structure only. These features were therefore neglected in modelling.

Behaviour-specific models were developed and implemented to address cross-anisotropic behaviour as appropriate for roof, pillar and floor behaviour, as shown in Table 4-5.

Parameter		**Pillar Failure Study**	**Roof and Floor Failure Study**
Geological Strength Index, GSI		92	92
UCS (MPa)		119	95
UCS* / UCS		41.4%	41.4%
Adjusted Tensile Strength, T_{adj} (MPa)		-4.3	-4.3
Modulus of Elasticity Intact, E_i (GPa)		49.4	32.3
Modulus of Elasticity Rock Mass, E_{rm} (GPa)		47.8	31.3
Poisson's Ratio, v		0.29	0.29
Spalling Parameters	a_{sp}	0.250	0.250
	m_{sp}	0.819	0.654
	s_{sp}	0.029	0.029
Residual Parameters	a_{res}	0.750	0.750
	m_{res}	9	7
	s_{res}	0	0
Common Parameters: *Density = 0.026 MN/m*^{3} *Hoek-Brown Parameter,* $m_i = 12$ *Tensile Strength, T = -6.4 MPa* *Damage Index, D = 0*		$\frac{UCS^*}{UCS} = 0.414$ $\frac{E_i}{UCS} = 340$	

Table 4-5 – Cobourg Lower Member Strength Parameters – Diederichs Spalling Failure

4.5.1.2 Preferred Shape of Openings

General experience is that excavations in massive rocks may be in any shape appropriate for the stress regime and the excavation function. Excavations in strongly bedded rocks are nearly always rectangular with the roof following a persistent bedding plane or fallout patterns being parallel to bedding direction. If persistent bedding planes are present in the roof, ground control elements (such as rock bolts) can be used to build thicker beams (like a linear arch) to span the room.

Excavation experience in the Cobourg Lower Member is limited to shallow depths. Despite this, the OPG projects at the Darlington NGS Intake Tunnel and the Wesleyville Access Tunnel provide some guidance. The Darlington NGS Intake Tunnel is illustrated in Figure 4-13. The photograph shows that the tunnel has an arched roof with the formation bedding being evident in the tunnel sidewall, but the rock appears to be relatively massive.

In comparison, the Wesleyville Access Tunnel as shown in Figure 4-13 is a tunnel with a flat roof with a series of rock beams exposed. Formation bedding is evident in sidewall and roof. Overall, the rock appears to be bedded and blocky (i.e. rock mass behaviour is controlled by discrete, rectangular blocks – or large size in this instance).

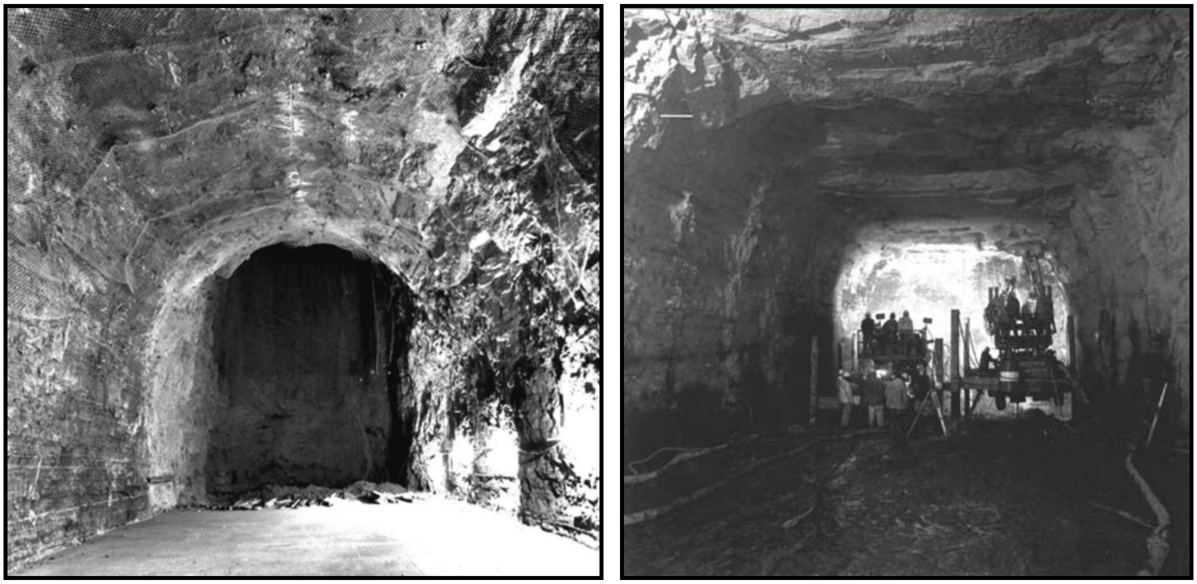

Figure 4-13 – Darlington NGS Intake Tunnel (left) and Wesleyville Access Tunnel (right)

Significant ground control problems may arise if the wrong roof shape is selected. In strongly bedded rock, an arched roof can create ground control problems because the roof arch cuts off the linear arches. This condition is illustrated in Figure 4-14, where a large rock wedge is formed by the excavation roof, a bedding plane above and a vertical joint to the left. Such wedges are thin near the room centreline and may be difficult to support. In massive rock, an arched roof is preferred in order to create a reinforced roof arch. A flat roof leaves in place more rock, requiring longer rock bolts to form the arch.

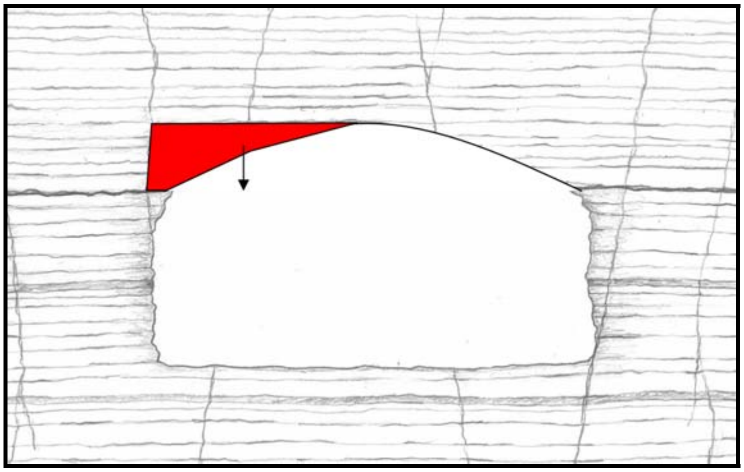

Figure 4-14 – Arched Roof Behaviour in Strongly Bedded Rock

The emplacement room and access tunnel shape preferences discussed in the following sections will be revisited in subsequent design phases and a final decision will be made on the basis of investigations at the repository level and functional requirements (see Section 9.1.2.3).

4.5.1.2.1 Emplacement Rooms

The preferred emplacement room shape depends primarily upon functional requirements for waste package stacking and constructability considerations. Trade-offs between these considerations are necessary to achieve the optimum room shape.

Rectangular rooms provide the greatest usable volume for package stacking, since the majority of waste packages are also rectangular. A rectangular room is also effective for the emplacement rooms as the anticipated bedding planes for the Cobourg Lower Member at the repository level are likely to be sub-horizontal.

Depending upon observed stress levels at repository depth, rounded corners or a shallow arched roof may be required due to unavoidable over-break in the roof and corners. This can, however, result in significant over-excavation and inefficient functional shape.

4.5.1.2.2 Access Tunnels

The preferred access tunnel shape depends primarily upon geomechanics. Due to the orientation of the panel access tunnels with respect to the assumed major principal horizontal in-situ stress, spalling failure is predicted in the roof. As such, an arch may be required to reduce the extent of failure and therefore the amount of rock that will need to be supported.

When selecting the optimal access tunnel shape, it will be necessary to consider potential for roof spalling, clearances required for waste package transportation and ventilation requirements (e.g. position and size of ventilation ducts).

4.5.1.3 Preferred Opening Orientation With Respect to In-situ Stress Tensor

The majority of underground space is comprised of emplacement rooms. In an effort to optimise the design of the repository, the longitudinal axis of the emplacement rooms has been oriented parallel to the direction of assumed major principal horizontal in-situ stress, which may vary but has been assumed to act along an ENE bearing (refer to Section 2.5.6).

The rotational orientation of the emplacement rooms relative to the stress tensor would affect the magnitude of resultant stress redistribution that would be predicted in response to room excavation. The higher the horizontal stress acting transverse to the room, the greater would be magnitude of stress redistribution and hence the greater the likelihood of overstressing the rock in the walls and roof of the emplacement rooms.

Geomechanical modelling has confirmed that the emplacement rooms should be oriented with their longitudinal access parallel to the major principal horizontal in-situ stress direction to minimise likelihood of overstressing the rock in the walls and roof of the emplacement rooms. Since there is uncertainty about the actual principal stress direction, three-dimensional geomechanical modelling was carried out to assess the tolerance of emplacement room orientation relative to the in-situ stress tensor direction [R50]. Based on these results, a tolerance of 15° has been established for the purposes of preliminary design.

With respect to access tunnels, geomechanical modelling has predicted that spalling in the roof and floor will be more substantial in excavations oriented perpendicular to the major principal horizontal in-situ stress. In an effort to reduce the extent of damaged rock in the roof, further analyses will be performed to determine the optimal access tunnel orientation with respect to the in-situ stress field.

4.5.1.4 In-Situ Pillar Width Requirements

In the context of a rib and pillar emplacement room layout, cost minimisation for the DGR is achieved by selection of the smallest acceptable pillar width between parallel rooms over the full range of expected rock mass conditions and how this pillar width would be adjusted to address the full range of rock mass conditions. This approach represents a flexible design that can be altered in response to observed rock mass conditions (that may differ from the conditions assumed during design).

For the sizing of pillars between emplacement rooms, it is assumed that any rock support installed in the pillars will not enhance the strength of the rock pillar but only contain loosened or failed rock. The cost of reinforcing the pillars to increase stability (thus reducing the required minimum width) is expected to be greater than the cost of using wider unreinforced pillars to achieve the required level of safety.

Pillar damage modelling was completed for the most common size of emplacement room (8.6 m wide by 7.0 m high) with pillar widths ranging from 14.0 m to 22.0 m. Results from the modelling were assessed with respect to the predicted depth of pillar damage. The extent of damage was then categorised to allow easy comparison of modelling results.

Based upon an expected value approach and extensive pillar modelling, the optimal pillar width for an 8.6 m wide by 7.0 m high emplacement room has been determined to be 17.2 m, which is approximately two times the emplacement room width. The pillar modelling predicts that three equivalent pillar lengths (750 m) will experience at least corner spalling and wall fracturing parallel to pillar walls. At pillar widths (or room spacing) greater than 17.2 m, the cost of constructing larger pillars exceeds the cost of maintenance and repair associated with any pillar damage. Therefore, increasing the pillar width beyond 17.2 m to achieve the required level of safety would not be cost effective.

The modelling results therefore affirm the findings of previous studies performed in conceptual design that established that a rib pillar width equal to twice the effective width of adjacent emplacement rooms provides an optimal, safe design basis for the DGR.

This analysis was based upon the assumption that the excavation methods produced little to no overbreak and minimal highly damaged zone (HDZ) beyond the excavation line. If the chosen excavation method produces overbreak or HDZ, then the effective pillar width would be reduced by the depth of the overbreak zone on both sides of the pillar. Therefore, the optimal pillar width stated above may need to be increased to maintain a consistent level of design safety. The reader is referred to Section 9.3.2.1.2.1 for information on overbreak using drill and blast methods.

4.5.1.5 Rock Support Basis of Design for Emplacement Rooms and Access Tunnels

Rock support for the deep repository facilities has been designed to protect the safety of workers both during the construction and operations phases and will consist of conventional underground excavation and mine support. This section describes the preliminary design of rock support to be used for most ancillary rooms, emplacement rooms and access tunnels. The basis for support design was primarily provided by the analysis of the geomechanical modelling results and previous construction experience.

Implementation of the rock support requirements described herein can be found in drawings H333000-WP408-20-042-0020 and H333000-WP408-20-042-0021. Additional information on the support rationale can also be found in [R49].

4.5.1.5.1 Rock Support Design Requirements

The rock support for the lateral development portions of the DGR has been designed to meet the following requirements:

- Rock Mass Conditions:
    - Provide structural stability of the tunnels and rooms for occupied and unoccupied conditions to protect personnel and equipment during waste package emplacement operations.
    - Rock support system in emplacement rooms and access tunnels will function as both the initial and final (permanent) rock support.
    - Rock behaviour and loading under excavation induced redistribution of in-situ stresses.
    - Expected values will be used for the basis of design presentation and estimate.
    - Full range of statistically significant range of geomechanical properties for assessment of alternatives.
    - The full range of in-situ stress conditions at the repository depth and location as currently understood.
    - Orientation of these underground openings relative to in-situ stresses.
    - Past underground construction project experience in the Cobourg Lower Member.
- Durability:
    - 100-year design life.
    - Minimise maintenance and repair of the rock support and rock mass surrounding the repository facilities during the life of the repository.
    - Corrosion protection for the rock support to address high salinity.
    - Protect the repository rock mass from degradation due to environmental exposure.
- Safety:
    - Protect personnel from rock fall during both construction and repository operational phases.
    - Minimise off-gassing of methane and other gases from surrounding host rock.
- Repository Functionality:
    - Anticipated excavation methods and sequence.
    - Room size and shape.
    - Permit repository operational use (adequate clearance for transport and placement of waste packages).

- Protect waste packages during transport and emplacement by providing a durable, smooth and level travelling surface.
- Minimise and control the generation of dust from exposed rock and vehicular traffic.
- Protect waste packages emplaced in the storage rooms from damage due to rockfall.
- Protect the ventilation and utility systems from damage due to rock fall.

4.5.1.5.2 Design Categorisation

The rock support requirements described herein have been developed on the basis of the full range of rock mass conditions that would likely be encountered in the Cobourg Lower Member. However, to provide a robust design, it is prudent to develop designs that address conditions that are at the lower end of the applicable range.

For the DGR, the preliminary rock support has been developed for conditions representing the average (or mean) value minus one standard deviation (refer to Section 2.5.4). This level of design is believed to provide a robust level of support that is not overly conservative. In addition, to be consistent with best practice, it is prudent to ensure the following:

- Rock support elements have a designed-in overstrength for the specified loads (often referred to as a factor of safety) and
- Monitoring and observations of rock mass and rock support performance is conducted to direct the need for replacement or supplemental support items. This would include core sampling and testing, geologic mapping and instrumentation (convergence, rock bolt load cells etc.).

Sub-division of the range of measured rock mass conditions into a number of categories and development of classes of rock support, each designed with a consistent level of safety for their condition category, offers an opportunity for design economy. When combined with field monitoring and observations, this approach can improve the economy and safety of rock support by allowing the selection of the most appropriate support class on the basis of observable / measurable conditions in the field. It is recommended that a design categorisation approach be developed in subsequent phases of design. The selection of support class to be implemented will be made by the engineer based upon observed conditions (mapping, probing, testing, stress measurements) during construction.

4.5.1.5.3 Rock Burst Potential

The potential for rock burst (brittle, sudden failure of rock in underground openings) is not considered to be of concern in the argillaceous limestones of the Cobourg Lower Member, which are considered to be more ductile and less brittle than granitic rocks (where rock burst can occur under high stress). In addition, the presence of rock support in the crown and upper wall portions of the repository (if installed in close proximity to the advancing excavation face) significantly reduces the risk of such a condition.

4.5.1.5.4 Potential Failure Mechanisms

Two failure mechanisms were considered at the repository horizon to provide a geomechanical basis for the design rock support elements. These mechanisms are:

- Combined spalling and slabbing failure; and
- Discontinuity dominated failure in a jointed rock mass.

The primary failure mechanism at the repository level is expected to be combined spalling and slabbing failure. As localised zones of vertical / sub-vertical jointing are considered to be have a low probability of occurrence at the DGR level, discontinuity dominated failure in jointed areas is only expected to have a localised effect on rock mass quality.

Both mechanisms are discussed briefly in the following subsections. For additional information, the reader is referred to [R49].

4.5.1.5.4.1 Combined Spalling and Slabbing Failure

The primary failure mechanism in the repository openings will likely be combined spalling and slabbing failure, as predicted through geomechanical modelling. Spalling develops due to excavation induced stress redistribution leading to crack initiation under low confinement. A slab is created when spalling propagates between parallel incipient planes of weakness, resulting in a fallout mechanism.

This combined mechanism was evident in the geomechanical modelling results, which predicted a depth of failed rock for excavations oriented both parallel and perpendicular to the major principal horizontal in-situ stress. While the depth of spalling failure is predicted to be greater in the roof of access tunnels, it is still present in emplacement rooms and will need to be addressed by rock support.

Based on the results of geomechanical modelling, combined spalling and slabbing failure is expected to extend as much to 2.5 m into the roof and walls of the lateral excavations. In order to design support appropriately, rock bolts must extend beyond the extent of damage rock (anchor to solid ground) and have an appropriate spacing such that they are able to support the weight of the slabs. Additionally, as spalling will cause small pieces of rock to detach from the excavation boundary, shotcrete or mesh will be required to protect workers and machinery from falling rock. These support requirements are shown in Figure 4-15.

To address this failure mechanism, a bolt spacing of 1.5 m is recommended for all excavations with a bolt length of 3.5 m to ensure the bolts are anchored beyond the zone of damaged rock. By using a spacing of 1.5 m for the bolts, this would allow for a 1 mm corrosion allowance around the bolt while preserving a factor of safety of 1.5 on the yield strength. Shotcrete or wire mesh will also be required.

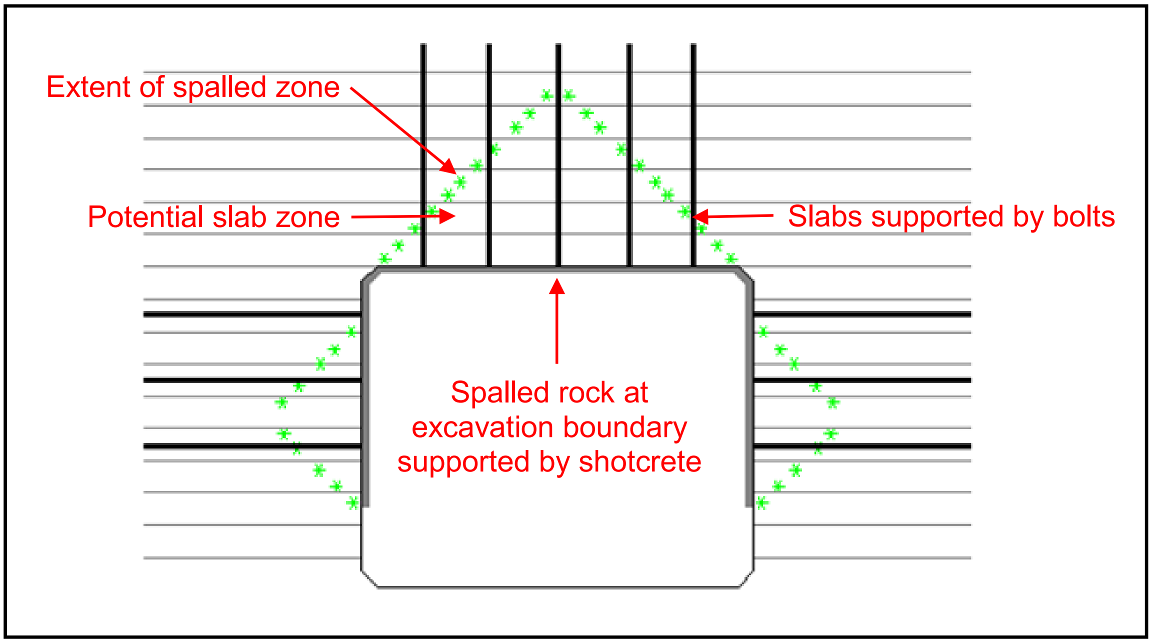

Figure 4-15 – Recommended Support to Address Slabbing and Spalling Failure

4.5.1.5.4.2 Empirical Assessment – Discontinuity Dominated Failure

Discontinuity dominated failure occurs in the presence of vertical and sub-vertical discontinuities, resulting in the creation of a kinematic mechanism for roof failure. This is considered to be a low-probability mechanism as few widely spaced vertical joints are expected at the repository level. The importance of this failure mechanism can be estimated through the use of empirical methods such as the rock mass rating system (RMR) and the tunnelling index (Q).

Based upon the Q analysis (shown in Figure 4-16), in the absence of spalling, failure caused by vertical / sub-vertical fractures is not expected to be a dominant mechanism at the repository horizon. If additional joint sets are locally observed (represented by the “localised jointing” category), supplemental support consisting of additional bolts and shotcrete would be needed.

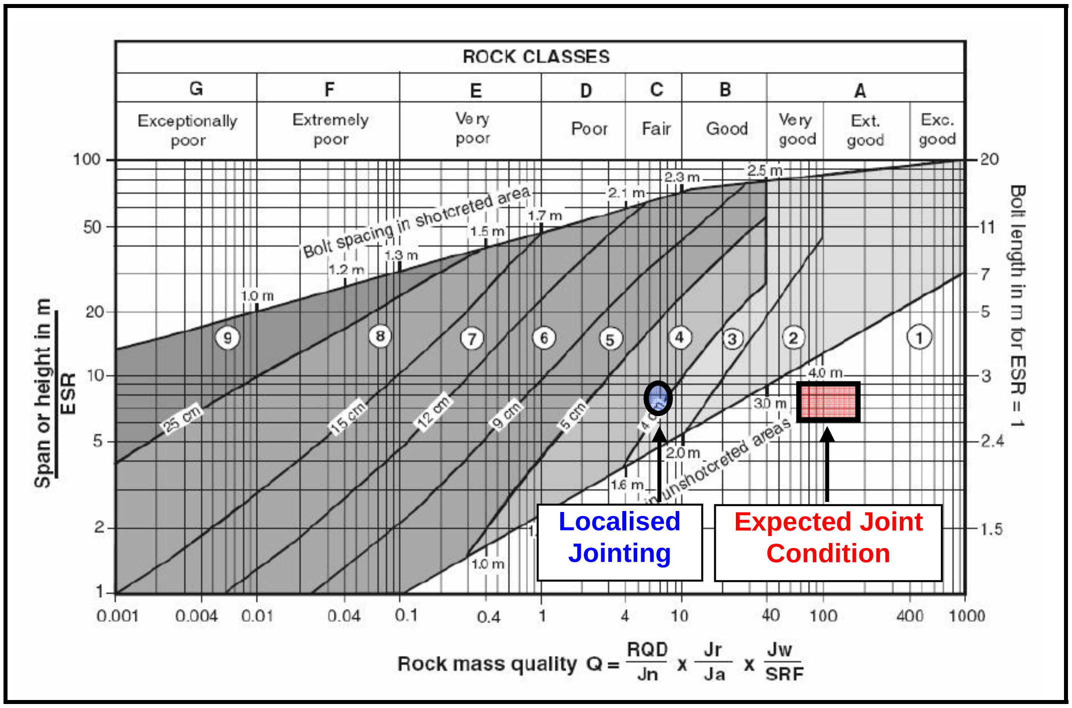

Figure 4-16 – Estimated Support Categories Based on Tunnelling Quality Index (Q)
Expected DGR Jointing Condition shown in Red, Localised Jointing Condition shown in Blue

4.5.1.6 Rock Support Details – Emplacement Rooms

The proposed rock support for expected rock mass conditions will consist of pattern steel rock bolts or rock dowels and shotcrete (sprayed concrete) as described in the following sections and shown in drawing H333000-WP408-20-042-0020. If observed conditions and behaviour are better than expected, it may be possible to substitute shotcrete with steel wire mesh.

The extended shotcrete coverage and rock bolting in the emplacement rooms is needed to protect workers and machinery during the construction and operations phases, as well as satisfy the 100-year design life of the repository facilities.

Rock pillars have been designed so that they are sufficiently stable without reinforcement. The rock support shown is not considered to act as pillar reinforcement, but rather to retain failed rock in roof and walls of the room excavations.

4.5.1.6.1 Rock Bolts

Proposed requirements for pattern rock bolts for wall and roof support are as follows:

Item	Requirement
Rock bolt steel bar	CT type, HDPE sleeved rock bolts. 22 mm diameter uniform solid, Grade 420.
Rock bolt anchors	Cone type anchors for rock bolts will require pre-tensioning immediately after installation to minimise the risk of rock slabbing and hold overstressed rock in place until shotcrete and grout can be installed.
Rock bolt length	Standard length of 3.5 m (embedded in rock). Anchor of bolt should extend beyond length of predicted overstress. Correspondingly, longer lengths may be required in weaker rock.
Rock bolt spacing	1.5 m centre-to-centre spaced longitudinally and transversely.
Rock bolt orientation	Roof: oriented vertical in all directions.
	Roof abutments/corners: oriented vertical in longitudinal profile and inclined 30°-45° from vertical.
	Sidewalls: oriented perpendicular to the wall in the horizontal plane and 15° above horizontal in the vertical plane.
Rock bolt coverage	Across the full opening width of the roof of all deep repository facilities and to within 2 m above the base of excavation. Rock bolting for the shaft stations should extend full height down the sidewalls to the floor.
Rock bolt bearing plate and nuts	150 mm square or round, 10 mm thick, Grade 300 with rebar loops for shotcrete anchorage, galvanised, spherical washer and nuts – all galvanised.
Rock bolt bar corrosion protection	Full-length, hot-dip zinc galvanised; full-length, corrugated HDPE sheath encasement; and full-length, cement grout encapsulation.
Rock support corrosion protection	Full-length, hot-dip zinc galvanising of all steel bearing plates, steel nuts, and steel wire mesh.
Installation	Rock bolts should be installed up to the rock face after each muck cycle, within eight hours of roof exposure and to within a maximum horizontal distance of 4 m from the advancing face at all times. Full length, pressure grouting of all bolts for corrosion protection. Grouting may be performed before or after shotcrete installation.

Table 4-6 – Rock Bolt Requirements

4.5.1.6.1.1 Rock Bolt Length

The geomechanical modelling included modified failure envelopes that recognised the brittle behaviour of the rock at low levels of confinement. The zones of plasticity around the openings were clearly shown and were shown to vary only marginally over the range of pillar widths. The damage zones were found to vary significantly with changes in rock strength.

In subsequent phases of design, consideration will be made to assessing the amount of steel mesh or chain link fence in lieu of shotcrete. Such a consideration will be made on the basis of probability distribution and the observed rock strength characteristics scalable design basis.

The rock bolt length has been specified to extend beyond the damage zone limits (potentially 2.5 to 3.3 m above the roof) determined by thorough geomechanical modelling. An example of the recommended type of rock bolt is the CT rock bolt as manufactured by Orsta Stal AS of Norway. This is shown in Figure 4-17.

Figure 4-17 – Corrosion-Protected Rock Bolt

4.5.1.6.1.2 Supplemental Rock Support

Additional bolts will be required to address localised structural features such as in areas with inclined, vertical and sub-vertical joints (depending upon their strike and dip relative to the opening) and areas of thinly laminated bedding planes or weaker rock. The need for these supplemental rock support elements can be assessed on a probabilistic basis during design with confirmation performed on an observational basis during construction.

4.5.1.6.1.3 Skewed Openings

Additional rock bolts through the rock pillars and chamfering of rock pillars at the skewed emplacement room openings from the access tunnels will be required to support the rock mass in these areas of complex stress conditions. This will need to be addressed in subsequent phases of design.

4.5.1.6.2 Shotcrete and Steel Wire Mesh

Fibre-reinforced shotcrete (steel or fibreglass) is recommended for use with the rock bolts to provide supplemental corrosion protection for the bolts, to protect against rock mass degradation due to environmental exposure, to minimise off-gassing from the rock mass and to preserve the rock mass quality for the 100-year design life of the repository.

Shotcrete provides more effective support for spalling or loosening rock between the rock bolts due to overstress fracturing, relative to steel wire mesh. The use of shotcrete can also result in less long-term maintenance of the rock support system. Steel wire mesh can only be used in areas of highly massive and competent rock as verified at the time of construction.

Proposed requirements for shotcrete and steel wire mesh in the emplacement rooms are as follows:

	Comment
Shotcrete	35 MPa 28-day compressive strength, steel fibre-reinforced – 40 kg per m3; 50 mm minimum installed thickness.
Shotcrete coverage	Across the full opening width of the roof of all deep repository facilities and to within 1.5 m from the floor on the sidewalls for all facilities except the shaft stations and emplacement rooms. Shotcrete for the shaft stations and emplacement rooms should extend from the roof down the full height of sidewalls to the floor.
Steel wire mesh	100 x 100 – MW25.7 x MW25.7 welded wire mesh installed and fastened to the rock surface by the rock bolts. Chain link mesh should not be installed as shotcrete application may be required at a subsequent date.
Installation	Shotcrete should be applied within 24 hours after the rock has been exposed.

Table 4-7 – Shotcrete and Wire Mesh Requirements

4.5.1.6.3 Concrete Floor Slab

The floors will be over-excavated as needed to provide sufficient depth to place a 200 mm thick concrete floor slab and maintain the required finished clearance heights. A concrete floor slab is needed for the emplacement rooms to provide:

- Surface for safe and efficient waste package emplacement.
- Uniformly level floor for waste package stacking.
- Rock dust control and to minimise dust generated by pedestrian and vehicular traffic particularly in areas with a high frequency of vehicle turning movements.
- Efficient drainage pitching for wash water and groundwater collection.
- Improved ventilation efficiency.
- Means to control floor buckling and stress fracturing in rock.
- Safety of pedestrian operational personnel against tripping and falling hazards.

A bare or exposed rock floor will result in an uneven or non-horizontal profile, potholing, and depressions caused by rock overstress fracturing or buckling and the undulating nature and any slight horizontal bedding dip of the rock mass. Some maintenance of the floors over the life of the repository will be necessary due to these effects over time and wear and tear due to construction and waste package handling traffic.

Proposed requirements for the concrete floor slab in emplacement rooms are as follows:

	Comment
Floor Concrete	35 MPa 28-day compressive strength, self-levelling or placed with travelling screed. Provide drainage channels as required. Floor is to be blown clean before placement and be cast in place.
Reinforcement	No reinforcement required in emplacement rooms.

Table 4-8 - Floor Requirements

4.5.1.6.4 Corrosion Protection for Rock Support

Due to the high salinity of the groundwater encountered within the Cobourg Formation, corrosion protection for the rock support is needed to:

- Provide the required 100-year operating life of the deep repository facilities.
- Maintain structural stability of the rock mass and the repository facility openings.
- Minimise degradation of the rock mass.

Based upon experience in sanitary sewer and combined sewer overflow tunnels, which are considered to be more corrosive than the DGR, passive triple-corrosion protection is required to meet these objectives. This consists of the following:

- Full hot-dip zinc galvanising of all rock support steel elements (i.e. bars, tendons, wire mesh, nuts, plates).
- Full-length plastic sheath encasement of embedded rock bolt steel bars or strand tendons with corrugated high density polyethylene (HDPE).
- Full encapsulation of embedded rock bolt steel bars or strand tendons with ordinary portland cement (OPC) grout.

4.5.1.7 Rock Support Details – Access Tunnels

Based upon geomechanical modelling results, spalling failure is expected to be more significant in the roof and floor for excavations oriented perpendicular to the major principal horizontal in-situ stress. To address this, additional support elements beyond those discussed in Section 4.5.1.6 will be required for the access tunnels.

Given the spalling potential in the roof, spiles can be used to support the rock mass during excavation. These spiles would be resin-grouted and angled ahead of the excavation with 2 m centres. To reduce damage potential, the spacing of the vertical rock bolts could be reduced to 1.0 m (from 1.5 m for the emplacement rooms) and round lengths could be reduced to 2 m for excavation of the access tunnels.

In the floor of the access tunnels, additional requirements must be addressed above those for emplacement rooms. They are:

- Safe and efficient waste package transfer and transport by rail or rubber-tired vehicle.
- Minimise long-term access-way grading and rail maintenance.

- Control of floor rock spalling and buckling.

Based on the results of geomechanical modelling, it is predicted that overstressing will occur in the floor of the access tunnels. Therefore, dowels are recommended to stabilise the rock in these areas. Overstressing in the floor as well as the presence of water beneath the slab can cause rock degradation over time. Dowels would help to stabilise the rock and provide a strong foundation for the floor slab, limiting excessive flexure. These dowels would be installed after completion of excavations and during the pouring of the concrete slab. An alternative method for stabilising the floor would be to use a significantly thicker floor slab.

Proposed requirements for floor support materials in the access tunnels, which will be examined further in future stages of design, are as follows:

	Comment
Floor Concrete	35 MPa 28-day compressive strength, self-levelling or placed with travelling screed. Provide drainage channels as required. Floor is to be blown clean before placement and be cast in place.
Reinforcement	Reinforced with welded steel wire mesh in access tunnels, unreinforced in emplacement rooms.
Steel Anchor Dowels	Untensioned floor dowels in access tunnels and other rooms oriented more than 30 degrees to major principal horizontal in-situ stress. Grade 400, M25 deformed reinforcing bar, galvanised. Grouted full length using cement grout. Can be installed immediately prior to placement of concrete. Number and size of dowels may be adjusted depending on level of in-situ rock stress as measured at repository depth.
Anchor Dowel Plate and Nuts	150 mm square or round, 10 mm thick, Grade 300 with rebar loops for concrete anchorage, galvanised, spherical washer and nuts – all galvanised.
Topping	High abrasion floor topping (such as Emerytop 400) to be applied in access tunnels and stations (high load and high traffic zones) – not required in emplacement rooms.

Table 4-9 – Access Tunnel Floor Requirements

4.5.1.8 Rock Support Details – Other Underground Areas

The foregoing sections describe the standard rock support to be used in emplacement rooms and access tunnels. These openings represent over 80% of the openings at the repository level of the DGR. The following areas will require further investigation for support selection and may require special treatment:

- Shaft stations.
- Excavations in the underground Shaft and Services Area.
- Rock handling tunnels.
- Access tunnels crossing bays.
- Emplacement rooms / access tunnel intersections.

Based on geomechanical modelling results, 6 to 7 m of roof failure is predicted for a 7.7 m high Ventilation Shaft station with support installed [R50]. As the Main Shaft station is 14 m high, it is expected that this area will experience a similar or greater depth of failure. It is believed that these areas will therefore require extensive specialised rock support. Additional modelling will be performed in future stages of design to develop a safe excavation and support sequence for this and similar areas.

The rock support design for these areas will be developed in future phases of design.

4.5.1.9 Geologic Monitoring and Instrumentation

A geologic monitoring and instrumentation program will be developed in subsequent phases of design and implementation to include:

- An instrumentation plan for:
    - Pillar convergence monitoring extensometers.
    - Rock bolt and shotcrete load cells.
    - Multi-point borehole extensometers to measure roof convergence.
    - Tape or laser extensometer arrays to measure convergence of rock openings.
- Geologic mapping of the exposed rock face should be performed to document rock conditions as encountered and to permit rock mass classification for support type selection.
- Probing ahead of the excavated face and into the pillar to sample and test intact rock strength parameters.

Such a program will confirm the effectiveness of the rock support and identify areas of opportunity where rock support requirements may be relaxed due to better than expected rock mass strength conditions.

4.5.1.10 Wall Drains and Crystal Growth

The expected volumes of groundwater in the Cobourg limestone are expected to be very small (to non-detectable). This combined with the presence of shotcrete placed over the surfaces of the emplacement room roofs will minimise the humidity and air flow gradient and hence minimise crystal growth. In addition, monitoring of the condition or rock support, recognising that shotcrete is an excellent tell-tale of such a phenomenon will allow early detection and repair. Correspondingly, crystal growth is not believed to be of significant risk to the rock support for the DGR.

Wall and strip drains can be installed prior to shotcrete placement at observed seeps from the rock mass to prevent build up of hydrostatic pressures behind the shotcrete and to minimise the potential for crystal growth. If necessary, weep holes can also be cored through the shotcrete or floor concrete if seeps are observed after placement.

4.5.1.11 Geotechnical Guidelines for Development of DGR Layout

Based on the current understanding of the area geology and rock strength parameters, the following geometric guidelines were used to develop the underground layout shown in this report:

1. All excavations should be located at least 100 m from exploratory boreholes.
2. Axis of emplacement rooms should be oriented parallel to the major principal horizontal in-situ stress (σ_H) for the project area, which is nominally ENE (067.5°).
3. Minimum roof cover (roof of excavation to Cobourg Collingwood Member / Cobourg Lower Member contact) should be 8 m to minimise stress impacts to the shaley Collingwood Member and provide sufficient depth for installation of rock support elements within competent limestone.
4. Minimum floor cover (floor of excavation to Cobourg Lower Member / Sherman Fall Formation contact) should be 5 m to avoid overstressing of the weaker Sherman Fall Formation.
5. Roof cover should be maximised subject to the minimum in floor cover.
6. Pillars between emplacement rooms should be equal to the sum of the widths of the adjacent rooms.

Flexibility has been incorporated into the layouts to accommodate any changes to these guidelines in future stages of engineering.

4.5.2 Layout of Underground Shaft and Services Area

The underground Shaft and Services Area is laid out based on the “Shaft Island Panel” concept of locating both the Main and Ventilation Shafts in close proximity and “clustering” the service (ancillary) rooms in the same area: see Figure 4-18 or drawing H333000-WP408-20-042-0003. The ancillary rooms are located on a south looping tunnel that provides a degree of isolation from the movement of the waste packages. This concept also provides an alternate egress route from anywhere in this area.

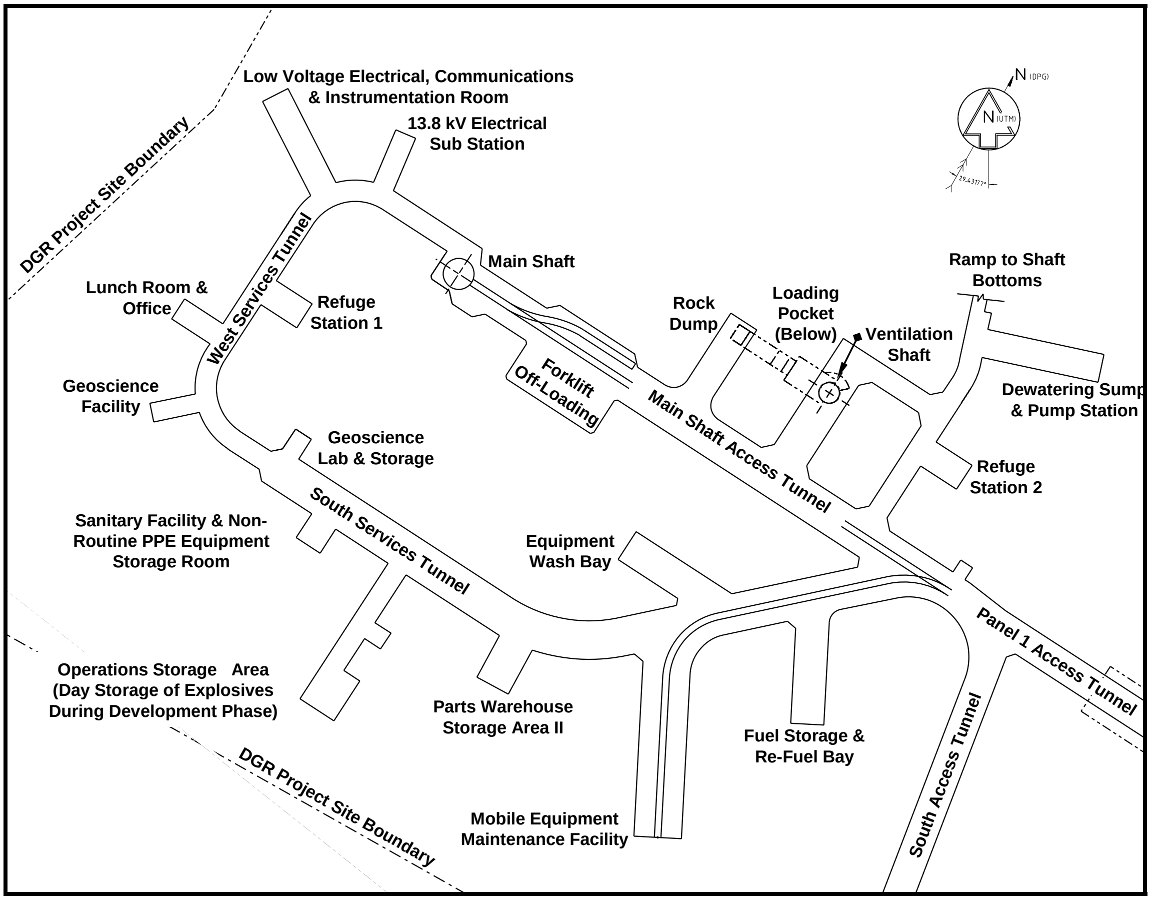

Figure 4-18 – Underground Shaft and Services Area

There are a number of ancillary rooms located near the shafts that would be required for the support services. The room listing and dimensions (in metres) are shown in Table 4-10.

Room	Length (m)	Width (m)	Height (m)
Sanitary and Non-Routine PPE & HP Equipment Storage	6.0	6.0	4.0
Fuel Storage and Refuelling Bay	20.0	7.0	5.0
Mobile Equipment Maintenance Bay	35.0	10.0	11.0
Equipment Wash Bay	20.0	7.0	5.0
13.8 kV Electrical Substation	22.0	6.0	5.0
Low Voltage Electrical, Communications and Instrumentation	12.0	4.5	5.0
Geoscience Facility	10.0	4.0	3.0
Geoscience Lab & Storage	5.0	4.0	3.0
Office / Lunch Room	17.0	5.0	3.0
Services Side Refuge Station 1	9.0	6.0	3.0
Operations Side Refuge Station 2	9.0	6.0	3.0
General Storage (Utilised as Explosives Storage/Staging during the Development Stage)	4.0	10.0	4.5
General Storage (Utilised as Detonator Storage/Staging during the Development Stage)	4.0	4.0	4.5
General Storage / Parts Warehouse	10.0	7.5	3.0

Table 4-10 – Ancillary Room Dimension Summary

The General Arrangement of the key ancillary rooms are shown on drawings:

- H333000-WP408-10-042-0001 – Sanitary, Non-Routine PPE and HP Equipment Storage.
- H333000-WP408-20-042-0017 – Fuel Storage and Refuelling Bay.
- H333000-WP408-50-042-0001 – Mobile Equipment Maintenance Bay.
- H333000-WP408-50-042-0002 – Office / Lunch Room.

To the west side of the Main Shaft, there are two Electrical Rooms, the first for the 13.8 kV switchgear and the second for step-down transformers, MCCs and communications / instrumentation cubicles. This location provides them with fresh air and allows them to be excavated early in the development phase (off-shaft development) and constructed early in the facility set-up. This avoids the requirement to construct temporary facilities to enable the initial development.

In addition to the electrical facilities in the underground Shaft and Services Area, there will be temporarily designated locations in unused emplacement rooms for mine power centres (MPC). The MPC are skid mounted and robust for field use and are relocated as the development advances.

A Refuge Station is located in a non-operational area close to the Office and Lunch Room and readily accessible from to the Main Shaft, as shown in Figure 4-18. In addition, there is provision for placement of portable refuge stations in the panel access tunnels.

There is a combined Office and Lunch Room facility, at which one to two supervisory people can access the computer system and DGR monitoring systems located to the rear of the Lunch Room. The Lunch Room is capable of seating about 24 people as shown on drawing H333000-WP408-50-042-0002. Future engineering studies may consider combining the refuge station with the Office / Lunch Room.

The Geoscience Facility and Geoscience Lab & Storage are located to the south-west side of the services tunnel as the activities are not related to the waste packages and workers are not required to travel past any waste package emplacement activities to reach these facilities. This location is also a low equipment travel area for improved pedestrian travel.

Along the South Services Tunnel is a sanitary facility and storage facility for non-routine personal protective equipment (PPE), health physics (HP) equipment and instrumentation (refer to drawing H333000-WP408-10-042-0001).

Two operational storage areas are provided on the south side of the South Services Tunnel. The western one is to be configured and used for storage of explosives and detonators in their separate areas during the development and construction stage, while the eastern one will act as a parts storage and warehouse. Once the development stage is complete, the explosives storage area will be converted to a storage area as explosives will not be stored at the DGR during operations.

The mobile equipment maintenance shop, Equipment Wash Bay, Fuel Storage and Refuelling Bay are on the south-east side of the South Services Tunnel (see drawings H333000-WP408-50-042-0001 and H333000-WP408-20-042-0017). This location provides isolation from the waste package handling route, while providing ready access to the equipment for servicing requirements. These rooms are also close to the exhaust Ventilation Shaft, which facilitates routing of the exhaust ventilation ducting from the rooms direct to the shaft. Rail will be installed from the Main Shaft Access Tunnel to the shop to facilitate maintenance of rail equipment, such as the T-H-E Handler.

The Ventilation Shaft area has rock handling facilities for the development and construction stage and for primary exhaust ventilation in all stages. The south side of the Ventilation Shaft station provides access to the Main Shaft Access Tunnel. The DGR level Exhaust Fans will be located in this shaft station. Most service lines and cables will be routed through this shaft station although some services will also be fed from the Main Shaft to provide redundancy. To the west is the Rock Dump access to an inclined raise for handling the development waste rock (see 4.5.6). To the east of the south side of the Shaft Station is a tunnel running to the north that provides access to the north side of the Shaft Station and also leads to the ramp going down to the Loading pocket and the shaft bottoms. A second permanent refuge station is located off this tunnel. This location for the refuge station provides ready access to people working in the mobile equipment shop, Main Shaft station, shaft bottom areas (via ladder-way in the Ventilation Shaft from the loading pocket or up the ramp) and from the emplacement room area. It also provides close access to the Ventilation Shaft for egress and emergency operations.

The north side of the Shaft Station provides ready access for concrete / shotcrete receiving during construction, while keeping the mess and congestion away from the Main Shaft station. The facility will be used during the construction stage and be placed in a care and maintenance state prior to handing the facility over for operations. The access will be at a slightly lower elevation, (approximately 1 m), to aid in controlling spill and preventing water from entering the shaft. There will also be a local collection sump for flush water and sludge collection from the concrete and shotcrete delivery process. Detailing of this arrangement will be performed during a future design stage.

4.5.3 Main Access-ways

The main access-ways consist of the Main Shaft access, Shaft and west services, Panel 1 access, south access, and Panel 2 Access Tunnels. All of these tunnels have slightly differing dimensions and services (i.e. ducts, piping and cabling) installed for specific purposes of each tunnel section. Figure 4-19 and Figure 4-20 show the Main Shaft access and south access which are most typical of the dimensions and services.

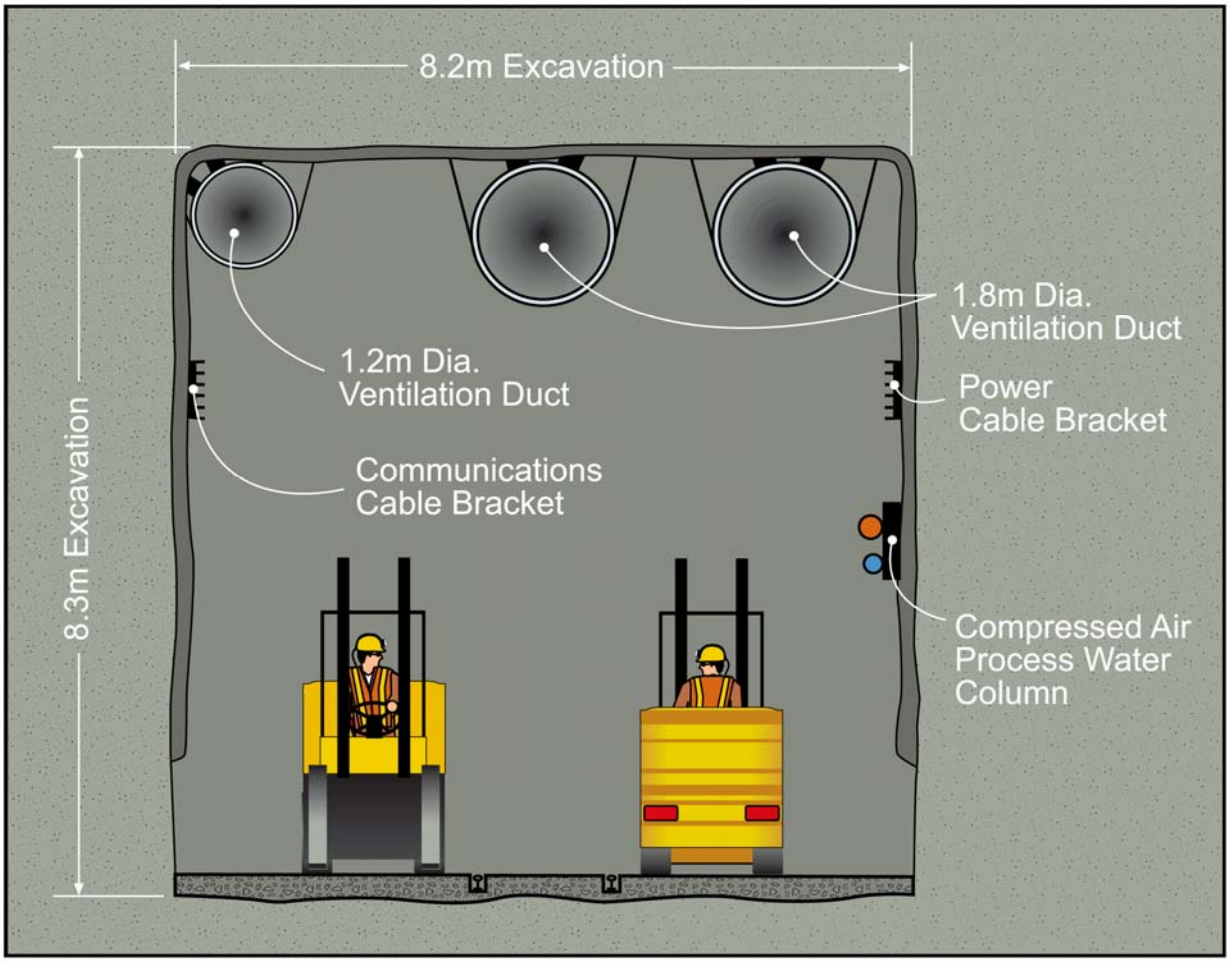

Figure 4-19 – Main Access Tunnel Showing Typical Services

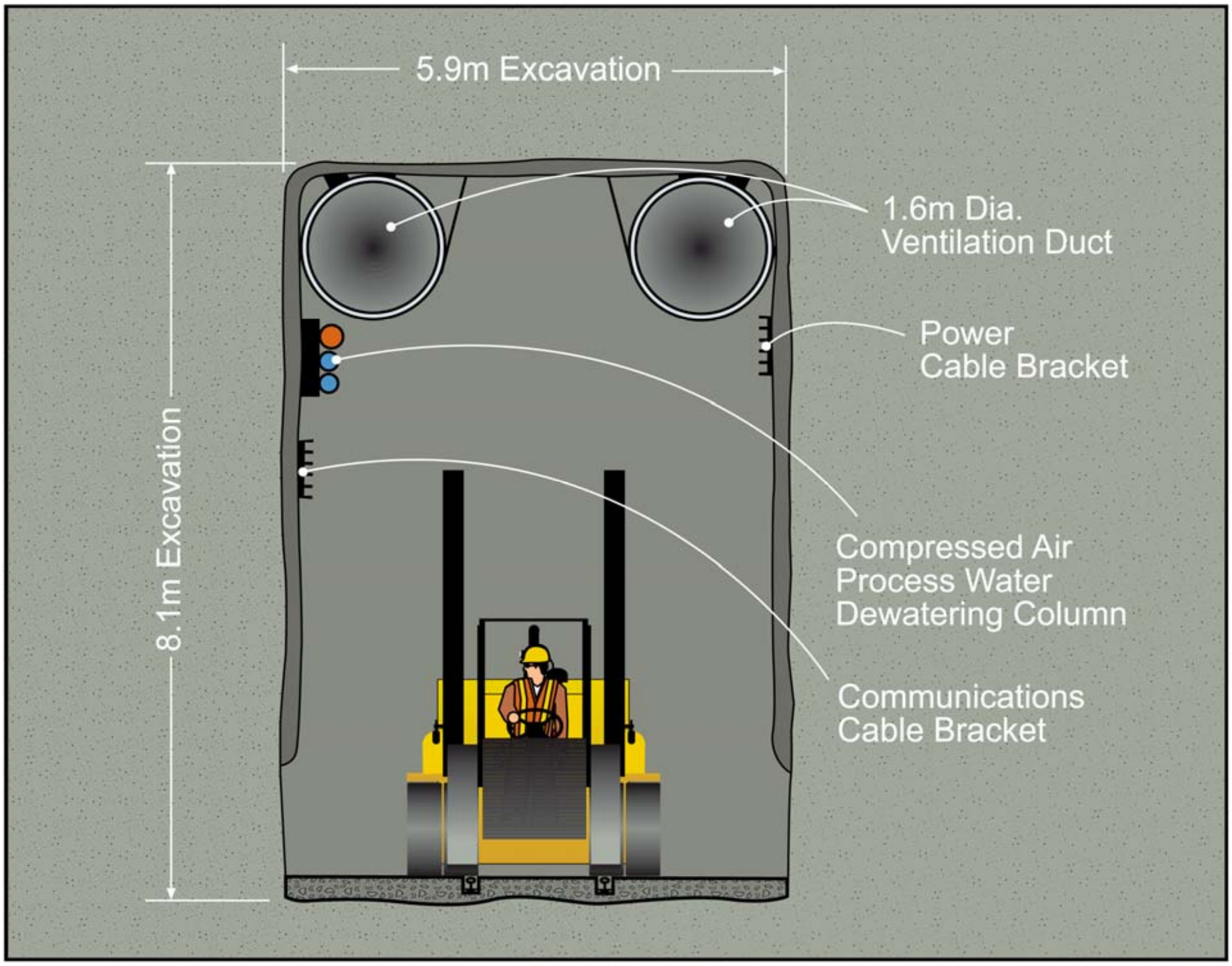

Figure 4-20 – South Access and Panel Access Tunnels Showing Typical Services

4.5.3.1 Basis of Tunnel Dimension Determination

The access tunnel profile dimensions have been determined considering a variety of factors:

- Waste package transporting and turning circle dimension requirements.
- Development equipment requirements.
- General operating and maintenance envelope requirements.
- Ventilation air velocity, particularly in the south loop tunnel.

The primary development equipment considered for construction are in the 10 t (6.0 m^3 or 8 yd^3) load-haul-dump (LHD) and 30 t truck class with a width of 2.8 m and height with nominally heaped loads of 2.8 m. It should be noted that any parameters selected for a given class of equipment were taken as typical values across several suppliers so as not to limit later procurement activities to sole sourcing equipment.

The operational equipment was based on the heavy duty forklift with a width of 2.7 m.

The determining waste package dimension was a combination of the Bruce B Steam Drum Segment with a width of 3.6 m and the Resin Liner shell from a Quadricell in a sacrificial pallet with a transport height of 5.4 m.

The minimum width to eliminate the requirement for safety bays, in accordance with OMR §112(b) [R48], is for the tunnel to be at least 2.0 m wider than the equipment / package width. Otherwise, the minimum width is 1.5 m plus the equipment / package width.

A summary of the equipment and waste package dimensions used in determining the tunnel dimensions is found in Table 4-11 and Table 4-12.

Development Equipment	**Payload**		**Length**	**Height**	**Width**	**Turn Radius**	
	Mass (kg)	**Volume (m^3)**	**(m)**	**(m)**	**(m)**	**Inner (m)**	**Outer (m)**
Haulage Truck (30 t)	30,000	14.4	10.2	2.8	2.8	5.1	8.6
Lateral Development LHD (10 t)	10,000	5.6	10.4	2.4	2.8	3.4	6.8
Ramp LHD (3 t)	3,500	1.4	7.0	1.9	1.5	2.6	4.8
Maximum for use in Tunnel Dimension Determination	**30,000**	**14.4**	**10.4**	**2.8**	**2.8**	**5.1**	**8.6**

Table 4-11 – Development Equipment Dimension Summary for Tunnel Dimensioning

Waste Packages and Operational Equipment	**Length (m)**	**Width (m)**	**Height (m)**
Large Forklift	8.0	2.7	4.5
Rail Cart	5.2	2.7	NA
Resin Liner Shell from Quadricell (tilted transport height)	N/A	2.6	5.4
Resin Liner Shield 2 (tilted transport height)	N/A	N/A	4.8
Encapsulated Tile Hole (tilted transport height)	N/A	N/A	4.8
Bruce B Steam Drum Segment	N/A	3.6	N/A
Retube Waste End Fitting	N/A	3.4	N/A
Maximum Dimension for use in Tunnel Dimension Determination	**N/A**	**3.6**	**5.4**

Table 4-12 – Equipment and Waste Package Dimension Summary for Tunnel Dimensioning
(Note: Refer to drawings for detail dimensions)

4.5.3.2 Calculation of Excavation Overbreak

It should be noted that the excavation sizes listed in the following sub-sections are for the “neat” excavation dimensions, clear of any protrusions or bumps in the rock wall inside of the opening envelope. The “neat” excavation quantities have been increased by NWMO assumption of 150 mm overbreak on the perimeter of all excavations.

4.5.3.3 Main, South and Panel Access Tunnels – Dimension Determination

The location of the tunnels is shown in Figure 4-21; and Table 4-13 provides a summary of the tunnel widths.

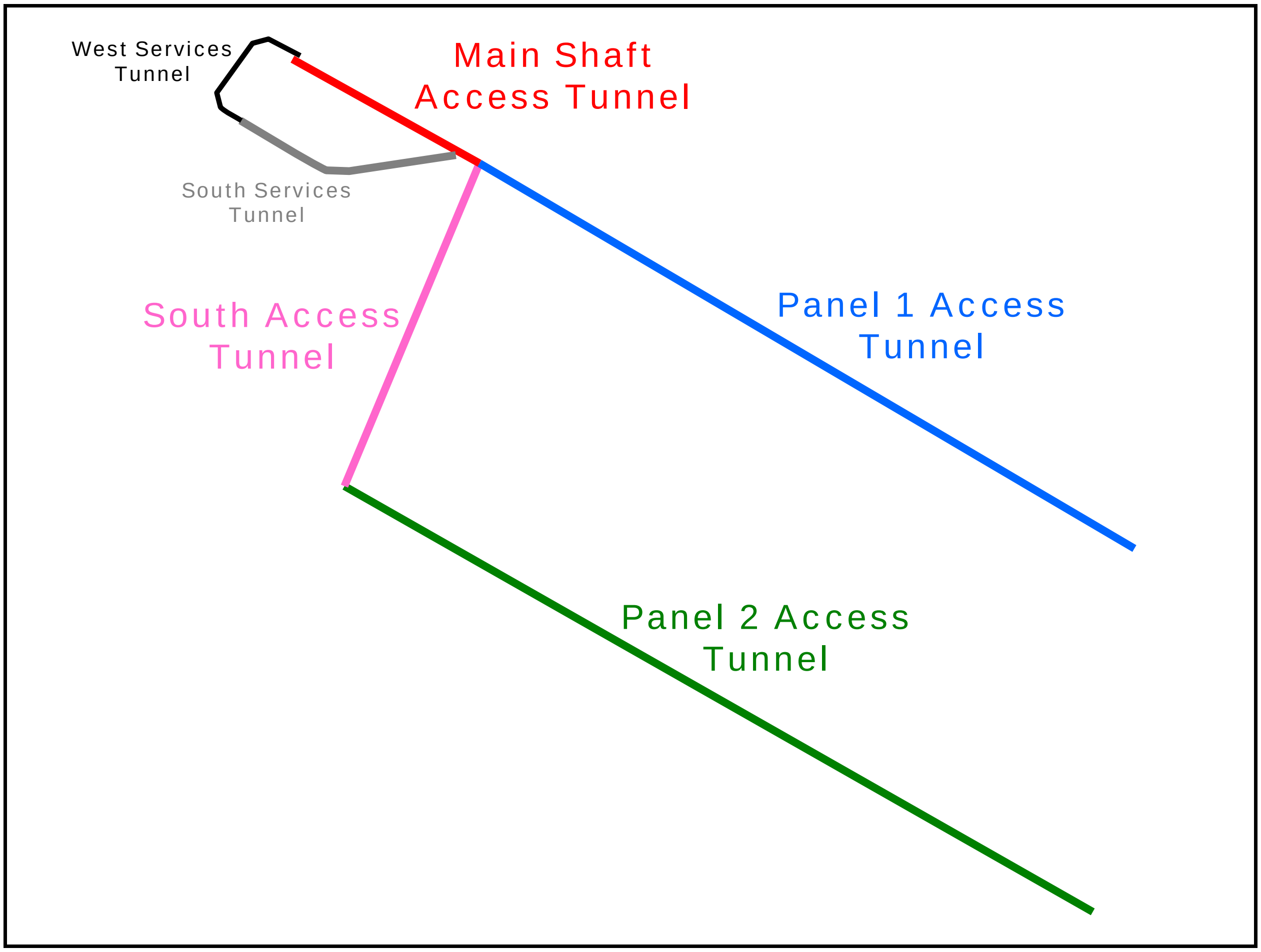

Figure 4-21 – Tunnel Location Key

The width of the Main Shaft Access Tunnel is based on the ability for development equipment to pass each other. Also, as this is a critical area of waste package handling and personnel travel, consideration is given to provide operating space beyond the minimum requirements. The width is to be 8.2 m.

The South Access Tunnel includes a 20 m long passing bay near its mid point with space for either haul trucks to pass during the development stage or a loaded and unloaded heavy duty forklift to pass during the operations stage.

The width of the two panel access tunnels is based on the Bruce B Steam Drum Segment width of 3.6 m plus minimum clearance of 1.5 m. The provision of safety bays is not required in this case as the emplacement tunnels are spaced apart at about 28 m to 30 m centre to centre distance providing suitable refuge more frequently than the 30 m spacing required by the OMR §112(b) [R48]. An exception to this will be the provision for location of the closure walls and in this location either the closure wall hitch or a safety bay will be excavated. Passing of the development equipment is not provided for due to the number of emplacement room entrances that would provide haulage units the ability to pass.

Criteria	**Main Access (m)**	**Panel Access (m)**	**South Access (m)**	**South Passing Bay (m)**
Ground Support – Bolt Heads	0.15	0.15	0.15	0.15
Wall Space	0.30	0.00	0.00	0.40
Equipment / Package	2.80	3.60	3.60	3.60
Passing Space	0.50	NA	NA	0.50
Equipment / Package	2.80	NA	NA	2.70
Wall Space	0.00	0.00	0.00	0.40
Pedestrian Walkway Space	1.50	1.50	2.00	NA
Ground Support – Bolt Heads	0.15	0.15	0.15	0.15
Total – Minimum Excavated Size	8.20	5.40	5.90	7.90
Tunnel Clear Width	7.90	5.10	5.60	7.60

Table 4-13 – Main, South and Panel Access Tunnel Width Determination

Notes to Table 4-13:
Each element is listed individually in order going across the width of each tunnel.
The Main Access provides for haulage equipment passing.
The Main Access is not providing for forklift empty and loaded to pass as there is space at the former waste rock dump to allow passing and queuing.
South access provides width required to eliminate safety bays.
Panel access provides width with safety bays; however, emplacement rooms are spaced to eliminate specific safety bays.
The south access is to have a passing bay that will work for both haulage and emplacement stages.
In the main access tunnel the passing wall space is overlapping with the walkway space.
The specific waste package reference of 3.6 m is the Bruce B Steam Drum segments.

The heights of the access tunnels are based on the operational requirement when transporting the Resin Liner shell from a Quadricell in a sacrificial pallet, ventilation ducting, and the required clearances, as shown in Table 4-14.

Criteria	**Main Access** [m]	**Panel Access** [m]	**South Access** [m]
Ground Support – Bolt Heads	0.15	0.15	0.15
Duct Installation Clearance	0.20	0.20	0.20
Duct Dimension	1.80	1.60	1.60
Operating Clearance to Duct	0.30	0.30	0.30
Tilted Package Height	5.40	5.40	5.40
Package Transport Clearance	0.30	0.30	0.30
Concrete Floor	0.20	0.20	0.20
Total – Minimum Excavated Size	8.35	8.15	8.15
Tunnel Clear Height	8.00	7.80	7.80

Table 4-14 – Access Tunnel Height Determination

Due to the diameter of the packages and space between the ventilation ducts, the top of any waste package during transport along the tunnels must be clear below the bottom of the ducts.

In the potential expansion case, there is room to install a third duct in the South Access Tunnel, should this be required.

4.5.3.4 West and South Services Tunnels

The dimensions for the west and South Services Tunnels are determined primarily on the basis of ventilation air velocity combined with a reduction in dimension where there is minimal equipment travel, i.e. the West Services Tunnel. The other consideration is the use of similar dimensions as the Main Shaft Access Tunnel to provide operational space and consideration for equipment and pedestrian travel.

Although not detailed, the air volume to pass through this area is approximately 110 m^3/s (see Section 5.4.4). With a profile in the South Services Tunnel of 8.1 m (wide) x 7.5 m (high), the velocity is about 1.8 m/s, which is considered acceptable for this area where equipment moving in the tunnel will increase the “local” air velocity slightly. Additional consideration was given to the equipment and pedestrian travel together in this area in determining the tunnel dimension.

In the West Services Tunnel, ducting will be installed on the intake side of one fan, thus reducing the air volume in the tunnel to about half, i.e. 55 m^3/s. This approach allowed the tunnel dimension to be reduced to 4.5 m (wide) x 4.5 m (high), which resulted in an increased velocity to about 2.7 m/s in the tunnel. Although getting “brisk”, this is still well below velocities that would pick up or entrain dust and is, thus, considered acceptable. The West Services Tunnel will have very little equipment travel, so the reduction in dimension is not considered to present any concern for pedestrian travel.

The operations storage / explosives tunnel is short and needs to be sized for its different purposes. During the development stage this tunnel and storage area will be accessed with equipment carrying quantities of explosives. Although the logistics and volume of space required has not been determined, in order to reasonably match the dimension of headings and equipment being used for the excavations, a mid-range size of scissor truck or similar gear is envisioned for explosives loading and transportation. This would typically require a tunnel of 4.5 m x 4.5 m.

The longer range use of this space for operational storage would indicate the use of a forklift to move equipment and materials. The large forklift is 2.7 m wide and would be suitable to operate in a 4.5 m x 4.5 m tunnel.

The north side access to the Ventilation Shaft station is also to be 4.5 m x 4.5 m to support the shotcrete delivery and loading of concrete transmixers. While this equipment has not yet been sized, it would typically be in the 2.0 m to 2.5 m width range. Providing the operational clearance for this equipment would require a tunnel of around 4.0 m to 4.5 m dimension. Consistency of tunnel profiles in this dimension range led to the final dimension determination.

4.5.4 Layout of Emplacement Rooms and Access Tunnels

4.5.4.1 Base Case

The Base Case Layout is comprised of two panels: Panel 1 with fourteen rooms and two closure walls, and Panel 2 having seventeen rooms and one closure wall. This was developed as the DGR Base Case as shown in Figure 4-22 and drawing H333000-WP408-20-042-0001. Panel 2 is to be filled first, primarily with LLW materials (13 of 17 rooms) and is the furthest away from the shaft area. This panel is expected to be filled within approximately the first five years. The furthest nine rooms of Panel 1 are filled next, consisting of a mix of LLW and ILW rooms, and taking about the next fifteen years to fill. The closest five rooms are filled with primarily ILW materials with three of the rooms being configured for rail and gantry crane capabilities. These rooms will be filled during the subsequent fifteen years.

All of the Base Case rooms and facilities are located within the DGR Project Site Boundary and respect a 100 m radius clearance from any of the DGR-1 to DGR-6 boreholes.

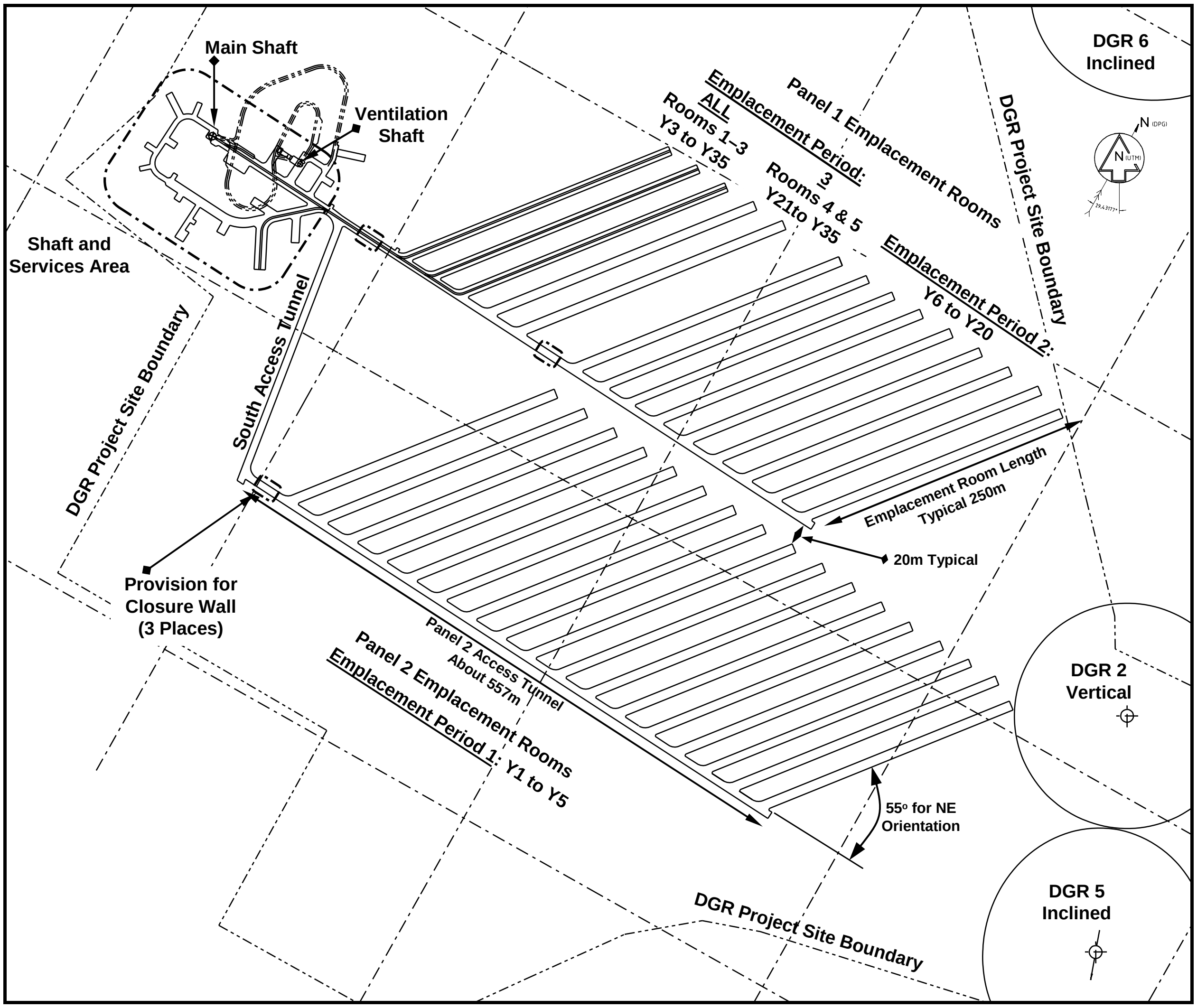

Figure 4-22 – DGR Base Case Layout

The vertical placement of the DGR level facilities is to be within the Cobourg Lower Member with a guideline of 5 m floor cover and 8 m roof cover (see Section 4.5.1.11). To facilitate following the slope of the Cobourg Lower Member, an initial low spot was selected at the junction of the Main Shaft access and the panel access tunnels. From this location the access tunnels are laid out to run parallel to the Cobourg Lower Member contact. Figure 4-23 shows the primary drainage slope direction. The underground Shaft and Services Area and Panel 1 collection sumps are indicated. Given that the emplacement rooms do not follow parallel to the Cobourg Lower Member contact, i.e. 0.25% slope versus the formation slope of approximately 1.1%, the north end of the emplacement rooms govern the placement of the DGR level within the Coburg Lower Member.

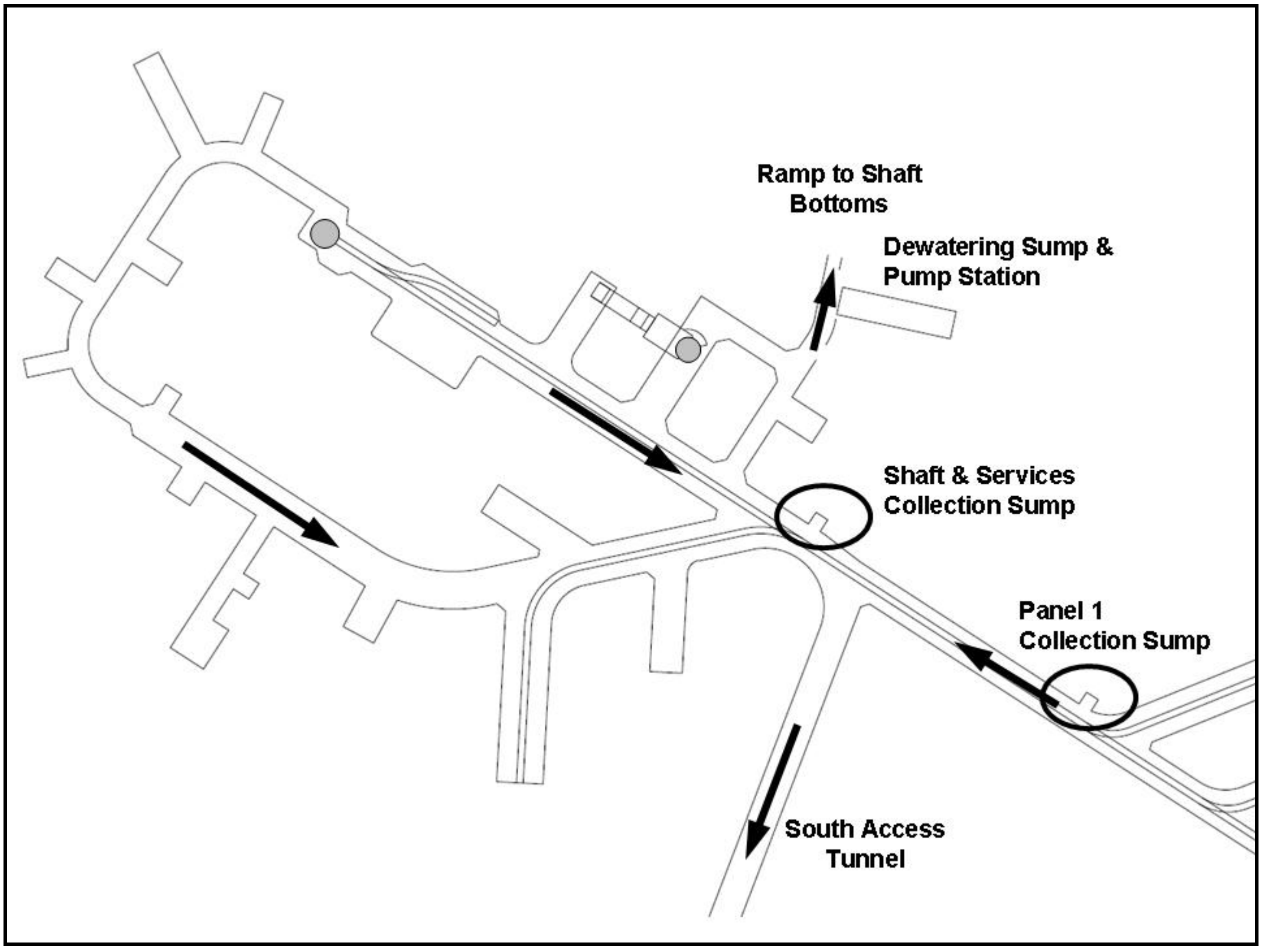

Figure 4-23 – Primary Drainage Flow Directions

It is good practice to have a shaft station slope down and away from the shaft for water control and to prevent equipment unintentionally rolling towards the shaft. Therefore, the Main Shaft station and access tunnel is laid out with a slope down towards the underground Shaft and Services Area collection sump at a 0.5% grade. The South Access Tunnel slopes down to the south at a 0.6% grade. The panel access tunnels slope up to the east at a 0.7% grade. The crest of the ramp to the shaft bottoms is located slightly below either shaft stations, thus ensuring the shafts and the Electrical Rooms remain high spots within the overall DGR level layout.

The emplacement room floor slope was set on the basis that floors had to be suitable for warehouse stacking of packages while allowing for drainage. A design slope of 0.25% down towards the entrance was used. This floor slope will be confirmed in the next stage of engineering.

4.5.4.2 Alternate Orientations

Alternate orientations for the emplacement rooms to demonstrate the flexibility to align the rooms with the anticipated maximum variations of the assumed major horizontal principal stress orientation were investigated and found to be feasible for the layout presented above. The UTM azimuth change from ENE to NE orientation is made by simply changing the angle from the panel access tunnel into the emplacement room. The change from ENE to E orientation is primarily realised by changing the access tunnel to emplacement room angle to a minimum of 45° and then rotating the panel access tunnel to complete the rotation required to achieve the proper orientation. In order to maintain the borehole stand-off distance of 100m, a few emplacement rooms may need to be shifted from Panel 2 to Panel 1 and the lengths adjusted to fit. It was confirmed that this layout concept provides a very flexible arrangement to make the adjustment after the in-situ stress orientation determination tests are conducted in the field during initial lateral development off the shafts.

4.5.5 Emplacement Room Dimensions

The emplacement room dimensions have been determined based on the waste package emplacement requirements (see Section 6.3). The width requirement for transporting packages into the rooms is less than the width requirement for package stacking. A cross-check for the transport height (i.e. tilted versus vertical) was performed. This became a driving criterion for determining the height required in the P2 profile emplacement rooms.

Figure 4-24 and Figure 4-25 show the typical profile and dimensions of two of the six emplacement room profiles.

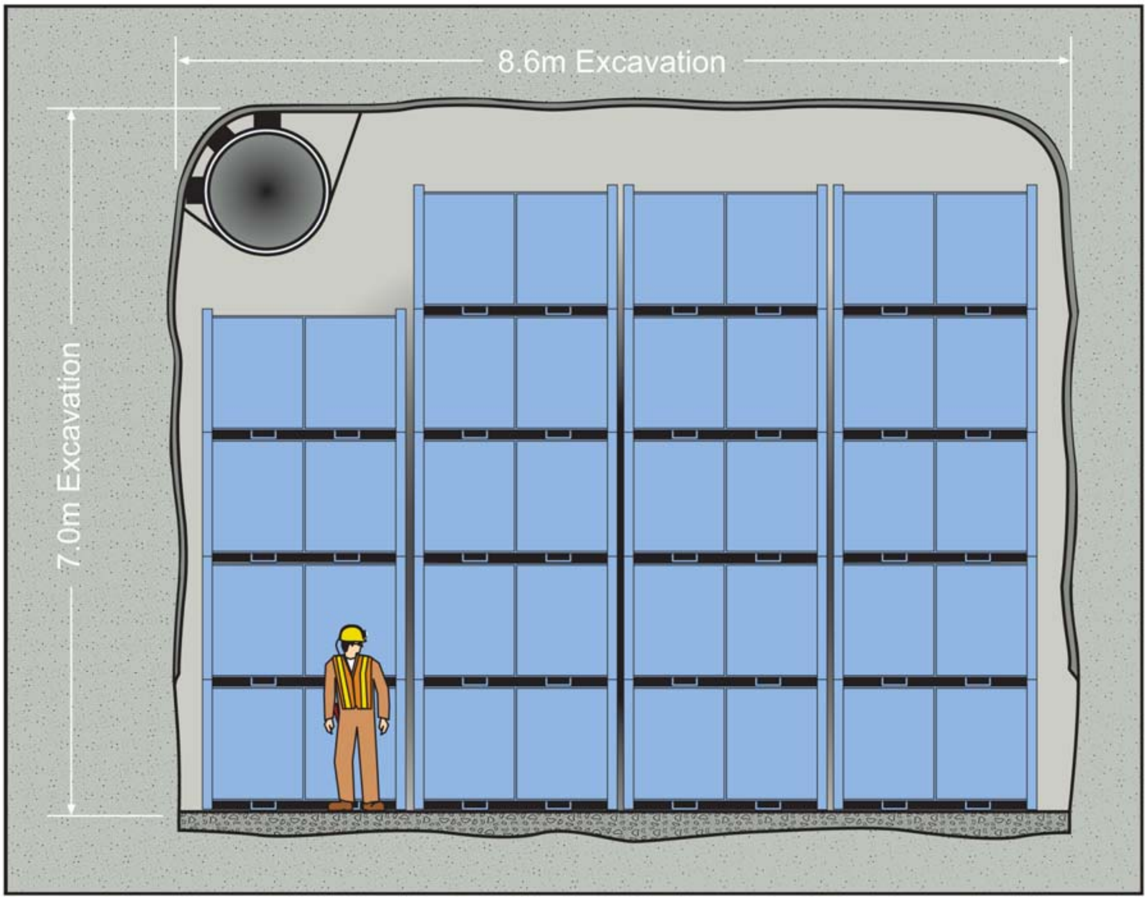

Figure 4-24 – Emplacement Room Section View – P1 Profile for Bin Type Waste Packages

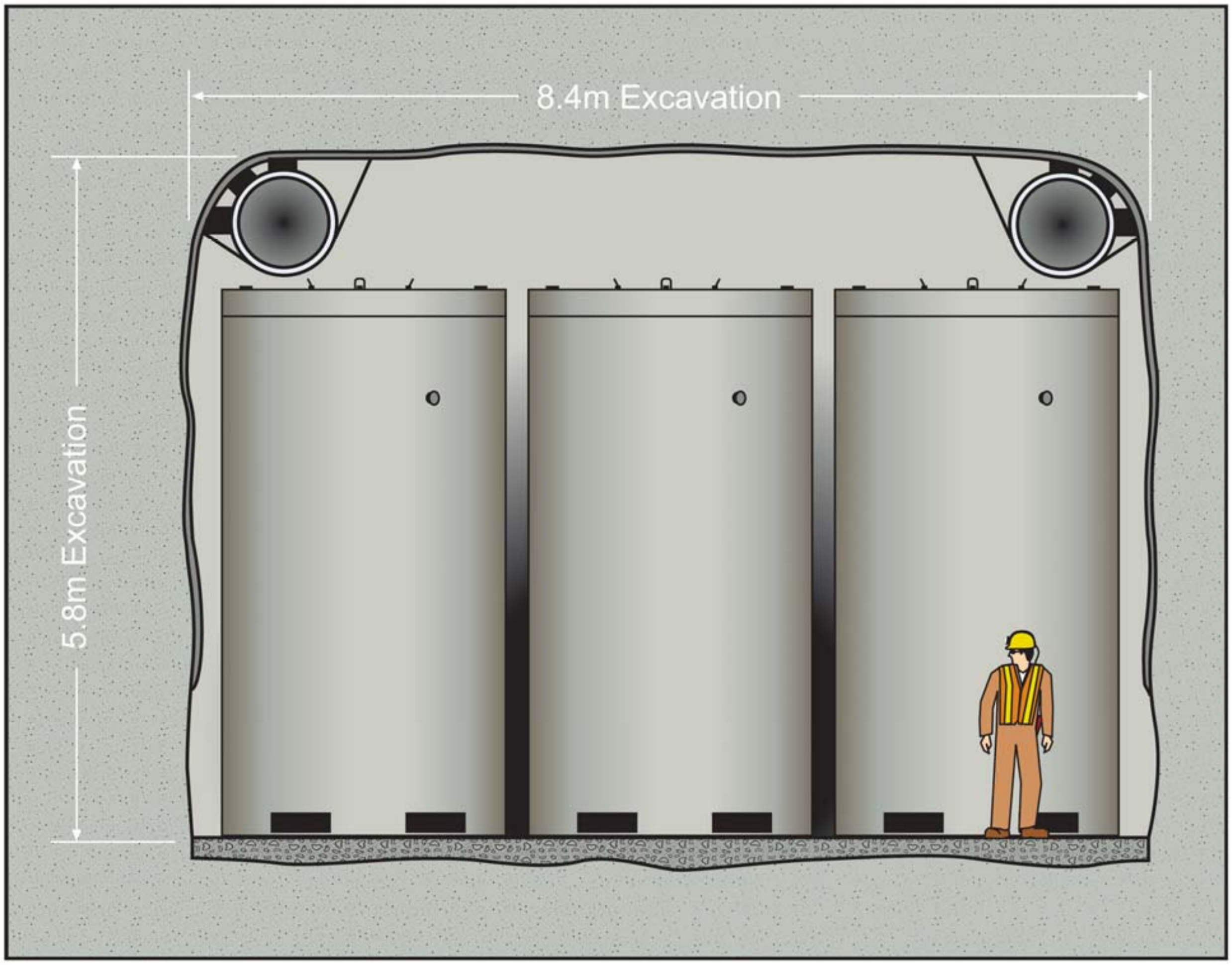

Figure 4-25 – Emplacement Room Section View – P3 Profile for Resin Liner Type Waste Packages

4.5.5.1 Emplacement Room Length Determination

An optimal length of 250 m was selected by considering the following factors:

- Health and safety considerations; i.e. difference in egress time from rooms, health physics considerations, and operational time span for a given room.
- Ability to place the repository within the Coburg Lower Member while respecting the recommended guidelines for roof and floor cover (8 m and 5 m respectively).
- Emplacement room sealing and closure.
- Ventilation (all aspects).
- Capital cost (general).
- Operating cost (general).
- Development stage – efficiencies and subjective considerations.

- Operating stage – efficiencies and subjective considerations.

4.5.5.2 Waste Package Emplacement Allocation

The waste package emplacement allocation requirements are discussed in Section 3. The updated inventory was considered to determine the placement of waste packages from Health Physics, package handling, and packing efficiency perspectives. This updated information provided input for the emplacement room general arrangements regarding the profile dimensions of the rooms, the quantity (number and length) of each profile required to hold the packages and preliminary grouping of the rooms based on the allocation of waste package emplacement described in Section 6.3.1. The grouping of the rooms to provide the ability to close sets of emplacement rooms was based on the evaluation and selection of an emplacement room closure option that considered ongoing ventilation and long-term safety aspects. The summary of room profiles is shown in Table 4-15.

Profile Name	Waste	Groups[8]	Width [m]	Height [m]	Gantry Crane	Rail Access	Vent Duct[9]	Drawing Number
P1	LLW	A1-A8	8.6	7.0	N	N	1 R	H333000-WP408-05-042-0001
P2	LLW/ILW	C4, F1, F4, F5, F6	8.6	6.35	N	N	2 R	H333000-WP408-05-042-0002
P3	ILW	C1, C2, E1-E4, F1-F3, F5-F8, F9, F10	8.41	5.8	N	N	2 R	H333000-WP408-05-042-0003
P4	ILW	C3, F9, F10	7.4	6.5	N	N	2 R	H333000-WP408-05-042-0004
P5	ILW	F2, F3	8.4	6.2	N	N	2 R	H333000-WP408-05-042-0005
P6	ILW/LLW	B1, B2, D1-D2	8.1	7.2	Y	Y	2 S	H333000-WP408-05-042-0006

Table 4-15 - Emplacement Room Profiles

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[8] Group codes as given in Appendix D

[9] R - Round, S – Rectangular.

Table 4-16 provides a listing of the waste package groups, container code and waste package types. More details of these packages are given in Sections 3 and 6.

Group	Container Code	Waste Package Type
A1	BINOPK	Bin Overpacked
A2	B25	Compactor Box
A3	BRACK	Bale Rack
A4	DRACK	Drum Rack - non-processible drums
A5	DBIN	Drum Bin
A6	NPB47	Non-Pro Bin (47" high)
A7	NPB4	Non-Pro Bin (NPB4)
A8	RTK	Low Level Resin Pallet Tank
B1	SPC	Shield Plug Container
B2	HX	Heat Exchanger
C1	RL	Resin Liner, Unshielded, No Overpack, Pre In-Service Date
C2	RLOPK	Resin Liner, Unshielded, Overpacked, Pre In-Service Date
C3	ILWSHLD	ILW Shield
C4	THLSTG3	Tile Hole Liner
E1	RL	Resin Liner, Unshielded, Post In-Service Date
E2	RLSHLD1	Resin Liner - Shield 1, Post In-Service Date
E3	RLSHLD2	Resin Liner - Shield 2, Post In-Service Date
E4	RLSHLD3	Resin Liner - Shield 3, Post In-Service Date
D1	THLIC2	IC-2 Liner
D2	THLIC18	IC-18 T-H-E Liner - filters, IX columns, etc. & core components
F1	SGSGMT	Steam Generators - Bruce A
F2	SGSGMT	Steam Generators - Bruce B
F3	SGSGMT	Steam Generators - Pickering
F4	ETH	Encapsulated Tile Hole
F5	RLSHLD	Resin Liner Shield from Quadricells
F6	RLSHLD1	Resin Liner - Shield 1, Pre In-Service Date / Resin Liner - Shield 1, Overpacked, Pre In-Service Date
F7	RLSHLD2	Resin Liner - Shield 2, Pre In-Service Date
F8	RLSHLD3	Resin Liner - Shield 3, Pre In-Service Date / Resin Liner - Shield 3, Overpacked, Pre In-Service Date
F9	RWC(PT)	Retube Waste (Pressure Tubes)
F10	RWC(EF)	Retube Waste (End Fittings)

Table 4-16 - Listing of Waste Package Groups, Codes and Type Descriptions

4.5.6 Rock Dump on DGR Level and Rock Handling System

To facilitate the excavation of the repository, a rock handling system will be developed and constructed as part of the initial development from the shaft sinking period. Preliminary Engineering has developed an initial draft layout, which will require additional engineering in future design stages.

The rock handling system from the development headings to the rock storage pile on surface is shown in Figure 4-26. The estimated quantity of development rock is 2,090 t/day. The excavation methodology is discussed in Section 9.3.

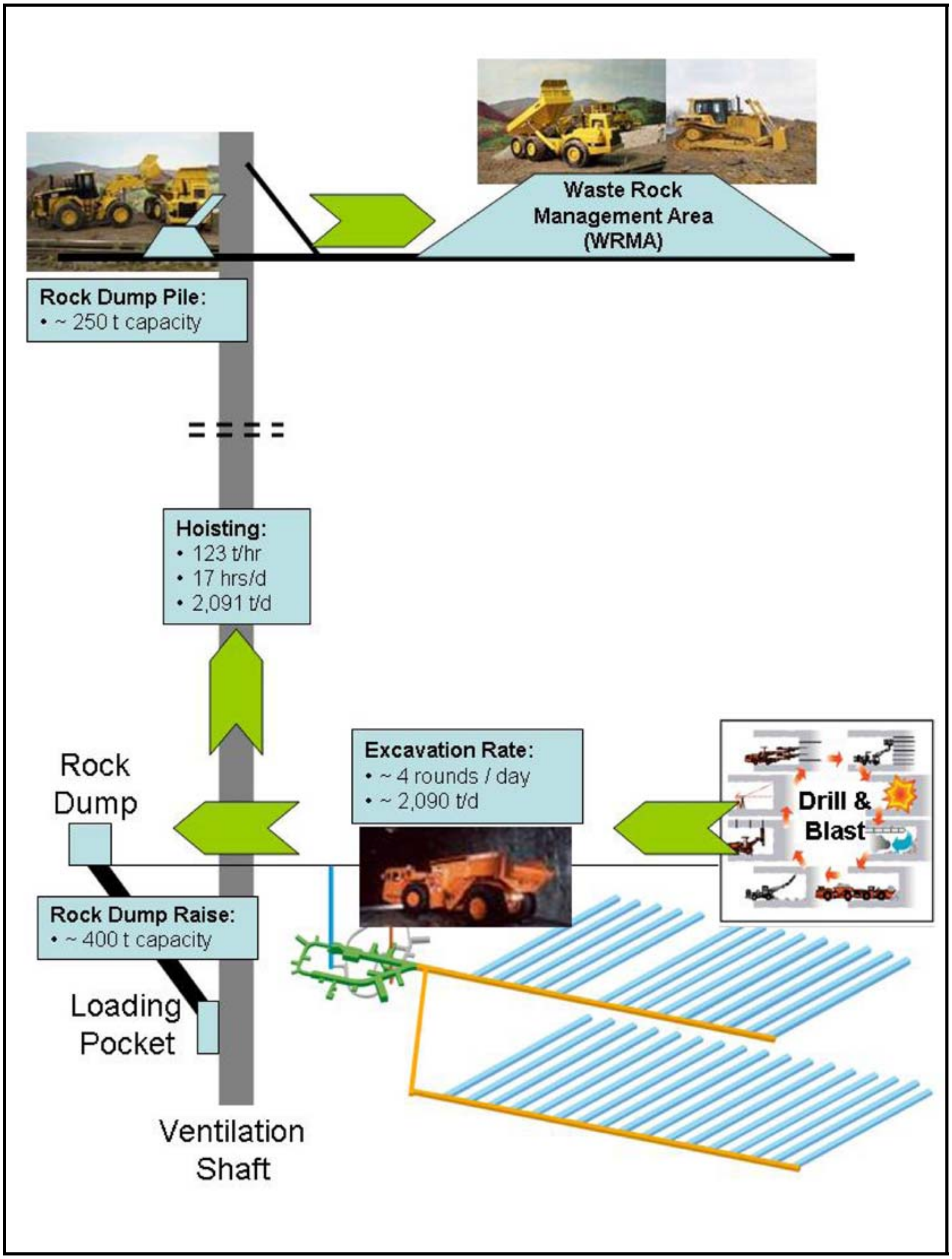

Figure 4-26 – Rock Handling Schematic (Underground to WRMA)

From the development heading the rock will be trucked to the rock dump adjacent to the Ventilation Shaft and dumped into the rock raise at the DGR level passing through a sizing grizzly, with secondary breakage as necessary. Alternatively, a LHD would be used for closer distances or possible re-handling of temporarily stored muck from Room 1 in Panel 1. The maximum haul distance in Panels 1 and 2 is about 835 m and 1,135 m respectively. For reference, the maximum typical haul distance in mining for this size of LHD is between 300 m and 400 m.

The rock raise has a capacity of about 400 tonnes to provide a buffer between the hoisting and the development schedules. Should more buffer space be needed, once Room 1 in Panel 1 is excavated it could be used as a re-mucking location to ensure the development activities can continue with some buffer to the shaft rock hoisting system.

The rock is loaded into the skips at the loading pocket. The loading pocket is configured with a control chute at the bottom of the rock raise, a vibrating feeder, diverter slide and two measuring flasks to control both volume and weight of the material being fed to the skip. The measuring flask then dumps the muck into the skip when it is in position and the necessary system permissions are received. For further discussion of the shaft and related facilities see Section 4.4.2.

Spilled muck from the skip loading operations falls to the shaft bottom, from where it is mucked using a small LHD, nominally a 3.5 t (3.0 yd^3) unit, and hauled back into the rock raise on the DGR level.

On surface the rock is dumped from the skips via a slide through the headframe onto the ground, where it is loaded into surface haul trucks and hauled to the WRMA. The rock pile is levelled as needed with a bulldozer.

The underground portion of the rock handling system general arrangement is shown in Figure 4-27 and drawing H333000-WP408-20-042-0010.

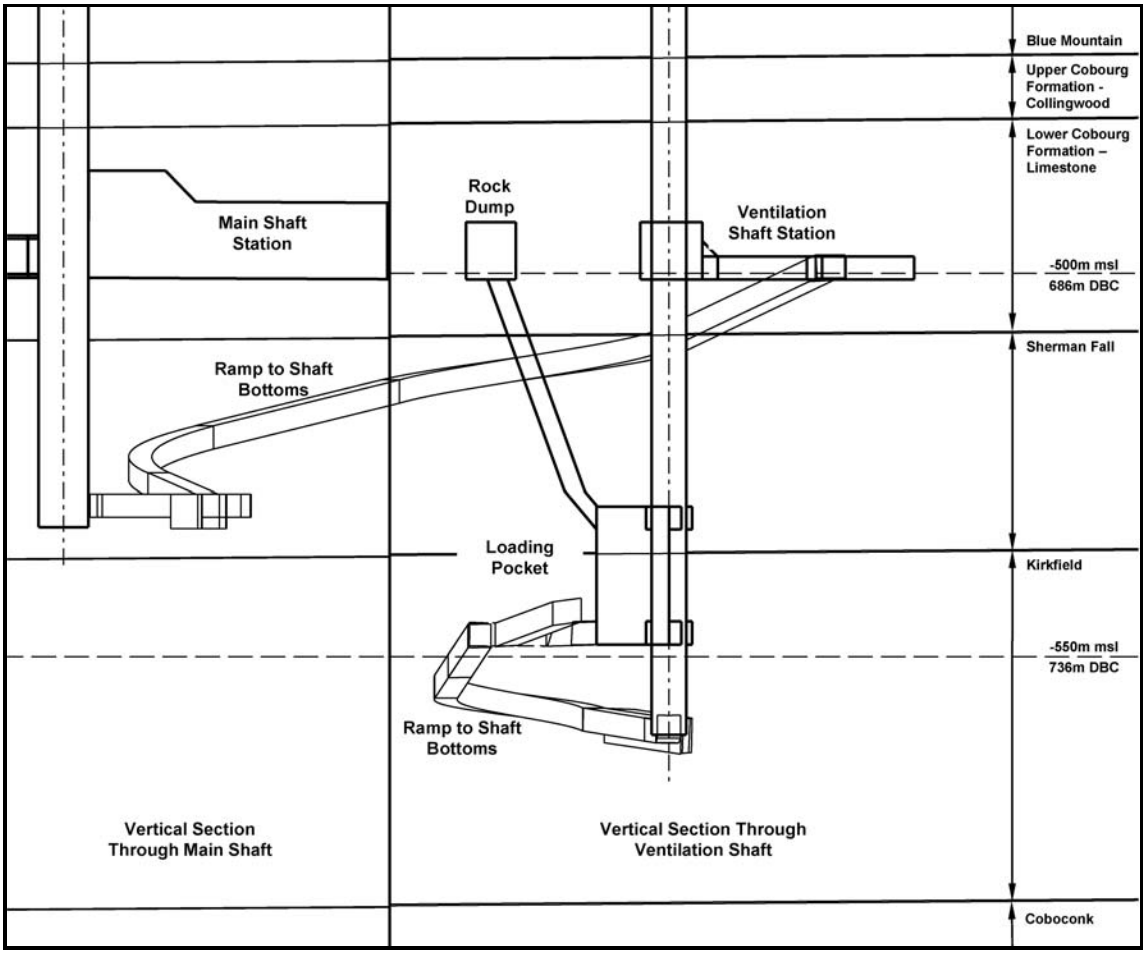

Figure 4-27 – Development Rock Handling Facility General Arrangement

4.5.7 *Ramp to Shaft Bottoms*

In the Conceptual Design, access to the shaft bottoms was configured as a ladder-way in each of the shafts, with any detail being out of scope. As part of the Preliminary Design – Stage 1, an initial draft ramp layout to provide access to both shaft bottoms and the loading pocket has been developed as shown in Figure 4-28 and drawing H333000-WP408-20-015-0001, for which additional engineering will be required in future design stages.

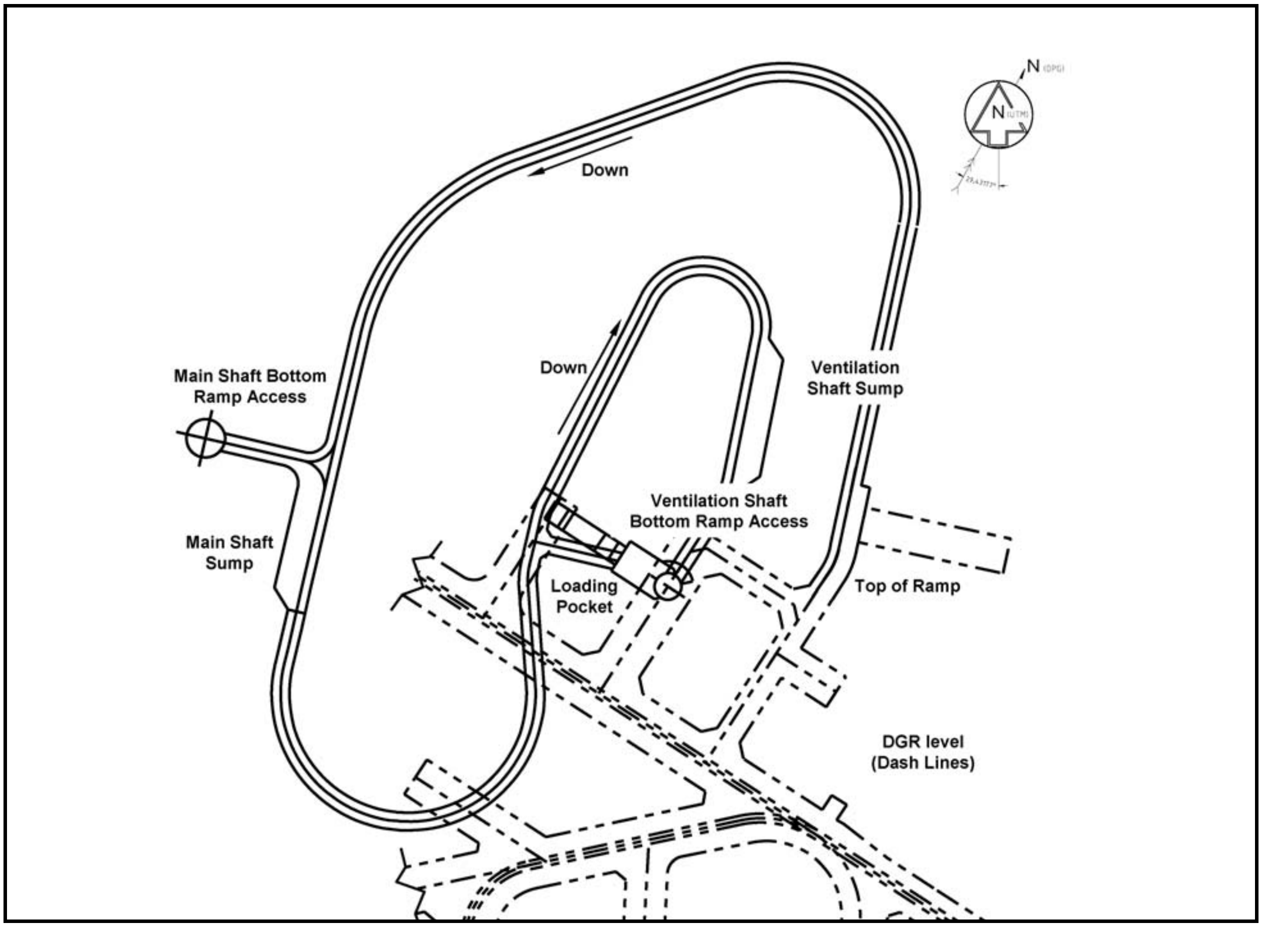

Figure 4-28 – Shaft Bottom Ramp Concept Sketch

There are a number of supporting factors to including a ramp in the design:

- Provides efficient and safe means of handling spilled muck (waste rock) from the skip loading pocket and shaft bottom arrangement during the development stage.
- Provides access for personnel and equipment to the loading pocket versus climbing down from the DGR level for operation and maintenance requirements. (A ladder-way will be installed from the DGR level to the shaft bottom, providing an alternate means of egress from the loading pocket and shaft bottom.)
- Provides efficient shaft bottom sump configuration and the ability to construct suitably sized sumps for each shaft at significantly lower cost than “in-shaft” sump configurations.
- Servicing of the shaft bottom pumps is from the ramp versus internal to the shaft; thus making it safer, simpler and less labour intensive to install and maintain.
- Provides access to the Main Shaft bottom for servicing of tail-rope monitoring sensors and other hardware at this location. (The configuration of the shaft cross-section does not provide space for a ladder-way access from the DGR level in a safer manner.)

- Provides significantly increased sump capacity in the ramp and shafts to mitigate unforeseen flooding events prior to water levels reaching the DGR level.

The ramp access to the shaft bottoms is for service purposes and as access to the loading pocket during the development phase. The ramp dimension in this case would be of the minimum practical dimensions, while recognising the use is to provide access to the loading pocket for operation and maintenance during the development stage and long-term access to the shaft bottom sump and pumping installations.

A ramp dimension of 3 m x 3 m is considered about the smallest practical dimension suitable to support the construction and maintenance of the loading pocket equipment. The development of this ramp would be completed as part of the shaft sinking process as discussed in Section 9, and can support the use of a small to mid-sized LHD and either a one or two boom jumbo. Nominally, the LHD size would be a 2.9 to 3.5 tonne (2.5 yd^3 to 3.0 yd^3) class of equipment.

5. Ventilation

The reliable delivery of a supply of fresh air to the underground workplaces is critical for the health and safety of workers. This air supply will be used to maintain safe working conditions through all stages of the DGR life. The total volume of air supplied to the DGR will vary based on the nature of work being performed and number of active and non-active rooms, and will be periodically adjusted throughout the life cycle of the facility.

Ventilating air will be supplied to the facility to ensure that:

- There is breathable air available for all underground personnel.
- To dilute and remove contaminants.
- Personnel are not exposed to levels of noxious gases that exceed regulatory limits.
- Levels of explosive gases do not exceed explosive limits.
- Temperatures within the DGR are maintained such that it remains safe and acceptable for both personnel health and infrastructure integrity.

5.1 Ventilation System and Operation

The unique considerations of the DGR facility, particularly with regard to the type of waste packages being placed underground, determine that a distinct approach is required to provide ventilation that both addresses potential contaminants within the air and also ensures that personnel underground are in an environment in which it is safe to work.

The DGR is designed to be a “pull-type” ventilation system. Ventilation flow throughout the facility is facilitated primarily by the action of maintaining the underground facility under a negative pressure such that air flows from the Main Shaft (acting as the fresh air intake) and through the repository level to the Ventilation Shaft (acting as the exhaust route). This is achieved through the application of a pressure differential between the main and exhaust shafts by the operation of the Surface Exhaust Fans.

Whilst designed as a pull-type ventilation system, low-pressure fans will be used to deliver a controlled air volume from the surface intake to the collar of the Main Shaft so that the main Exhaust Fans do not cause a “negative pressure” condition in the Main Shaft Headframe. The fresh air supply fans will deliver air at a volume and pressure such that a positive pressure is imparted to the Main Shaft Headframe. The positive pressure in the headframe, and adjoining WPRB, ensures that should there be an incident at the surface facilities, the potentially contaminated air is not sent down the shaft.

Referring to Figure 5-1, fresh air enters the facility through the Heater House by the action of the twin Surface Intake Fans and is delivered to the Main Shaft through the intake plenum. The Heater House contains a direct-fired propane heating system used between November and April to ensure air enters the Main Shaft at a temperature such that services, particularly with regards to water, within the Main Shaft are not affected by cold surface ambient air temperatures. Heating is, therefore, applied to the air intake for the Main Shaft to a minimal level to prevent such freezing during those months.

Following distribution of the fresh air underground and collection of the return air at the base of the Ventilation Shaft (described in subsequent paragraphs), the return air is drawn up the Ventilation Shaft and through the exhaust plenum by the action of the Surface Exhaust Fans before being discharged to the surface atmosphere. A small amount of fresh air is drawn down through the Ventilation Shaft Headframe to maintain fresh air in the headframe.

Whilst the Main Shaft and Ventilation Shaft are located approximately 85 m from each other (with the intake and Exhaust Fans being approximately 160 m apart), the shafts were located relative to each other so that the upcast Ventilation Shaft is generally downwind of the air intake at the Main Shaft, taking into account the prevailing wind directions at the Bruce nuclear site. Siting of the large Main Shaft complex, which includes the WPRB, between the ventilation Exhaust Fan discharge and fresh air intake will also assist in dispersing and diluting the concentration of any contaminants in the air flowing in the direction of the intake.

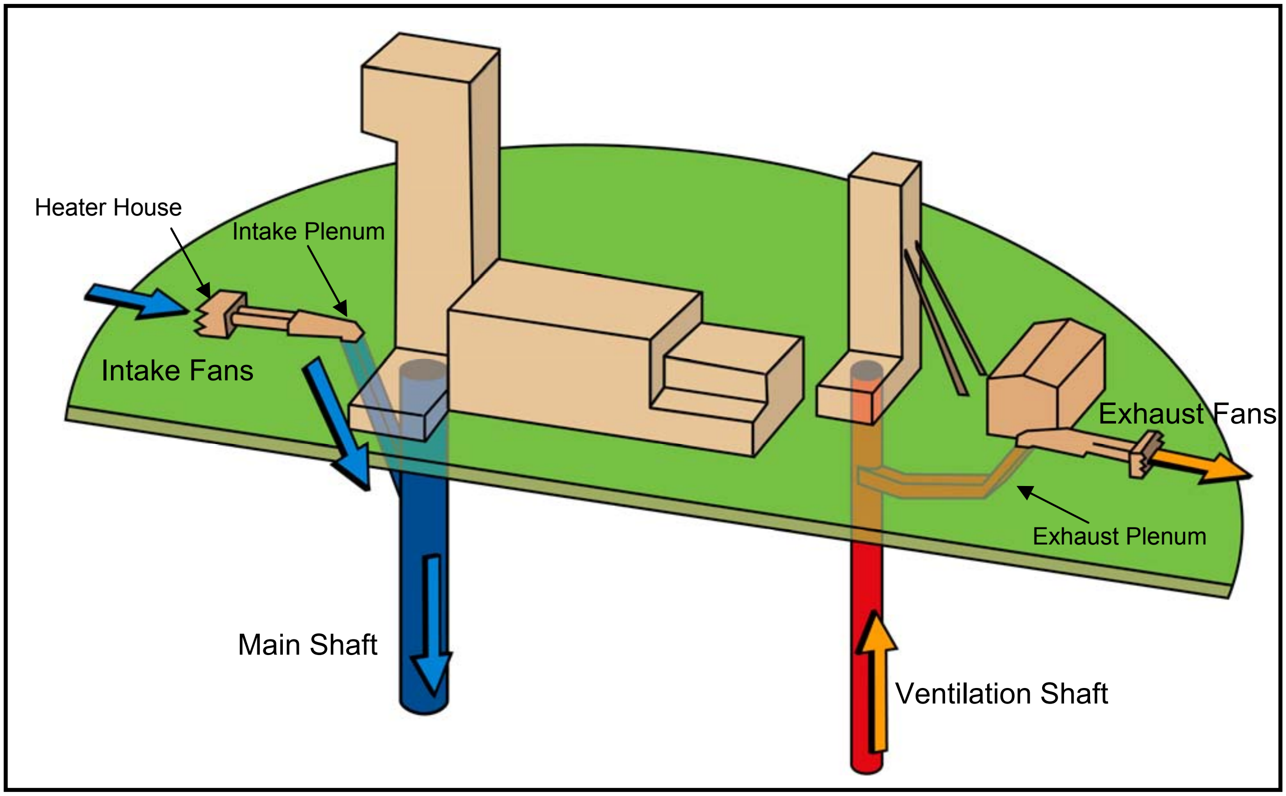

Figure 5-1 – Primary Surface Ventilation System

The distribution of the air underground is controlled primarily through the use of booster fans and ducting. Referring to Figure 5-2, the downcast fresh air exits the Main Shaft at the repository horizon and divides between the access tunnels to the east and west of the Main Shaft station.

To ensure a correct quantity of fresh air is taken from the Main Shaft, through the services tunnel and to the access tunnels, two fresh air booster fans will be located across the top of the ventilation doors in the South Services Tunnel, one of which will have a duct connected to its intake. This duct will extend along the south and West Services Tunnels to the Main Shaft to reduce the quantity and velocity of air flowing unconstrained in the services area to acceptable levels.

The balance of the fresh air flows freely across the underground staging area, past the rock dump and through to the north access to the Ventilation Shaft.

The criterion for air distribution to the emplacement rooms is that the airflow direction shall be from areas of low potential of contamination to areas of greater potential contamination. To ensure this is maintained, fresh air is taken along the access tunnels to the emplacement panels while the return air from the panels is removed through exhaust ducts in each room which feed into a larger common duct that extends back to the Ventilation Shaft. To enable this system to function, high pressure Exhaust Fans are located in each exhaust duct at the Ventilation Shaft. These place the ducts under negative pressure, which not only encourages the fresh air to travel outwards along the access tunnels, but also ensures that any leakage along the duct length will be into the duct reducing the potential for mixing of return air with the fresh air in the access tunnels.

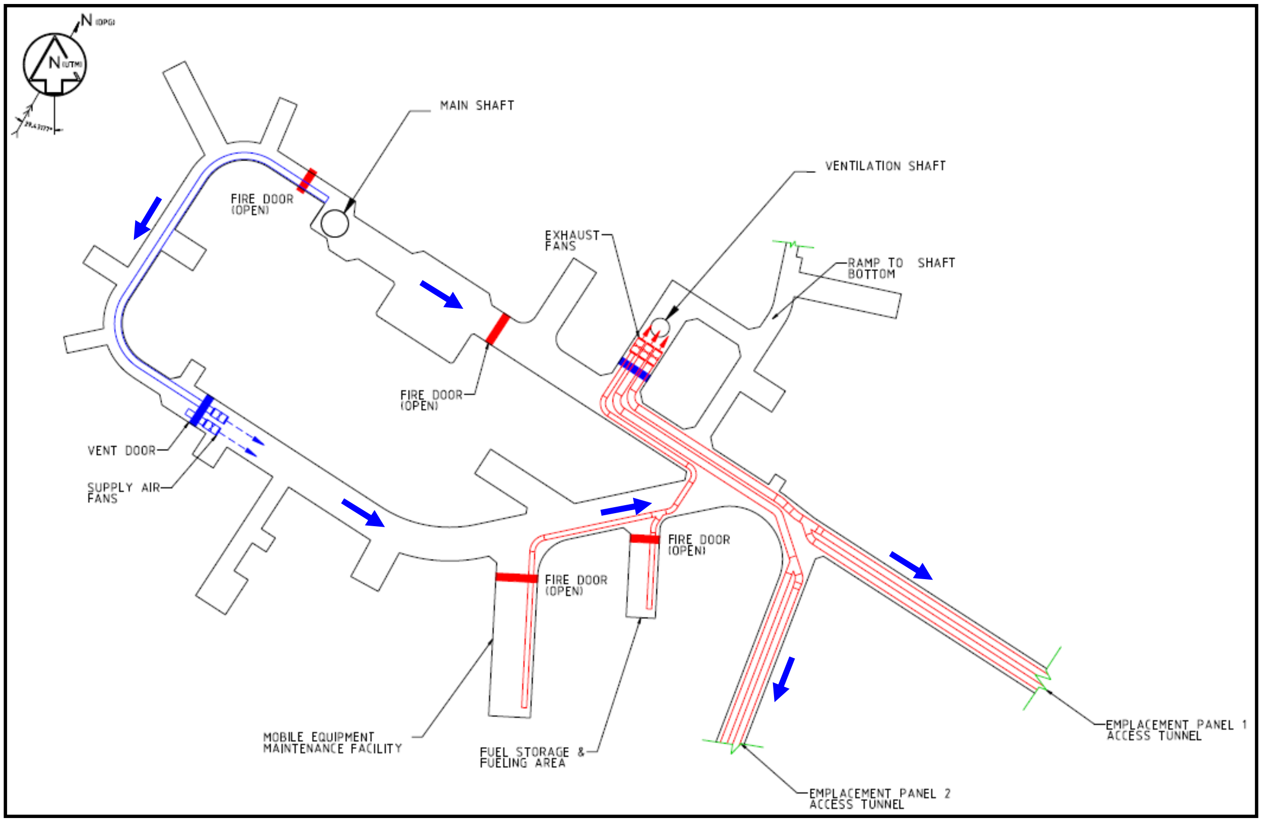

Figure 5-2 – Underground Ventilation Distribution System

5.2 Ventilation System Capacity

The primary driver for the total airflow requirements will be the amount of diesel equipment in operation underground.

Engineering undertaken during this phase of study has determined that the most likely method of excavation will be drill and blast. Such a method of excavation requires a sizable fleet of diesel equipment.

However, not all diesel equipment will be used at the same time. It is prudent, therefore, to plan for the most likely maximum diesel equipment usage at any point especially in light of the requirement to work a number of development faces concurrently. Using preliminary advance rate calculations, the following diesel equipment will likely be in use at the same time:

- One face being mucked – one LHD and three trucks.
- One face being shotcreted – two shotcrete transmixers (note that the sprayer will be on electrical tether during this process and is, therefore, not counted in the airflow calculations).
- One face being drilled – Jumbo on electrical tether.
- One face being loaded with explosive – Assume diesel operated emulsion loader.
- One other piece of diesel / electric equipment (jumbo, bolter, sprayer) moving between locations.

Table 5-1 shows the estimated air allocation for diesel equipment during construction based upon the above premise.

Equipment	Number of Units	Rated Power (kW)	Total Rated Power (kW)	Required Air Quantity (m^3/s)
Jumbo/Bolter/Sprayer	1	58	58	3
LHD	1	200	200	12
Shotcrete Transmixer	2	179	358	21
Haul Trucks	3	304	912	55
Explosives Carrier	1	179	179	11
		Total:	1707	102

Table 5-1 – Air Requirements for Diesel Equipment during Construction

Further to this, the emplacement period for each group of rooms in the panels has been determined and is discussed in Section 10.1 of this report. In the final years of the DGR operations period, only rooms 1 to 5 of Panel 1 will be required to have continuous flushing ventilation maintained as the other groups will already be isolated by closure walls. Assuming that, in the event that the DGR is expanded, construction commences while these five rooms are still being ventilated, and that drill and blast will continue to be the excavation method, the expected maximum airflow through the DGR facility will be as follows:

- Construction diesel equipment = 102 m^3/s.
- Shop = 11 m^3/s.
- Refuelling Bay or Wash Bay = 11 m^3/s.

- Five emplacement rooms filled with waste, shielded but no closure wall in place = 5 m^3/s.

The addition of each of these gives a total maximum airflow through the DGR of 129 m^3/s.

5.3 Ventilation during Construction

All tunnel excavations underground will employ a drill and blast technique for face advancement. Ventilation will be required for all phases of the drill and blast cycle (drill, blast muck, support, etc.). Of particular note, the ventilation requirement for this process will need to:

- Clear any residual dust generated primarily by mucking.
- Remove heat generated from diesel engines and, to a lesser extent, heat from electric / hydraulic equipment such as jumbos and bolters.
- Dilute and remove diesel engine exhaust to acceptable levels.
- Remove noxious gases after blasting.

To define the required ventilation flow for the excavation heading, a minimum flow velocity of 0.5 m/s is necessary to ensure the above requirements. This velocity will ensure a “positive flush” of dust and gases and will provide adequate dilution of diesel exhaust. Based on the largest room size of 8.6 m by 7.0 m, this relates to a quantity of 30 m^3/s.

The room under construction would use both an exhausting duct and fan system along with a fresh air delivery fan and duct system. For the exhaust part of the system, an 80 kW fan is mounted in the exhaust duct near the entrance to the room with steel duct on the inlet side of the fan extending towards the development face. Due to potential for damage to the ducting during blasting from fly-rock, the duct will be kept a suitable distance from the working face. To ensure fresh air is delivered to the face, a smaller 40 kW fan will be located prior to the end of the exhaust duct and temporary flexible duct extended to the working area at the face. Note that, with this arrangement, it is important that the exhaust system remove more air than what the fresh air delivery system can achieve. This will prevent recirculation in the room leading to unsatisfactory conditions.

As the development face progresses, the end of the temporary duct is extended so that fresh air is kept close to the working personnel. After a yet to be determined number of rounds have been excavated, the steel exhaust duct is extended and the smaller fresh air delivery fan moved forward relative to the end of the exhaust duct. The process is repeated until the heading is completed.

The dual exhaust / intake arrangement is shown in Figure 5-3.

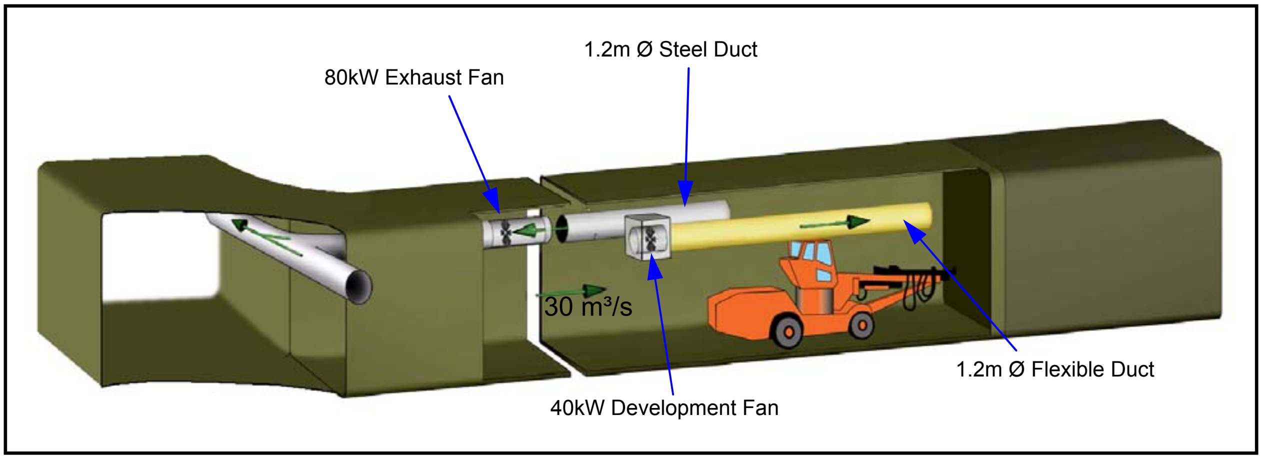

Figure 5-3 – Ventilation During Construction

5.4 Ventilation during Emplacement Operations

Subsequent to the construction phase of the DGR, the operations phase commences. During this phase, each room that has been excavated will be either empty, active or filled. Each of these stages requires a different approach to ventilation.

5.4.1 Empty Emplacement Rooms

Upon completion of the excavation of an emplacement room, there will likely be a period of some time before active emplacement commences. During that time, it is planned that the empty emplacement rooms will not be ventilated. As such, these rooms will be considered "confined spaces" and access to non-active empty rooms prevented.

Unventilated empty rooms will therefore require:

- Installation of a barricade at the entrance to the room.
- Adequate signage indicating room is prohibited for entry.
- A procedure for re-entry (e.g. fan installation, air monitoring, ground inspection, etc.) that meets health and safety guidelines.
- Atmospheric monitoring to test for build-up of potentially explosive gases. Monitors will be located at the far end and near the highest point of each room. At regular intervals, the monitoring unit will require access for calibration and / or maintenance. This will require that confined space re-entry procedures be followed.

See Figure 5-4 for example of a non-active empty room.

Figure 5-4 – Non-active Empty Emplacement Room

5.4.2 *Active Emplacement Rooms*

Upon commencement of emplacement operations, the auxiliary exhaust ducting system will be used to collect all air that has passed over waste packages and duct that return air to the base of the upcast Ventilation Shaft. All active underground areas will thus be in fresh air or air that has only passed through non-contaminated tunnels. The system used to collect exhaust will be used for both active and filled emplacement rooms. This return air coming from areas of potential contamination will be transported in ducts to the Ventilation Shaft.

Typical arrangements for these scenarios are demonstrated in Figure 5-5 and Figure 5-6. To achieve the optimal distribution of fresh air throughout the DGR, the exhaust system in active emplacement rooms will be used as primary exhaust points. As such, the majority of air flowing into the repository will be removed from the ends of the ducts in those rooms.

The control and distribution of airflow through each panel is attained by the operation of the exhaust duct booster fans located at the Ventilation Shaft. The volume of airflow in an individual emplacement room is ensured by the location of a fan in the exhaust duct near to the entrance of the room. The volume of airflow is primarily dictated by the kW rating of diesel equipment in the room. However, whilst a smaller forklift does not require 18 m^3/s, a higher airflow is necessary due to the size of the rooms to ensure a reasonable velocity for clearance of diesel exhaust.

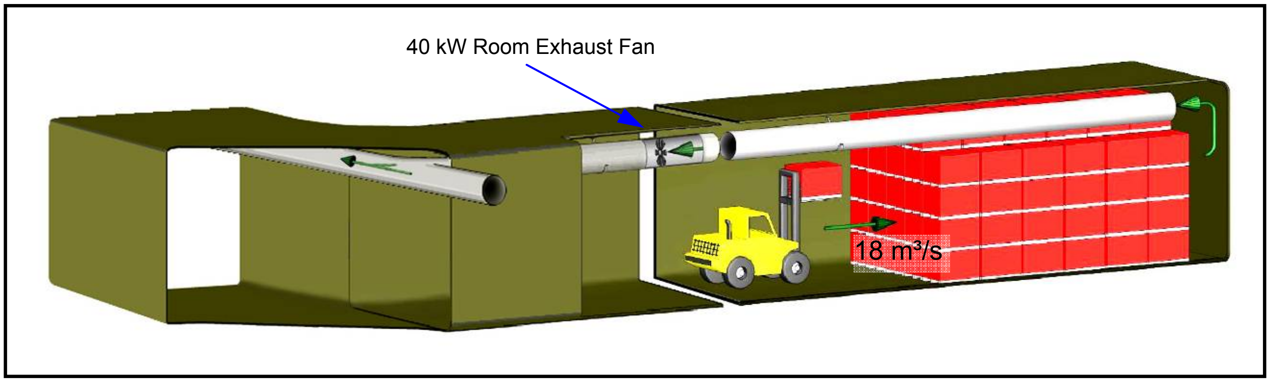

Figure 5-5 – Active Emplacement Room – Typical LLW

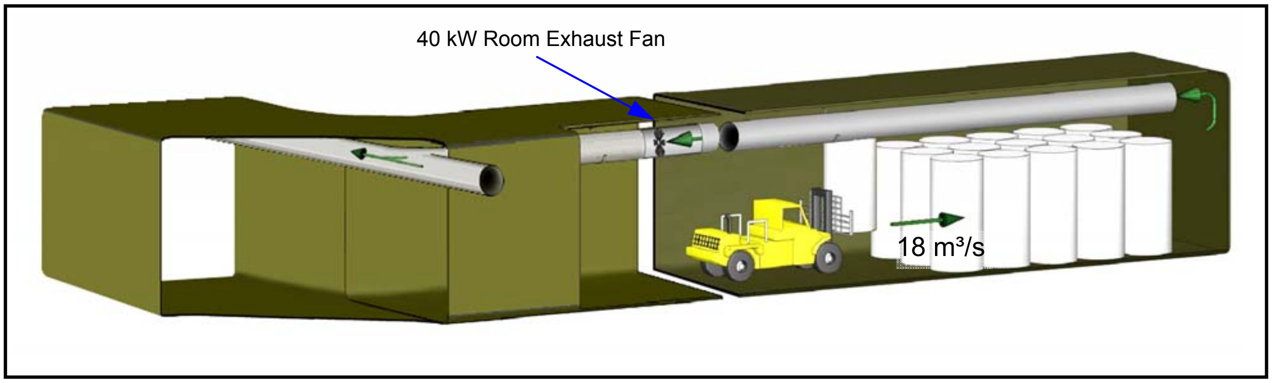

Figure 5-6 – Active Emplacement Room – Typical ILW and Heavy LLW

5.4.3 Filled Emplacement Rooms

Following emplacement activities, a filled emplacement room will be monitored while adjacent rooms are being filled. During that period of time, the room will be continuously ventilated, albeit at a much reduced flow rate to enable one air exchange every 2 to 4 hours. Continuous flushing provides the following benefits:

- Maintenance of temperature and humidity levels. A non-continuously flushed room may allow humidity to rise, which may accelerate the corrosion of duct, duct hangers, ground support and waste packages.
- Minimal opportunity for gases to collect or concentrate.
- Monitoring of contaminants in the exhaust flow is continuous.
- Timely reaction to fire - continuous smoke detection available, smoke from any part of room will report to duct where it can be detected.

The Exhaust Fans previously located in the duct near the entrance to each room will be replaced by an actuated damper to regulate the flow of air.

A shield wall will be constructed at the entrance to each emplacement room, as and if required. This will provide worker protection from any cumulative dose rate or “shine” effect of all the waste packages in the room, prevent people from entering the room and act as part of the ventilation control. Additionally, the duct already in place from the construction and operations periods will remain in place for continuous flushing of the return air back to the Ventilation Shaft.

Following the above mentioned period of continuous flushing, a group of rooms will be permanently sealed by the construction of a closure wall in the panel access tunnel. This closure wall will be sufficient to withstand any unexpected ignition of flammable gases behind the wall.

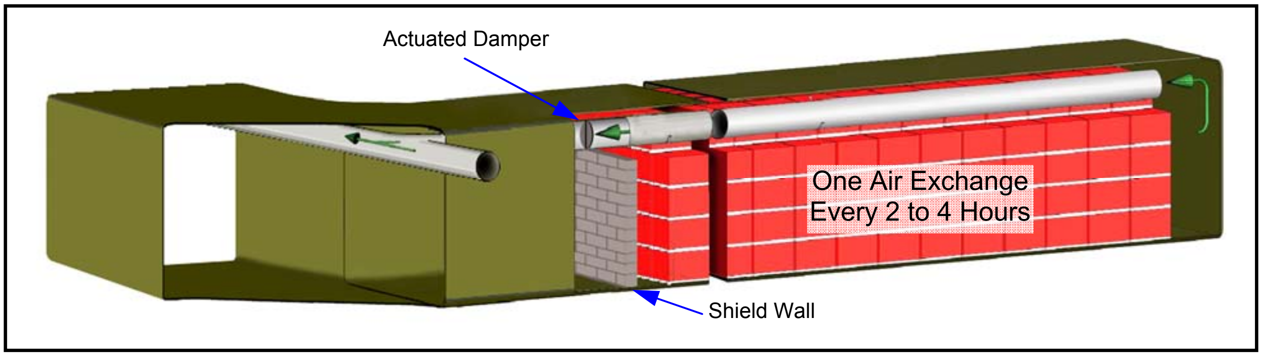

Figure 5-7 – Filled Emplacement Room – Typical LLW

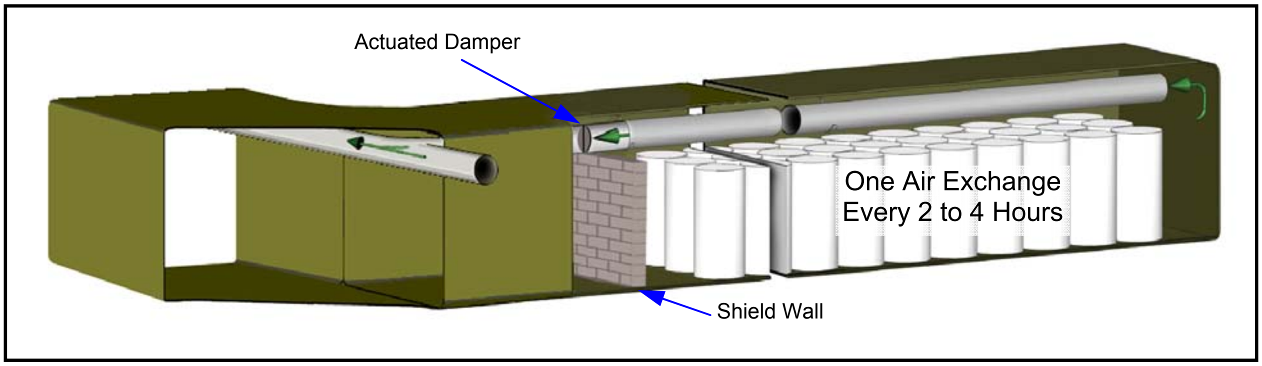

Figure 5-8 – Filled Emplacement Room – Typical ILW and Heavy LLW

5.4.4 Ventilation Ducting

Permanent ventilation ducting at the DGR repository will be of steel or comparable construction. During the construction phase, permanent steel ducting will be used for exhausting each development heading, although at a distance back from the face to prevent damage from fly-rock during blasting. Fresh air will be delivered to the development face by temporary fabric ducting. For the operations phase, all ducting will be permanent steel or comparable ducting.

A small section of fresh air ducting will be installed from the Main Shaft to one of the two fresh air booster fans. This ducting reduces the amount of air flow in the West Services Tunnel itself to an acceptable velocity. No dampers are required on this section of ducting. All other fresh air in the repository will move through the tunnels.

All return air will be ducted back to the Ventilation Shaft, with the exception of a small amount of air in the service tunnel and Main Shaft staging area that will flow through the tunnels directly to the Ventilation Shaft.

In the Shaft and Services Area, return air ducting will be installed from the maintenance facility, wash bay and fuel storage area to a return air booster fan near the Ventilation Shaft.

In the emplacement panels, each emplacement room will have return air ducting along its full length, joining a return air header in each emplacement panel access tunnel. The ducting in the emplacement rooms will have sufficient durability for the expected life of the emplacement room prior to closure. The return air header in each emplacement panel access tunnel will be connected to a dedicated return air booster fan near the Ventilation Shaft. Note that each access tunnel will have two panel access ducts. The two panel access ducts will combine into one larger duct at the junction of the South Access Tunnel and the Panel 1 Access Tunnel.

A damper will be installed in the ducting out of every emplacement room, the maintenance facility and the fuel storage room. The dampers in the fuel and maintenance rooms will aid in controlling the flow of air out of each room and allow the ventilation to be isolated in the event of a fire.

5.5 Intake Fans, Air Heating and Conditioning Plant

The function of the Surface Intake Fans is to provide the required airflow for the DGR at a pressure that overcomes the losses across the:

- Heater House.
- Silencers.
- Intake plenum.

The fans will also generate pressure sufficient to impart a positive pressure into the Main Shaft Headframe whilst providing enough pressure to a neutral point, (point at which pressure from Intake Fans and pressure created by the Exhaust Fans equal zero), in the Main Shaft below the plenum. The fans will be designed to deliver the maximum anticipated flow at any point through the life of the DGR.

The two Intake Fans will be of equal specification, arranged to operate in parallel and will be located on the outlet side of the Heater House. An additional fan, of equal specification, will act as a standby. In the event that one fan stops operating at the Heater House, the other will deliver a minimum 66 % of the total flow that both fans are capable of delivering together. (Note that because the DGR will generally run less than 100 % of design flow, one fan will provide a minimum of 66 % of the design demand and may indeed provide more.)

The operating point of the Intake Fans is expected to change throughout the life of the facility. As such, each fan will be operated through a variable frequency drive (VFD), which changes the rotational speed of the fan hub and thus the fan operating point. When operating together at the Heater House, both fans will be run as close to the same rotational speed as practically achievable. In concert with the Exhaust Fans, use of VFD’s will provide the added benefit of permitting the ventilation system to be throttled back when no one is underground, resulting in power consumption savings.

The two Surface Intake Fans have been sized as follows:

- 2.13 m diameter axial fans.
- 75 kW each.
- 200 Pa static pressure at a volume of 65 m^3/s each.

At the DGR Project site, surface temperatures will fall below freezing at various times during the year. To ensure that services, particularly with regards to water, within the Main Shaft (fresh air intake) are not affected by these temperatures, heating is applied to the air intake for the Main Shaft to a minimal level to prevent such freezing.

During the normal heating season period, the heaters will operate as required when temperatures fall below the heater set point. At other times of the year, the air heating system will not be required as below zero temperatures will only be transient. The available turndown ratio for the burners will allow the target final temperature to be achieved, regardless of fluctuations in the ambient air temperature.

The heaters in the Heater House will be direct fired burners with the understanding that propane will be the fuel used. The heaters will also be designed for the lowest air temperature that has been measured in the area over the last 15 years recorded at the Wiarton meteorological station. This station has been used as it is the closest station in the region that complies with both the World Meteorological Organisation (WMO) and Environment Canada (EC) standards for Canadian Climate Normals.

In consideration of the need for a surface refrigeration plant to cool the air before being delivered to the Main Shaft for transport underground, heat flow modelling was undertaken. This modelling considered the application of heat loads at various points through the facility. The primary heat loads considered were as follows:

- Autocompression.
- Rock Strata.
- Diesel Equipment.
- Electrical Equipment.
- Concrete and Shotcrete Placement.
- Retube Waste Containers.

Modelling was undertaken for both construction and operation periods of the DGR, considering surface climatic conditions at yearly average, average maximum for the warmest month and average minimum.

The modelling considers the location at which the highest temperatures are likely to occur within the facility during both construction and DGR operation periods in respect of the design criterion of 28.5 °C Wet Bulb Globe Temperature (WBGT) [R47]. It was found that:

- Construction: the design criteria would be exceeded when surface conditions reach 26.4 °C dry bulb and 21.0 °C wet bulb which happens for around 138 hours per year.
- DGR Operation: the design criteria would be exceeded when surface conditions reach 28.5 °C dry bulb and 22.8 °C wet bulb which happens for around 47 hours per year.

Based upon the modelling undertaken and the results particularly with regard to temperatures expected at underground locations, it has been ascertained that a permanent surface refrigeration system is not required for the facility at this stage of preliminary engineering.

5.6 Exhaust Fans

The function of the Surface Exhaust Fans is to ensure that the DGR operates as a “pull” type of ventilation system. The fans will be located on the surface and connected by a plenum to the Ventilation Shaft. The plenum will commence from a point in the Ventilation Shaft below the collar and extend along the subsurface to the Exhaust Fan inlets. Note that it is likely that water will condense out of the exhaust air as it enters and travels along the plenum. The plenum will be designed such that the water will drain along the plenum and collect at a sump. The position and operation of this sump will be determined in future phases of engineering.

The fans will operate at a point such that the pressure created by these fans will induce a flow from a neutral pressure point in the Main Shaft just below the intake plenum, down the Main Shaft and through the underground circuit to the base of the Ventilation Shaft before finally travelling up through the Ventilation Shaft to the Exhaust Fans. The fans will be designed to exhaust the maximum anticipated flow (129 m^3/s) at any point through the life of the DGR.

The two Exhaust Fans will be of equal specification, arranged to operate in parallel and will be located at the exit of the exhaust plenum. An additional fan, of equal specification, will act as a standby. In the event that one fan stops operating, the other will deliver 66 % of the total flow that both fans are capable of delivering together. Noise mitigation will be attained through application of acoustic baffle type silencers on the outlet of the Exhaust Fans and, if deemed necessary, in the plenum inlet to the Exhaust Fans.

The operating point of the Exhaust Fans is expected to change throughout the life of the facility. As such, each fan will be operated through a VFD, which changes the rotational speed of the fan hub, thus changing the fan operating point. When operating together, both fans will be run as close to the same rotational speed as practically achievable. This will have the added benefit of permitting the ventilation system to be throttled back when no one is underground, resulting in power consumption savings.

The two Surface Exhaust Fans are sized as follows:

- 1.94 m diameter axial fans.
- 93 kW each.
- 740 Pa static pressure at 65 m^3/s each.

5.7 Ventilation for Potential Expansion Case

As discussed in Section 5.2, the maximum airflow through the DGR is 129 m^3/s, which takes the potential expansion case into account. This maximum airflow would occur during construction activities commencing prior to the construction of the closure wall across the final group of filled emplacement rooms in Panel 1.

At present, further expansion of the DGR will likely be achieved through extension of the South Access Tunnel. By the time excavation for the potential expansion commences, Panel 2 will already have been filled and a closure wall installed across the Panel 2 Access Tunnel. The twin 1.6 m diameter ducts for Panel 2 will, therefore, be available for both expansion construction and operations activities.

6. Waste Package Handling, Transfer & Emplacement

The DGR facility will be capable of receiving, inspecting, tracking, handling, and emplacing all of the DGR inventory, consisting of operational L&ILW from OPG-owned NGS's and L&ILW generated during refurbishment projects at OPG-owned nuclear stations. This waste, after being processed into a state that is acceptable to the DGR, is described in Section 3, and the grouping of packages is summarised in Appendix D. Flow diagrams outlining the full process are provided in Appendix E for each of the waste package groupings:

Group Designation	Group Name	Flow Diagram Drawing Number
A	Bin-Type Waste	H333000-WP401-05-030-0001
B	Heavy Non-forklift	H333000-WP401-05-030-0002
C	Light ILW	H333000-WP401-05-030-0003
D	T-H-E Liners	H333000-WP401-50-042-0001
E	Fresh Resin Liner	H333000-WP401-05-030-0004
F	Heavy Forkliftable	H333000-WP401-05-030-0005

Table 6-1 - Summary of Waste Package Groupings and Related Flow Diagram

6.1 Methods of Surface Waste Package Handling

6.1.1 General

All packages retrieved from the WWMF will be transferred in a DGR-ready state on flat-bed transporters, covered transporters, or forklifts to the WPRB adjacent to the Main Shaft of the DGR. The first operation at the DGR will be receiving the package(s), which will ensure that the package(s) on the transport vehicle:

- Have the DGR-ready status in the IWTS.
- Are on the roster of packages to be received in that given shift.
- Have not been damaged during transport from the WWMF.

The IWTS is a database system employed by WWMF to track status and location of each waste package. It is currently only used at WWMF, so packages only get entered into the system and tagged after they are received and processed (if required). It is anticipated that part of waste package retrieval at WWMF would involve verifying the IWTS tag in addition to updating the status for each package as "DGR-Ready". The IWTS system will be modified as required to encompass waste handling activities at the DGR.

A detailed roster for transferral will be drawn up by a DGR planning team prior to commencement of emplacement operations. The roster which will take into account the storage locations and accessibility for retrieval of the packages at the WWMF and the requirements for emplacement underground, so that groups of packages are delivered to the WPRB in the correct order for transfer. While the emplacement room configurations have been designed to provide a certain amount of flexibility in stacking, it will still be important to define a detailed plan that recognises waste package retrieval and transfer constraints at the WWMF as well as limitations on stacking underground.

Once the package has been deemed acceptable, packages will be off-loaded by forklift or mobile crane and placed into the staging area, if required, prior to being loaded onto rail carts for shaft transport. The WPRB will be arranged with off-loading facilities for both flatbed trailers and covered trailers.

A controller based at the WPRB will coordinate the process and ensure that all packages received are in accordance with the planning roster and undergo an incoming inspection process to confirm that the packages conform to the WAC. Because retrieved packages will be fully inspected at WWMF before transfer to the DGR, minimal inspection would be required. It would involve a visual scan for structural damage that could have taken place during transport from WWMF. A secondary inspection at the WPRB staging area may be executed only if required. Packages that do not meet the WAC may be returned to the point of origin if it is safe to do so, where the shipper will rectify package conditions that caused it to be rejected[10].

When packages are received at the WPRB off-loading bay, the barcode tag will be scanned and the database queried. Personnel will check to see that package status is “DGR-ready”. All retrieved waste packages and newly generated waste originating from WWMF will have an IWTS barcode tag applied, however should any waste package arrive at the WPRB without a tag, one will be attached to the exterior of package before transfer underground. The tracking data for all incoming packages within OPG's IWTS will be reviewed for completeness and updated as necessary. For packages which receive barcode tags at the WPRB, all tracking data will be entered into IWTS at the WPRB. The data will allow the packages to be tracked throughout the transfer process and interface with the DGR monitoring system to provide immediate confirmation of adherence to the schedule on the monitoring system at the MCR.

Newly generated waste packages will generally be transferred only from the WVRB at the WWMF. The major exception will be fresh Resin Liners, which will be shipped directly from the nuclear stations to the WPRB. Shipments from the nuclear stations will be planned with the DGR Controller to ensure that necessary preparations are made to receive the package and that underground emplacement allocations are made available to suit the delivery schedule.

All waste package shields will be generally designed to ensure that dose rate limits are not exceeded. However, there may be some packages on which the dose rate limit is exceeded. As an example, based on preliminary projections, 6% of the newly-received Resin Liners (62 liners) and 30% of the T-H-E Liners (142 liners) may not meet this dose rate limit. Any packages that are measured to have an unacceptably high dose rate may be left in appropriate surface storage at the WWMF until they can be safely retrieved, shielded and transferred. If packages that have dose rates in excess of the WAC are to be accepted by the DGR, spot shielding may be used and / or temporary shielding attached to the transport equipment as part of a specific ALARA (As Low As Reasonably Achievable) plan to protect workers from any dose exceeding the applicable dose limits.

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[10] If a package has an easily correctable non-compliance with the WAC, DGR Operations may opt to correct on site instead of returning it to the sender.

With the exception of the Group D (T-H-E Liners) packages, all waste will be transferred in the Main Shaft cage by means of a rail-based transfer cart. These rail carts are described in Section 10.4. Empty carts will move into the waste package loading area of the WPRB where forklifts or the overhead crane will place packages on their deck. The carts are loaded and unloaded from one side only; the forklifts are not required to approach the rail carts from either “end” or from the side not facing the unloading area. The packages will be secured on the cart as required to ensure that the load will remain stable while the cart is moved into and out of the cage and while the cage is in motion. To help secure the packages and ensure that the load is centred on the cart, moveable and interchangeable brackets can be fastened to the cart deck as seen in Figure 6-1. The embedded rail and the spare cart waiting on the siding can also be seen in this figure. Where practical, multiple packages can be placed on the cart, but the current assumption is that no packages will be stacked on top of others.

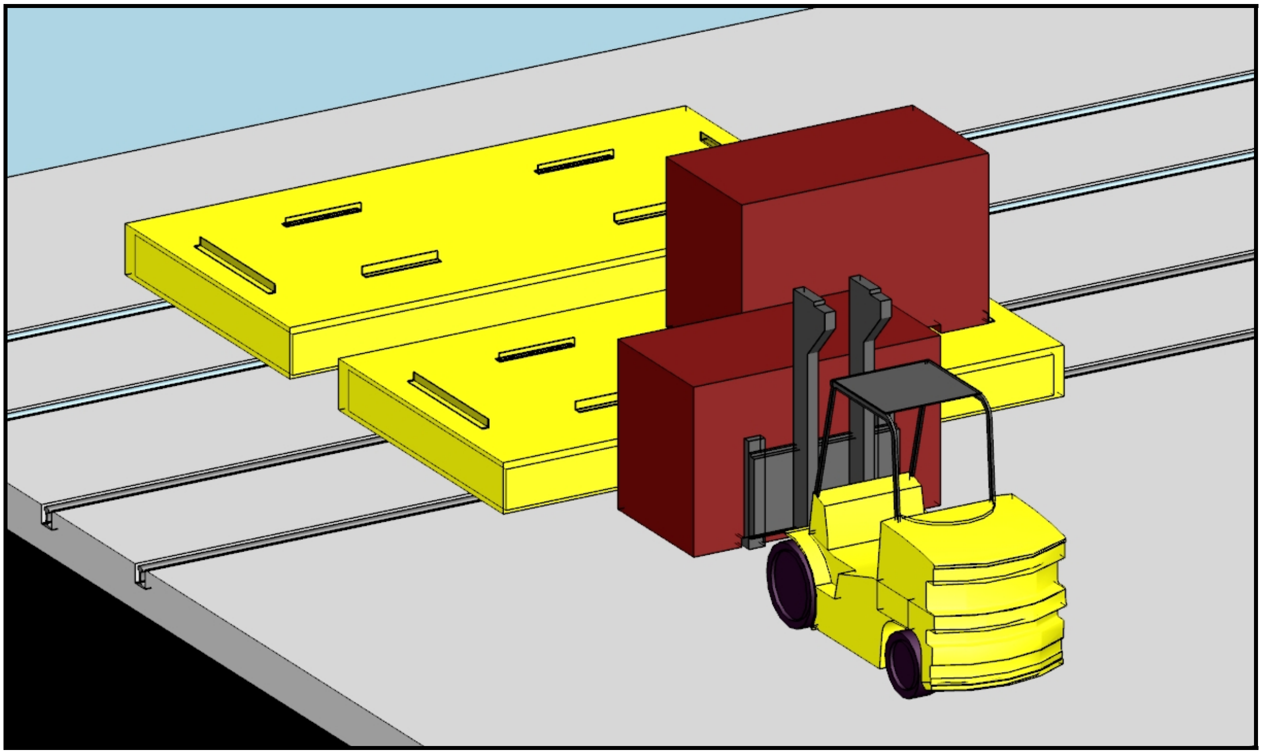

Figure 6-1 – Light Duty Forklift and Rail Carts

The following sub-sections describe the process for handling each Group type of waste packages at the WPRB. The packages in each of these Groups are defined in Section 3.

6.1.2 Group A – Bin Type Waste

The bin-type LLW packages will be transported in large quantities from the WWMF and will be off-loaded, inspected, and stacked in a staging area on the incoming side of the WPRB by a light duty forklift. A second forklift (or the same forklift if available) can be used to transfer the packages to awaiting rail carts. The DGR will be capable of receiving and transferring 24 of these packages in one shift.

6.1.3 Group B – Heavy Non-Forklift Waste

All Group B packages are large and heavy items, which will only be handled by crane (i.e. they are not set up for forklift handling). This will make their transfer more time consuming, however, there are only a total of 91 Group B packages. They will be transferred on a flatbed truck to the DGR and off-loaded into the staging area (if required) by the WPRB overhead crane. The same overhead crane in the WPRB will be used to place these waste packages on a rail cart for transfer into the DGR. To ensure stability of the cylindrical heat exchanger packages, they will be loaded horizontally onto a custom-designed saddle that is pre-installed on the rail cart.

6.1.4 Group C – Light ILW

The Group C packages are alike in overall size and mass to the Group A packages and thus the handling methodology is also similar. The light duty forklift will be used to off-load these packages from the transport vehicle and also to place them onto rail carts. Alternatively, operations may decide to transfer these packages from the WWMF using a light duty forklift if efficiencies can be found in so doing. Because they are generally higher in dose rate, the staging area will only be used at the WPRB when it is necessary, with most packages being loaded directly onto the rail carts.

At the WPRB, a similar light duty forklift will be used for off-loading, placement into the secondary inspection area (if required), and placement on the rail cart. Operations may consider using a forklift instead of a truck to transfer these wastes from the WWMF to the DGR.

6.1.5 Group D – T-H-E Liners

Since both the IC-2 and IC-18 T-H-E Liners are of a similar shape, size and mass, the preferred methodology for handling, transporting and emplacing the T-H-E Liners is applicable to both types. The liner retrieval and transfer process is described in Section 3.4.

The T-H-E Handler, described in Section 6.2.3, will be prepared in a ready position in the WPRB. The loaded Transfer Bell will arrive at the WPRB drive-through off-loading bay on a flatbed trailer. The WPRB overhead crane will be attached to the Transfer Bell. A spreader beam and balancing procedure will be required to ensure the Transfer Bell does not tilt when lifted, as liners are not expected to have the same centre of gravity. When the lifted Transfer Bell is clear of the trailer, the personnel handling the guide ropes will rotate the Transfer Bell 90 degrees to the same orientation as the T-H-E Handler.

6.1.6 Group E – Fresh Resin Liners

Resin liners that are produced by the nuclear stations after the start of DGR operations (i.e. post in-service date) may be delivered directly to the DGR. Surface transport would utilise a transport shield such as the currently used Trillium unit. Upon arrival of the truck and filled transport shield, the Resin Liner will be extracted using a work platform (See Section 10.4.5) and the overhead crane.

Depending on the dose rate of the specific Resin Liner being received, the level of shielding must be determined before it is extracted from the transport shield. If the dose rate of the unshielded liner is within the WAC limits it will be placed in the package staging area for direct transfer to the shaft cage after being secured in a sacrificial pallet.

For Resin Liners that will require shielding, the appropriate DGR shield will be placed nearby the transfer shield. The process of transferring these Resin Liners from the transport shield into a DGR shield is the only “remote handling operation” task that is anticipated in the WPRB. Because of the relatively higher doses encountered during this manoeuvre, special attention must be paid to equipment reliability and backup plans for recovery from failure. Once the package is inside the DGR shield, the respective shield lids will be replaced.

Resin liner Shields 1 and 2 have a capacity of two Resin Liners. After a new shield receives one liner, it will need to wait for a second one before being transferred to the repository. A platform within the WPRB will be designated to store these partially-filled Resin Liner Shields. This area will not require additional shielding, but will be slightly raised to provide a degree of protection from mobile equipment.

Fresh Resin Liners are the only packages anticipated to arrive at the DGR with no IWTS tag attached. A tag would need to be generated for each fresh Resin Liner received. Where a liner is to be handled in a shield, the tag would be applied to the outside of the shield. Note that a Shield 1 and Shield 2 would have two tags attached to identify both Resin Liners contained in the shield.

The DGR will receive and transfer the fresh Resin Liners on a priority basis. The planning team will be advised of these shipments and will be able to plan accordingly. To limit any disruption of waste transfers from the WWMF, only one fresh Resin Liner will be accepted by the DGR during any given shift.

6.1.7 Group F – Heavy Forkliftable Waste

The Group F packages are handled in the WPRB using the heavy duty forklift. This same forklift may be used to transfer these packages from the WWMF, or they will arrive on a low-deck flatbed trailer. The DGR will be capable of receiving and transferring at least four Resin Liners during an 8-hour shift.

6.2 Shaft Handling

The shaft handling description is divided into one procedure for packages utilising the rail cart and one procedure for the Group D T-H-E liners utilising the T-H-E Handler.

6.2.1 Capacity

The Main Shaft cage has a limited capacity for the total size and mass of waste packages transferred within it on any given trip between surface and the repository horizon. The deck is sufficiently large for several of the smaller packages to fit side-by-side. Because these smaller packages are also relatively light in comparison to the larger-sized packages, the combined mass when multiple packages are transferred does not approach the mass capacity of the cage.

Package Group and Type	Number Per Trip
Group A	
Bin Overpacks	2
Compactor Box	2
Bale Rack	2
Drum Rack	2
Drum Bin	3
Non-Pro Bin (NPB47)	3
Non-Pro Bin (NPB4)	2
Low Level Resin Pallet Tank	4
Group B	1
Group C	
Unshielded Resin Liner	2
ILW Shield	4
Tile Hole Liner Rack	1
Group D	1
Group E	
Unshielded Resin Liners	2
Resin Liners (Shields 1, 2, and 3)	1
Group F	1

Table 6-2 – Rail Cart and Cage Capacity (assuming no package stacking)

6.2.2 Groups A, B, C, E, F

The general process of shaft handling for all rail cart-based packages (i.e. all except for Group D) is the same. After the package or packages are properly loaded and secured on the cart, the steps are summarised as:

1. The Main Shaft cage is chaired at the collar shaft station, hoist brakes are set and the hoist “locked-out”, the cage door and station gate are opened, and the rail stop is removed.
2. If the cage contains an empty rail cart, the rail switch is closed, the cart is unlocked from the cage, the electrical tether is connected, and the cart is moved out to the empty cart siding.
3. The rail switch is opened, ensuring that the section of rail between the loaded rail cart and the Main Shaft cage is clear.
4. The loaded rail cart is traversed into the cage.
5. The electrical tether is disconnected. Note that the cart brakes are automatically applied.

6. The rail cart is locked in the cage as required, and the loaded conveyance is inspected to verify it is ready for travel.
7. The cage door and station gate are closed and the station rail stop is replaced, releasing the hoist control interlocks.
8. The cage is lowered to the underground station. This will involve the hoist operator un-chairing the cage and lowering it at the designated velocity.

The steps in unloading the cage at the underground station are similar to the reverse of the loading process:

1. The underground station and unloading area are prepared for receipt of a loaded rail cart. This will include opening the rail switch in addition to preparing an empty cart at the empty cart siding for the return cage trip.
2. The conveyance is chaired and the hoist brakes applied and locked out. With this complete, the interlocks will allow the station door and cage door to be opened and the rail stop to be removed.
3. The securing mechanism to lock the cart in place in the cage is released and the electrical tether connected.
4. The rail cart is moved out of the cage to the package off-loading area. The rail tether is disconnected from the full cart and connected to the empty rail cart.
5. The rail switch is closed and the empty cart moved onto the cage. The tether is disconnected, the cart locked in the cage and inspected.
6. The cage door and station gate are closed, and the rail stop is replaced, allowing the cage to be un-chaired and hoisted to surface, repeating the process.

Detailed procedures, involving pre-operation checklists and detailed inspections, will be developed to ensure that the trained operators can competently execute all required steps, with minimum reliance on system interlocks.

Note that in addition to the slow speed of the cart, hydraulic or mechanical dampers will be used to prevent any damage to the cage, rail cart, or package in the event that the operator fails to slow the cart at the end of travel. An example of a Bruce B Steam Drum Segment waste package in the Main Shaft cage is provided in Figure 6-2.

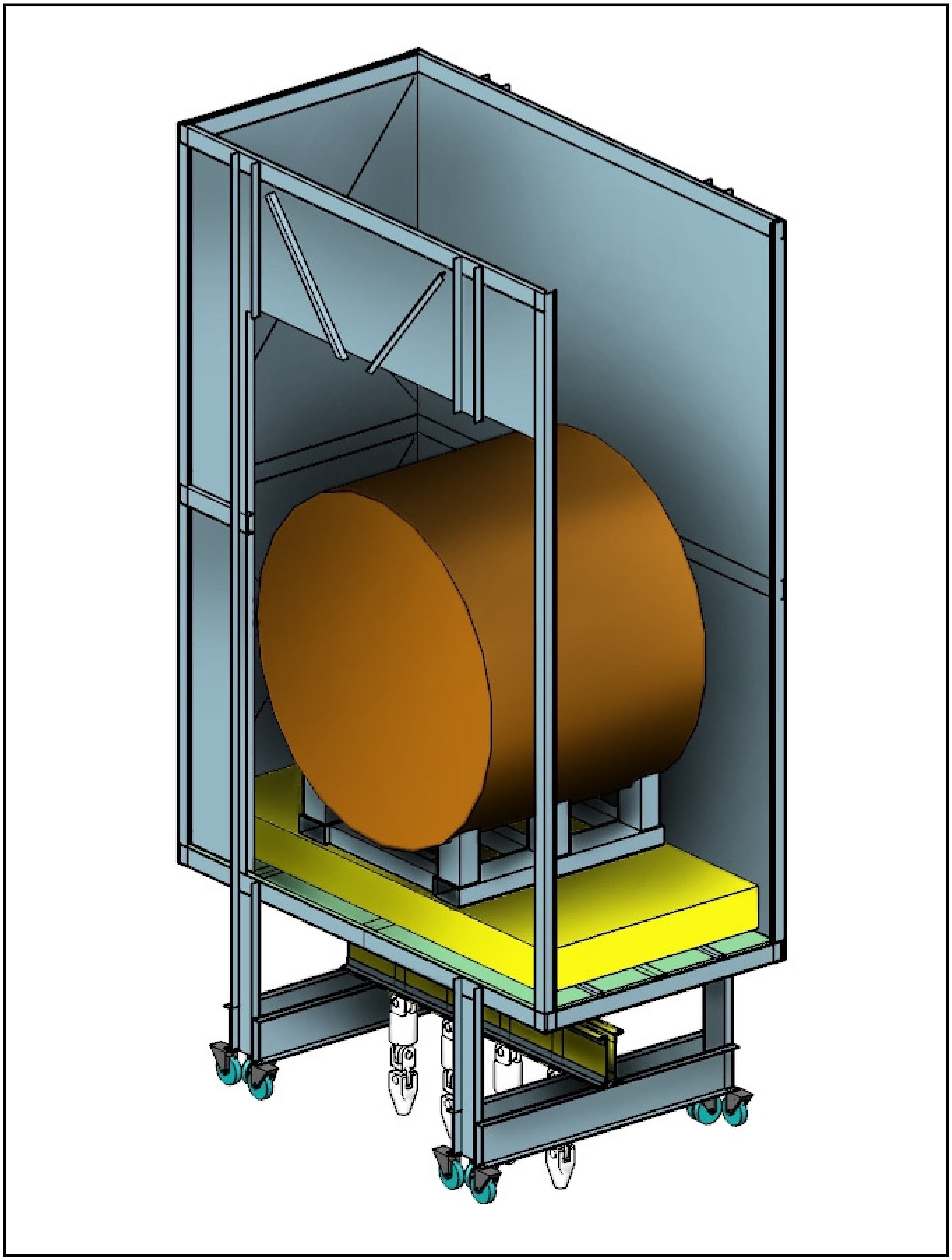

Figure 6-2 – Shaft Cage Orientation of Bruce B Steam Drum Segment

6.2.3 Group D

The Group D packages are handled with a T-H-E Handler instead of the rail cart, and thus the shaft handling of these packages is much different. A sketch of the T-H-E Handler is given in Figure 6-3. This approach is the current reference case for handling the Group D packages. Alternatives for transferring and emplacing these packages will be considered in the future.

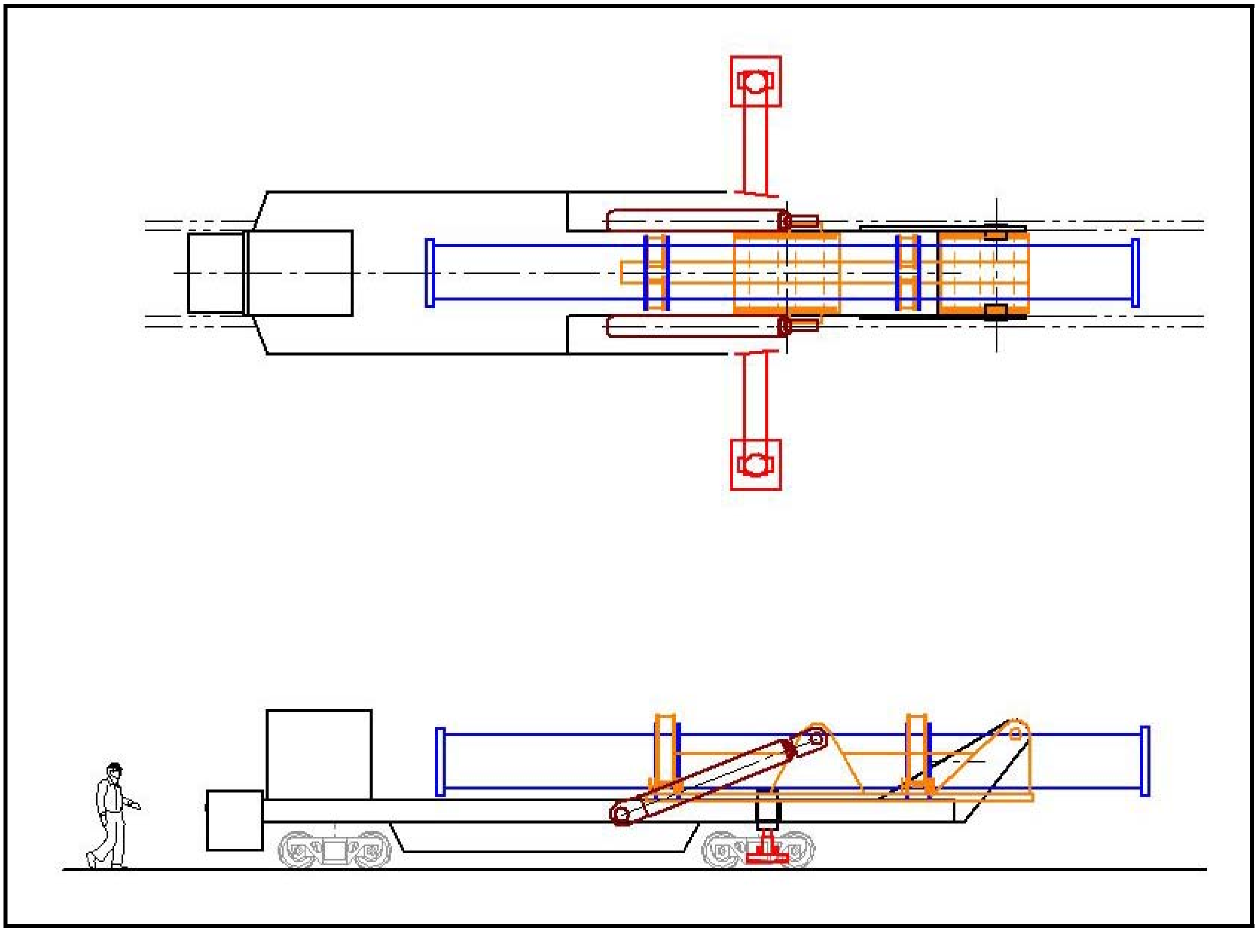

Figure 6-3 – Overhead and Side Views of the T-H-E Handler

The cage will require some preparation before handling the Transfer Bell. A stabilising frame will be installed on the cage floor and at an elevated position, as shown in Figure 6-4. The Transfer Bell will be fitted with trunnions that will be received by these frames. The upper frame will be slotted to receive the top trunnion and the lower frame on the cage floor will capture the bottom trunnion using a steel cap that will firmly hold the Transfer Bell in place.

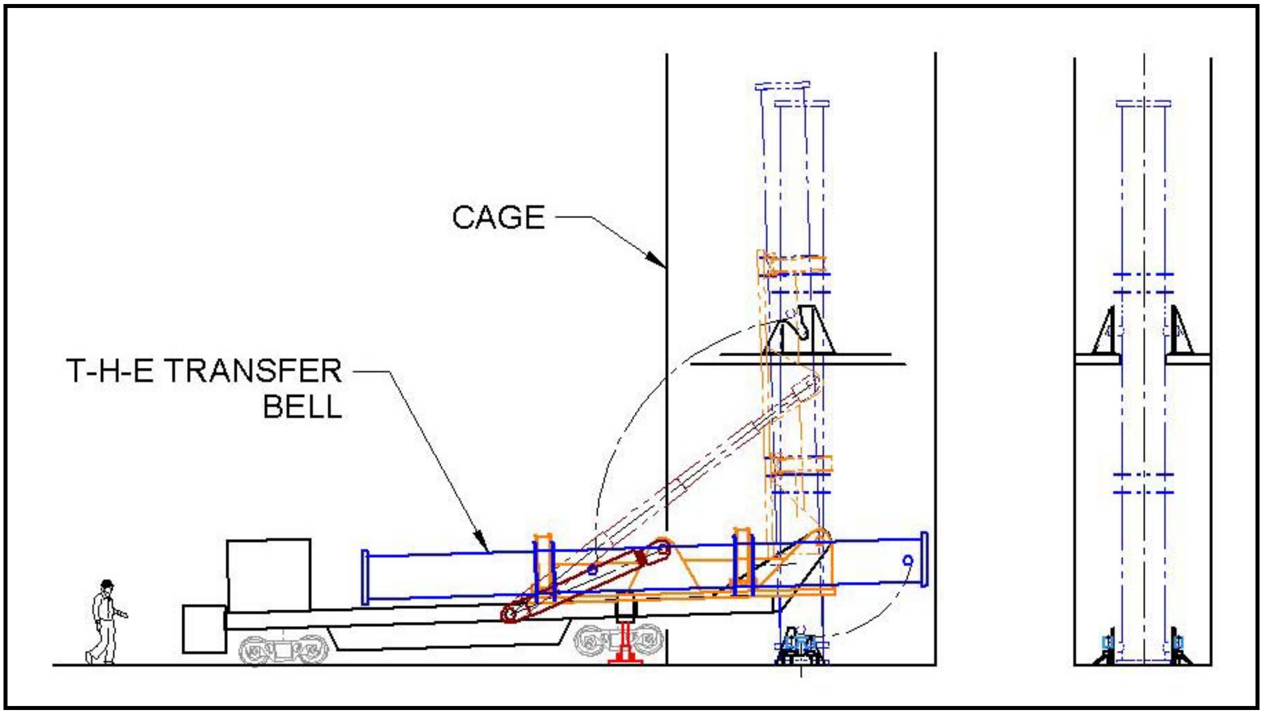

Figure 6-4 – T-H-E Handler Lowering the Transfer Bell in the Shaft Cage
(front view on right)

The package receiving and unloading operations at the WPRB will have the loaded T-H-E Transfer Bell secured in the mast of the T-H-E Handler. At this point, the cage will be prepared by installing the stabilising frames. The following steps outline the shaft handling procedure from this point:

1. The Main Shaft cage will be prepared to receive the package, with chairs engaged, brakes set, and open shaft gate and cage door.
2. The station rail stop will be removed and replaced with a new stop just outside of the cage door.
3. The T-H-E Handler will move on the rails from the package loading area to the entrance of the cage until positioned against the newly placed rail stop. The end of the Transfer Bell and handler will now be inside the cage
4. The outriggers will be extended and locked in place to allow a wide and stable footing for the machine. Stabilisers at the end of each outrigger will then be engaged to lift this end of the cart slightly.
5. The mast of the T-H-E Handler can now be used to erect the Transfer Bell to a vertical position in the centre of the cage. The Transfer Bell trunnions are now positioned slightly above the stabilising frame seats.
6. The stabilisers will be retracted, lowering the trunnions into the upper and lower stabilising frames. The Transfer Bell is now secured by both the T-H-E Handler and the cage.

7. The mast will now be detached from the Transfer Bell and lowered. After the outriggers are retracted, the T-H-E Handler will be withdrawn from the cage area.
8. To positively secure the Transfer Bell in the cage, caps will be placed over the bottom trunnions. The installation will be inspected to ensure it is ready for transport.
9. The temporary rail stop will be removed and the cage door and station gate closed. The primary rail stop will be replaced, releasing the hoist control interlocks.
10. The cage will be lowered to the underground station. This will involve the hoist operator un-chairing the cage and lowering it at the designated velocity.

The steps in unloading the Transfer Bell from the cage at the underground station are similar to the reverse of the loading process:

1. The T-H-E Handler unit at the underground station will be inspected and prepared to receive the loaded Transfer Bell.
2. The conveyance will be chaired and the hoist brakes set and hoist locked out. With this complete, the interlocks will allow the station door and cage door to be opened and the rail stop to be removed and replaced with another stop just outside of the cage opening.
3. The caps on the lower stabilising frame will be removed.
4. The T-H-E Handler will be positioned at the cage entrance, the outriggers extended, electrical tether connected, and the mast elevated to engage the Transfer Bell.
5. The stabilisers would then extend, lifting the trunnions out of the stabilising frames.
6. The mast will be lowered, taking the Transfer Bell to a horizontal position.
7. The stabilisers and then outriggers can then be retracted. The T-H-E Handler will be moved away from the cage, allowing the cage door and shaft gate to be closed. The primary rail stop will be replaced.

6.3 Underground Transfer and Emplacement in Rooms

6.3.1 Waste Package Allocation

The DGR will ultimately contain the full, currently projected inventory (see Section 3) of waste packages within 29 of the 31 emplacement rooms in Panel 1 and Panel 2. The remaining two rooms are planned to cater for potential growth in waste package quantities or dimensions.

An important facet of the DGR design process involves minimising the excavation volume and footprint of the repository, while respecting practical design and operational limitations. These limitations and design responses are summarised in Table 6-3. In Table 6-4, the required clearances around the waste packages are summarised.

The procedures and equipment used in waste package emplacement will be designed to minimise the time that workers spend in close proximity to the rows and stacks of emplaced waste packages.

Limitation	Design Response
Requirement to standardise excavation shapes for design and ground stability purposes.	Six standard room profile / designs are developed; each emplacement room is designated only one profile.
Number of rooms limited to 31, split into three emplacement periods.	Room profiles are flexible, with some waste types being allocated to more than one room profile.
DGR must emplace both retrieved waste packages and newly generated waste.	The group of rooms devoted to each emplacement period has sufficient capacity for the types and quantities of wastes transferred.
Stability of the excavated openings and capability of equipment used to excavate rooms.	Emplacement room width is maintained at or below 8.6 metres.
Geometries of underground layout and limited site footprint.	Emplacement room lengths are uniform, at a nominal length of 250 metres. (See Section 4.5 – Emplacement Room Dimensions])
Manoeuvring and stacking abilities of package handling equipment.	Rooms are sufficiently wide and tall for all equipment to operate within. Based on experience at WWMF, the emplaced package-to-wall clearance is set at 300 millimetres and emplaced package-to-package clearance is set to 50 millimetres.
Stack-ability and maximum stack height for the waste packages.	Sufficient height in the emplacement rooms is provided to stack the Group A packages to their design limit.
Package emplacement requirements such as requirement for installed gantry cranes or concrete emplacement arrays.	Gantry-equipped rooms are provided for Group B and Group D.
Excavation and construction costs should be minimised.	Profiles are designed to maximise packing efficiency, based on the shapes of the waste package inventory devoted to each. Also, the amount of embedded rail is minimised by placing the rail-serviced rooms as close to the Shaft and Services Area as possible.
Uncertainties in package dimensions and forecasted quantities.	Additional room provided for capacity growth factor.
Ventilation air must be supplied.	Duct shape and placement designed to manoeuvring and stacking clearances.

Table 6-3 - Summarised Design Factors for Emplacement Rooms

Location	**Reason for Clearance**	**Minimum Clearance (mm)**
Package to emplacement room side wall.	Ground support protuberances.	300
Package to package (all directions).	Practicality of package manoeuvring at final emplacement location.	50
Package to ventilation duct.	Practicality of package manoeuvring at final emplacement location.	150[11]
Top of package to roof – Group A waste.	Practicality of package manoeuvring at final emplacement location.	750
Package to roof clearance – all except Group A waste.	Practicality of package manoeuvring during transport in emplacement room.	1,150
Emplacement room entrance. (Unusable length from room entrance to first row of packages, measured at centre line)	Clearance to construct shielding wall.	8,000
Dead-end of emplacement room. (From last row of packages to wall.)	Room to allow ventilation airflow.	1,000
Wall to package clearance for gantry crane equipped rooms.	Clearance for “legs” of gantry crane.	1,000
Top of package to excavated roof clearance - gantry crane rooms.	This allows room for rectangular ducting, crane and hook, and rigging.	3,000

Table 6-4 – Summary of Clearances used in the Emplacement Room Design

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[11] It is recognised that this low clearance will present a challenge to package manoeuvring efforts – this will be reviewed in future engineering.

Packages will be stacked based on the limitations of the package construction *and* available headroom in the respective emplacement room, whichever is lower.

- The bin-type wastes (Group A) are to be kept in separate rooms compared to all other packages, but Heat Exchangers, Encapsulated Tile Holes, Steam Generator Segments, and Shield Plug Containers can be emplaced in the same rooms as ILW packages.
- It is anticipated that the collective dose rate conditions in the emplacement rooms can be managed by mixing lower and higher dose rate packages of the same type within the same rows of emplaced waste. Thus, it is assumed that mixing different waste types will not be required for the purpose of reducing dose rates.
- A capacity growth factor was applied to the emplacement room capacity to ensure that there is sufficient space to store the full volume of waste packages.
- The IC-18 T-H-Es and IC-2 Liners will have a room equipped with horizontal arrays made up of pre-cast reinforced concrete pipes surrounded by mass concrete to create the necessary permanent shielding. The pre-cast reinforced concrete pipes will be transferred underground in segments and assembled as formwork for the concrete array. This emplacement method has been retained from the Conceptual Design [R3], although it will be reviewed and potentially improved in future stages of engineering. To allow operation of the T-H-E Handler, gantry crane, and Horizontal Emplacement Machine (HEM) (used to insert liners into the array) within the same space, 48 m from the face of the last array to the room entrance is required.
- A sacrificial pallet will be used to transfer Resin Liners not requiring shielding and Resin Liner shells from Quadricells. Sacrificial racks will be used to transfer Tile Hole Liners and a lifting saddle will be attached to the Bruce B Steam Drum Segments. All of these items will facilitate transfer and emplacement using a forklift. Additional information regarding the sacrificial pallets can be found on drawings H333000-WP401-35-042-0001 to -0004.
- To minimise worker dose rates rooms will be generally filled starting at the furthest and working back in the direction of the Main Shaft. This will reduce the time operators will spend driving past rooms containing waste packages.
- Emplacement rooms will be filled based on the estimated schedule of emplacement.
- Bin-type LLW packages will only be stacked with packages that have same footprint.

Plan views of the emplacement room panels and associated room type distribution can be found in drawings H333000-WP408-20-042-0005 and H333000-WP408-20-042-0006. A summary of emplacement room profiles and their characteristics is provided in Table 6-5.

Room Profile	Waste Type	Groups[12]	Specific Waste Types	Width [m]	Height [m]	Rail / Gantry	Ventilation Ducts	Drawing Number (See Appendix E)
P1	LLW	A	Bin-Type Waste	8.6	7	No	1 Round	H333000-WP408-05-042-0001
P2	LLW / ILW	F	Bruce A Steam Generator Segments Encapsulated Tile Holes Tile Hole Liner Racks Unshielded Resin Liners Resin Liner Shield 2 Resin Liner Shells from Quadricells	8.6	6.35	No	2 Round	H333000-WP408-05-042-0002
P3	ILW	C,E, F	Unshielded Resin Liners Resin Liner Shield 1, 2, and 3	8.4	5.8	No	2 Round	H333000-WP408-05-042-0003
P4	ILW	C	ILW Shields Retube Waste Containers	7.4	6.5	No	2 Round	H333000-WP408-05-042-0004
P5	ILW	F	Pickering Steam Generator Segments Bruce B Steam Generator Segments	8.4	6.2	No	2 Round	H333000-WP408-05-042-0005
P6	LLW / ILW	B,D	Shield Plug Containers Heat Exchangers T-H-E Liners (in Concrete Arrays)	8.1	7.2	Yes	2 Square	H333000-WP408-05-042-0006

Table 6-5 – Summary of Waste Package Allocations to Emplacement Rooms

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[12] As described in Appendix D.

6.3.1.1 Profile 1 Rooms

The Profile 1 emplacement rooms are allocated for the Group A bin-type waste packages only. They are the most numerous rooms, as there is a very large quantity of these packages. One ventilation duct is utilised, removing the top corner package for some package types. The unassigned room for growth factor in Panel 2 is also to be a Profile 1.

6.3.1.2 Profile 2 Room

The first emplacement period requires one Profile 2 room, which is able to accept the tallest waste packages. These are the Resin Liner Shells from Quadricells and the Encapsulated Tile Holes, and require a minimum room height of 6.35 m. Two round ducts are utilised in order to maximise overhead clearance. The greater width of this room allows three-across placement for Steam Generator Segments from Bruce A.

6.3.1.3 Profile 3 Rooms

The Profile 3 emplacement room is optimised and used exclusively for the emplacement of Resin Liners. Both shielded and unshielded Resin Liners are placed in these rooms.

6.3.1.4 Profile 4 Rooms

Profile 4 rooms will be allocated Retube Waste Containers and ILW Shields. The 6.5 m height and two round ducts allows for stacking of two-high Retube Waste Containers and three-high ILW shields.

6.3.1.5 Profile 5 Rooms

Profile 5 rooms are used for Steam Generator Segments. The optimised width for this application is 8.4 m. The 6.2 m height allows for stacking of the Bruce B Head End segments on the Main segments.

6.3.1.6 Profile 6 Rooms

The Profile 6 emplacement rooms are connected to the embedded rail network and receive Group B heavy non-forkliftable packages and the Group D T-H-E Liners. Because these rooms remain open for an extended period of time, the room infrastructure and package integrity will need to be designed and controlled accordingly (see Section 10.1.3). A second set of embedded rails are also provided in these rooms for a gantry crane. The unassigned room for growth in Panel 1 is also Profile 6. This room would be capable of receiving any waste package from the inventory.

6.3.2 Integrated Waste Package Tracking System

When a package has been placed at its emplacement position, the IWTS will be updated using a portable barcode scanner unit. This unit would be able to scan the package barcode and allow manual input by the user which would be updated to the IWTS database at the end of the shift. Upon scanning, the package placement inside the emplacement room would be recorded and the package status would be updated to “emplaced”.

6.3.3 Group A

At the shaft station, these packages will be removed from the rail carts using a light duty forklift and placed in the staging area or taken directly to the emplacement room. There will be capacity for 6 of these packages at this underground staging area, and its use will be minimised.

To maximise the use of available space and ensure stability of the stacked packages within the rooms, each row of packages will only contain one type of package. This will be achieved during the planning of the transfer process. A typical stacking arrangement for Group A packages within the emplacement rooms is shown in Figure 6-5.

6.3.3.1 LLW Container Overpacks

The containers that are to be overpacked are the Ash Bins, ALW Sludge Boxes, Low Level Resin Boxes and about 10 % of the drum racks. The overpacks can be stacked three packages high in the LLW emplacement rooms.

Shielded overpacks may also be used to contain a small number of LLW containers that have dose rates higher than the WAC. However, the size and stacking of these packages have not been defined at this time.

6.3.3.2 Drum Racks and Bale Racks

OPG are currently assuming that 10 % of the drum racks will need to be overpacked for emplacement, but the remaining 90 % can be stored in the LLW emplacement rooms in stacks five racks high. Since Bale Racks and Drum Racks are essentially the same, the two package types can be stacked together provided the heavier Drum Racks are on the bottom. These two packages can also be stacked with old-style non-pro bins (NPB4).

6.3.3.3 Compactor Boxes

Compactor Boxes can be stacked five high in the LLW emplacement rooms.

6.3.3.4 Drum Bins

Drum Bins can be stacked five high in the LLW emplacement rooms. The bin tops have lids and can be stacked with new style Non-Pro Bins (NPB47).

6.3.3.5 Non-Pro-Bins (NPB4 and NPB47)

Non-Pro (non-processible) Bins can be stacked five bins high in the LLW emplacement rooms. The new style non-pro bins can be stacked with drum bins as the corner posts provide the structural strength and both package types have the same basic design and plan dimensions using corner posts. Non-Pro Bins will be covered with lids, which are not structural members, so other waste packages cannot be stacked on top of these lids.

6.3.3.6 Low Level Resin Pallet Tanks

Low Level Resin Pallet Tanks can be stacked three high in the LLW emplacement rooms.

Figure 6-5 – Perspective View of Emplaced Group A (Bin-Type) Waste Packages

6.3.4 Group B

The Group B packages on the rail cart are off-loaded from the cage in a similar manner to other packages moved by transfer rail. However, because forklifts are not used with these packages, the rail cart will not be off-loaded at the underground off-loading area. Instead, the rail cart will proceed on the extension of embedded rail leading to the access tunnel and into the Profile 6 emplacement room. As these rail carts will be self-powered using an electrical tether cord, several electrical connections will be provided en route to the emplacement room.

At the emplacement room, the package will be lifted off the rail cart by the gantry crane and stacked on the floor of the room. Heat exchangers will be stacked in pyramid-shaped pile two high (a row of three on the emplacement room floor and a row of two sitting on top). Support frames will be placed on the floor of the emplacement room to ensure that the bottom row cannot roll, providing a stable base for the top row of packages. While stacking the top row of heat exchangers, a remotely releasable sling arrangement will be used.

It is not possible to stack Shield Plug Containers due to their mass (28.6 tonne maximum) and the shape of the container. The top of the container is not flat, so smaller boxes cannot be stacked on top of them. Since there are only nine of these packages, these stacking limitations will, therefore, have minimal effect on the overall packing efficiency of the DGR. The gantry crane will be used to off-load the rail cart in the emplacement room.

6.3.5 Group C

6.3.5.1 Unshielded Resin Liners

There is capacity for two unshielded Resin Liners on the rail cart. On arrival at the station, these packages will be off-loaded from the cart by a light duty forklift and taken to the emplacement room.

While on an individual basis the unshielded Resin Liners can be handled and emplaced in the DGR without employing shielding, the accumulation of a number of these Resin Liners in a relatively small area within the confines of the emplacement room can, potentially, result in a dose field that exceeds allowable limits. This will be mitigated by mixing the higher-dose packages with the low dose packages in a way that is designed to use those low dose packages as shielding. Adequate planning will be required to ensure the proper availability and placement of the low dose packages in this procedure.

6.3.5.2 ILW Shields

In future, wastes that are currently being stored in the T-H-E Liners may be stored in the proposed new ILW Shields. They will be small, light-weight and stackable. It is estimated that there will be 7,383 of these new containers to be emplaced. On arrival at the underground station, a light duty forklift will remove these packages from the rail cart and stack them in the staging area or take them directly to the emplacement room.

ILW Shields will be stacked up to three high in a manner that will maximise utilisation of the available space in the emplacement room. The ILW Shields are stackable and are relatively small (1 m diameter and 1.7 m high) and will therefore be efficiently packed.

6.3.5.3 Tile Hole Liners

The Tile Hole Liners are smaller cylinders than the Resin Liners or the Encapsulated Tile Holes, and therefore there is more flexibility in the method of emplacement. However, because of their slender aspect ratio (ratio of 5:1), they will be placed on a rack that is compatible with inter-stacking of multiple racks. These racks will be off-loaded from the rail cart at the shaft station and transferred directly by the forklift to the emplacement room.

In the emplacement rooms the racks will be stacked three high (two double level racks and one single level rack) for a total stack height of five racks.

6.3.6 Group D

Similar to the Group B underground waste transport process, the T-H-E Handler will propel itself from the shaft station. The desired T-H-E Liner orientation for emplacement is the reverse to that how it was retrieved from the shaft. To correct the orientation, the T-H-E Handler is navigated into a switched turn-out, similar to the technique used for an automobile during a 2-point turn. The T-H-E Handler then proceeds into the emplacement room, still powered through the electrical tether. Once positioned inside the emplacement room, the awaiting gantry crane will be positioned over the T-H-E Handler to lift the Transfer Bell off the T-H-E Handler. With the Transfer Bell in an elevated position, the gantry crane will move the Transfer Bell to the awaiting HEM, which will push the T-H-E out of the shield and into a Concrete Pipe Array followed by a concrete plug to fully seal up the package.

The designated Profile 6 emplacement room will be equipped with horizontal arrays of T-H-E disposal tubes using pre-cast reinforced concrete pipes surrounded by mass concrete to create the necessary permanent shielding, as depicted in Figure 6-7. Each horizontal array will permit disposal of 30 T-H-E Liners in 0.69 m diameter by 11.8 m long holes created by the reinforced concrete pipes. Each horizontal array will be constructed, loaded with T-H-E Liners and closed prior to constructing a subsequent horizontal array. All 16 arrays will fit inside a single emplacement room.

Each array will be constructed by first building a steelwork lattice on which the pipes can be positioned, after which formwork will be erected at the front of the array and mass concrete poured into the void outside the pipes to provide stability and additional shielding to limit the "shine" dose from the accumulated packages in the previous array. The concrete caps, which will close the holes once the T-H-E liners have been pushed out of the Transfer Bell and into the pipe array, will be designed to ensure that the contact dose rate on the outside surface of the concrete array does not exceed allowable limits. This arrangement will provide adequate protection for the construction workers, who will build the next adjoining array.

The HEM unit, similar in function to the "Horizontal Emplacement and Retrieval Equipment" (HERE) used at the Waste Isolation Pilot Plant (WIPP) in New Mexico, will be positioned at the face of the horizontal array.

After the Transfer Bell is placed in a horizontal position in the HEM, the frame will be aligned in front of the horizontal tube designated to receive that specific T-H-E Liner. Shielding collars will be located at the transition from the positioning frame to the face of the emplacement array and at the rear of the shielded Transfer Bell. A hydraulic ram will be aligned at the rear of the shielded Transfer Bell and the shielded Transfer Bell end caps removed. The hydraulic ram will then push the T-H-E Liner into the tube and the disposal tube will be closed with a concrete cap.

The shielded Transfer Bell will be returned to surface to repeat the cycle with another T-H-E Liner from the WWMF. A side view of the HEM with the telescopic cylinder extended is provided in Figure 6-6.

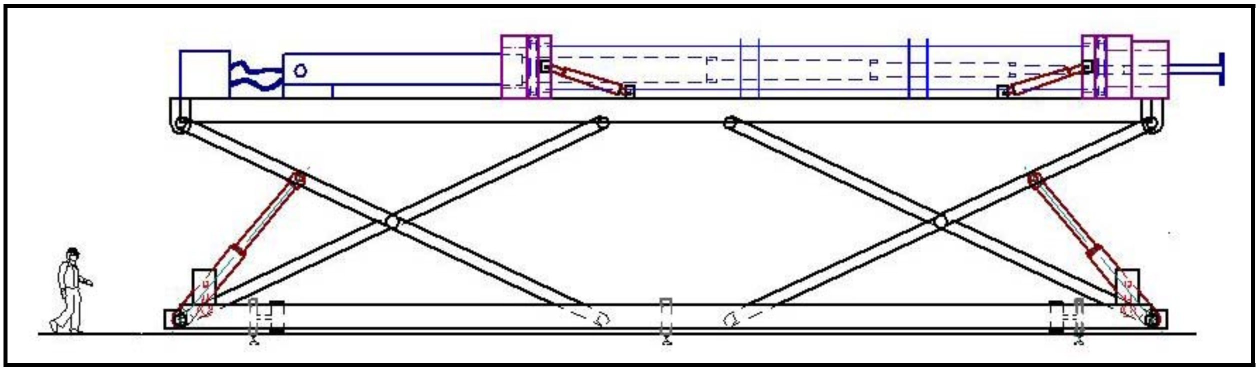

Figure 6-6 – HEM with Transfer Bell in Elevated Position

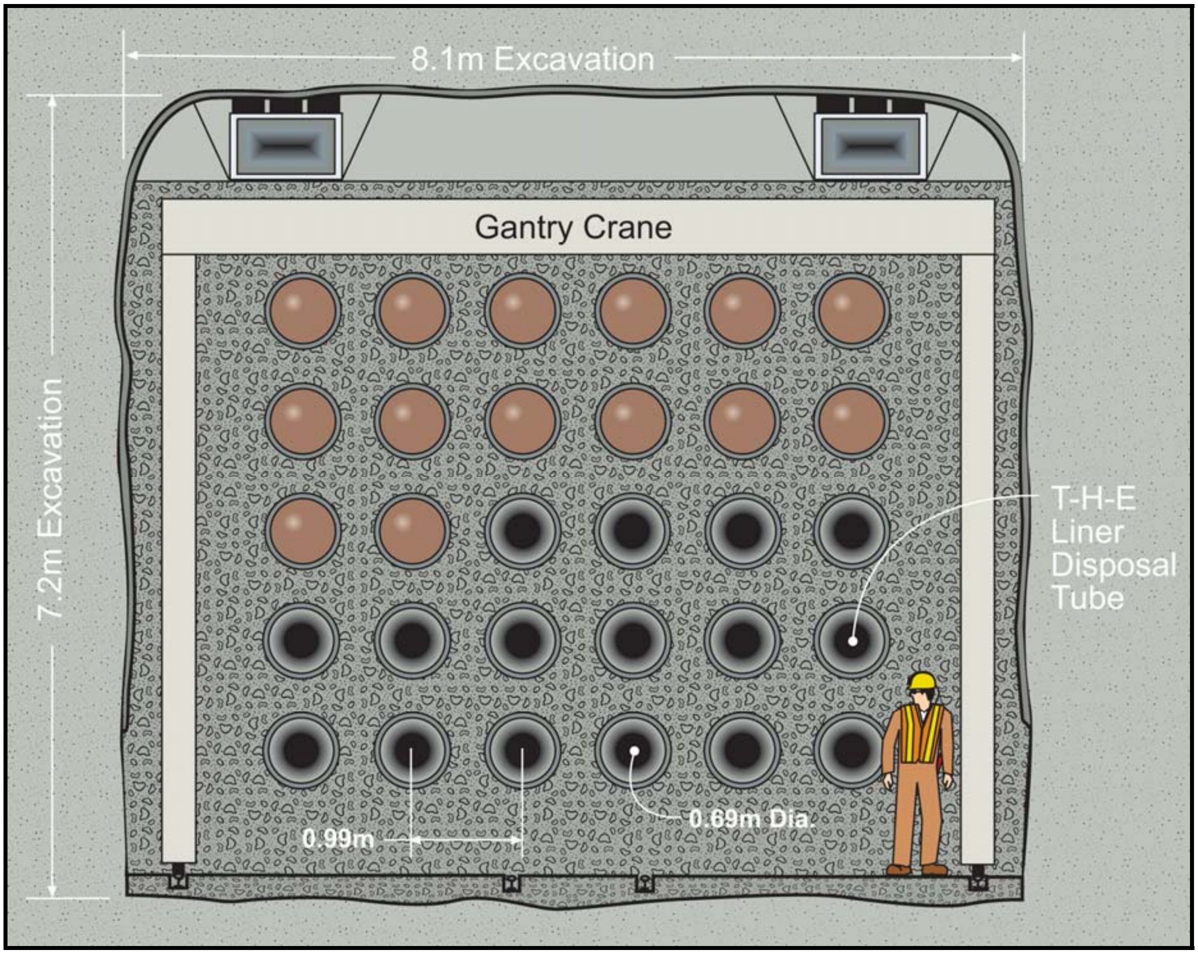

Figure 6-7 – Section View of Group D Emplacement Room

6.3.7 Group E

The fresh Resin Liners, after placement in the appropriate sacrificial pallet or shield, will form waste packages matching those in Group C (for those not requiring shielding) and Group F (for those requiring shielding). Underground handling of these packages is described in those respective sections.

6.3.8 Group F

6.3.8.1 Steam Generator Segments

All Steam Generator Segments are transported in the shaft using the rail cart. The package will be off-loaded using a heavy duty forklift, and the package will be transferred (without staging) directly to the emplacement room.

The only packages to be stacked are the Bruce B Head End packages, which will be placed on top of a Bruce B Main Section Segment. No other segments are planned to be stacked; however, future engineering phases may examine the potential to increase ILW emplacement room height to allow more segments to be stacked. Bruce B Steam Drum Segments will be emplaced on their round side with their cut ends perpendicular to the long axis of the emplacement room.

Source	Diameter (m)	No. of Segments @ Diameter	Row Axis (deg.)	No. per Row	Row Centre Lines (m)	No. of Rows
Bruce A	2.4	96	53	3	2.7	11
Bruce A	2.6	32	53	3	2.7	6
Bruce B	2.5	128	53	3	2.9	22
Bruce B	3.6	64	90	2	2.7	32
Pickering	1.8	144	90	3	1.9	32
Pickering	2.5	48	53	3	2.7	16

Table 6-6 – Emplacement Room Metrics for Steam Generator Segments

6.3.8.2 Encapsulated Tile Holes

Encapsulated Tile Holes (ETH) are large (4.6 m high), heavy, cylindrical packages. As they will be emplaced on their ends, nothing will be stacked on them. Positioning in emplacement rooms will be achieved in a similar manner to the Resin Liner Shields that contain two liners each (see Section 6.3.8.3). Tile Hole Liners are emplaced in the same room as ILW wastes.

6.3.8.3 Shielded Resin Liners

The Resin Liner Shields will only be transported one per cage trip on a rail cart. They will be off-loaded at the shaft station off-loading area by the heavy duty forklift and transferred directly to the appropriate emplacement room.

Shielded Resin Liners will not be stacked in the emplacement rooms. Rows of Resin Liners will contain only the same package types. However, as shown in Figure 6-8, the P2 and P3 profile emplacement rooms will contain alternating groups of shielded (and unshielded) Resin Liner types. The Shield 1 and Shield 2 packages will fit three across in each row. The smaller diameter Shield 1 packages will utilise a somewhat staggered approach to placement to increase the utilisation of space in the emplacement room. A rendered image of Resin Liners emplaced in an emplacement room in the repository is provided in Figure 6-9.

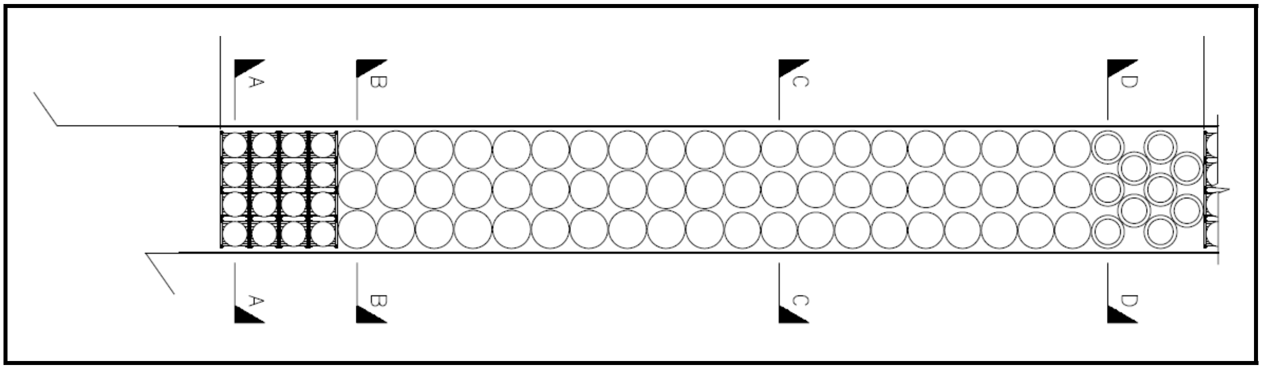

Figure 6-8 – Resin Liner Emplacement Room Arrangement

6.3.8.4 *Retube Waste Containers*

The Retube Waste Containers will be off-loaded from the rail cart by the heavy duty forklift and transferred by forklift to their emplacement rooms.

Retube Waste Containers are heavy, but have been designed to be stacked on top of each other. There are two types of container: the end fitting container and the pressure tube container. Both package types will be stacked two high.

Figure 6-9 – Perspective View of Emplaced Resin Liner Shield

7. Fire and Life Safety

The proposed DGR is unique in that it combines aspects of mining within a nuclear facility. The facility will consist of surface infrastructure and an underground facility. Fire and life safety requirements are of paramount importance and determine much of the principles and implementation of the design. There are two specifically different activities that will be associated with underground works for this facility: mining and construction of an underground facility, and emplacement of waste within the repository.

All nuclear waste management facilities fall under federal jurisdiction and therefore federal acts, regulations and codes will apply to the DGR facility, where they are relevant.

The DGR facility will be licensed in compliance with the Nuclear Safety and Control Act (NSCA) [R51] and its associated regulations, including:

- Class I Nuclear Facilities Regulations (SOR/2000-204) [R52].
- Radiation Protection Regulations (SOR/2000-203) [R53].
- General Nuclear Safety and Control Regulations (SOR/2000-202) [R54].

The DGR is defined as Class 1B nuclear facility under the NSCA and its regulations.

In accordance with Canadian Federal Regulation SOR/98-180 [R55], the responsibility for workplace health and safety at all OPG nuclear facilities, including OPG nuclear waste management facilities, has been delegated to the Province of Ontario. Therefore, workplace health and safety during the construction and operation of OPG's proposed DGR will fall under Ontario Occupational Health and Safety Act (OHSA) [R56], and its associated regulations. Labour legislation in the Province of Ontario (including OHSA) is enforced by the Ministry of Labour (MOL).

The construction of the DGR facility would be regulated under Ontario Regulation 213/91, Construction Projects [R57]. The DGR is not considered to be a “mine” under OHSA and, therefore, it is not a legal requirement to carry out any construction work in accordance the OMR [R48]. However, there are many aspects of the facility (e.g. hoists and shafts) that are not covered adequately in any regulations other than the OMR, and for this reason NWMO has decided to carry out construction work on the DGR facility in accordance with OMR where:

- These regulations are not in conflict with Construction Project regulations; and
- Application of these regulations will ensure worker health and safety.

7.1 Fire Safety

The design and operation of the DGR facility will be such that the risk of a fire occurring is minimised. Features of the DGR that lower the risk of fires include:

- Minimised use of combustible materials. Specifically, the shafts will be steel construction (timber construction underground will be limited to shaft guides in the Ventilation Shaft). Fire resistant cabling will be used and waste packages will be contained within non-combustible containers.

- There will be no diesel fuel storage on surface during operations. Fuel will be obtained from the existing storage facility at the WWMF.
- Underground, the amount of diesel fuel stored will be minimal, and the storage and fuelling facility will be a dedicated room with appropriate separations and fire protection systems.
- Diesel fuel will be transported underground in approved containers following appropriate procedures. No other packages, materials or personnel will be allowed in the conveyance while fuel is being transported.
- Propane storage on surface will be located away from the main (permanent) buildings and waste package handling routes.
- No explosives will be stored underground during operation of the DGR.

In addition to these items, the measures described in the following subsections will further mitigate the risk of fires at the DGR facility.

7.1.1 Fire Detection and Alarming

7.1.1.1 Surface Facilities

For the surface facilities, fire detection and alarming will be in accordance with the NBC [R36], OMR [R48] (for structures supporting the underground facility) and the National Fire Code (NFC) [R58]. Fire detection will be achieved using smoke detectors and manual pull stations in all surface buildings and activation / flow alarms on all automatic fire suppression systems listed in Section 7.1.2. Carbon monoxide (CO) detectors will be installed in the WPRB, Main Shaft Headframe and Emergency Diesel Generator building because of the use of diesel powered equipment in these areas. Audible and visual alarm signals, similar to those currently in use at the WWMF, will be activated when alarm levels are reached. Alarm signals will be routed to a fire panel that will transmit all alarm signals to the DGR control room on surface. Alarm signals will also be transmitted to an underground monitoring terminal and the control room at the WWMF for monitoring during DGR off-shift periods. It will be possible to identify which sensor has detected an alarm condition and its location.

7.1.1.2 Underground

Underground, fire detection will be achieved using smoke and carbon monoxide detectors at key points in the facility. The points will include:

- All underground infrastructure rooms situated in the Shaft and Services Area.
- The exhaust ventilation air ducts exiting each emplacement room (whether under construction, empty and awaiting start of emplacement operations, during emplacement operations, or full of waste packages and shielded).
- In the DGR air intake plenum at the exit from the Heater House to the west of the Main Shaft.
- At the discharge of the main exhaust ducts at entry to the upcast Ventilation Shaft.

This will provide levels of redundancy so that any failure of one instrument will not enable a fire to remain undetected. All in-duct monitors will be located external to any emplacement room shielding walls and will be accessible via flanged ports for ease of maintenance. All instruments that will be behind a closure wall will be disconnected prior to installation of the closure wall. A description of the locations and times of construction of the shielding and closure walls is given in Section 10.5.

All instrumentation signals will be displayed locally and also be transmitted to a fire panel underground. The fire panel will output all status and alarm signals to the DGR surface control room, an underground monitoring terminal and WWMF via the instrumentation network. It will be possible to identify which sensor has detected an alarm condition and its location in the repository. The underground monitoring terminal will display both surface and underground alarms signals. If alarm levels are reached, audible and visual alarms, similar to those currently used at the WWMF, will be automatically activated.

However, in underground mining-type environments, audible alarms may not be fully effective on their own due to the nature of the environment. The “stench gas” system used in Ontario mines is well proven. A stench gas is a foul-smelling but safe gas that is injected into the downcast ventilation air stream and compressed air line, which quickly and effectively reaches workers in all parts of the facility. Therefore, once a fire condition has been detected, the stench gas will be released into the intake adit at the Main Shaft and compressed air system.

In addition to the visual and audible alarms and the stench gas system, all workers underground will carry personal radios that communicate over the leaky feeder communication system. In the event of an emergency, a call will be put out over the radio system from the surface control room to provide an additional means of alerting personnel of the emergency.

7.1.2 Fire Suppression

7.1.2.1 Surface Facilities

Fire suppression for surface facilities will be achieved through the use of fire extinguishers, fire suppression systems, and fire hose systems.

All surface facilities will be equipped with hand-held fire extinguishers that are mounted on clearly demarcated boards. These fire extinguishers will be located at regular intervals throughout the buildings and will be selected to suit the potential fire hazards for the location.

Fire suppression systems will be installed in buildings as listed in Table 7-1. At this stage, the recommended fire suppression systems are for the general coverage required for buildings. In later stages of engineering, each building will be evaluated and zoned such that areas within each building may have different fire suppression requirements due to the potential fire hazard or to protect equipment and personnel.

Building	Recommend Fire Suppression
Ventilation Shaft Headframe	Sprinkler System
Ventilation Shaft Hoist House	Hoses / Fire Extinguishers
Ventilation Shaft Exhaust Fans	Fire Extinguishers
Main Shaft Headframe (including Main & Auxiliary Koepe friction hoist Rooms)	Sprinkler System
Electrical Room	Automatic dry chemical system
Amenities Building	Sprinkler System
Offices	Sprinkler System
Main Control Room	INERGEN System (INERGEN is a clean-agent fire suppression system that is people-safe and environmentally friendly)
Waste Package Receiving Building	Sprinkler System
Heater House & Intake Fans	Fire Extinguishers
Air Compressor Plant	Hoses / Fire Extinguishers
Electrical Substation	Fire Extinguishers
Emergency Diesel Generator	On board 'Ansul' system for diesel engine. Automatic dry chemical system for building

Table 7-1 – Surface Buildings Recommended Fire Suppression Systems

A fire water main will be installed around the surface facility complete with fire hydrants. The fire water main will be connected to the existing Bruce Power fire water system. Water for all fire suppression systems will be supplied by the fire water main.

Fire fighting services to the DGR facility will be provided by the Bruce Power Emergency Response Team (Bruce Power ERT), similar to the practice at the WWMF.

7.1.2.2 Underground

The principle for underground fire suppression is that there will be no water sprinklers or fire hose systems installed underground as their use could create a large volume of contaminated water that would have to be collected and treated before it could be released from the DGR facility. In addition, the use of water for fire suppression would introduce high levels of humidity, which could negatively affect the long-term integrity of other waste packages, structures and ground supports, which are not exposed to or close to the fire.

Underground, fire suppression will be achieved by the following:

- Hand-held fire extinguishers, which are mounted on clearly demarcated boards in or close to all rooms in the Shaft and Services Area. At any workplace that is not a fixed location, workers must have a fire extinguisher available and close at hand (e.g. mounted in the cab of their vehicle or if the location is reached on foot, the extinguisher will need to be carried there by the worker).
- A foam-based suppression system is recommended for the maintenance facility, fuel storage and fuelling areas, since there will be no fire water provided underground. Because the maintenance facility, the fuel storage and fuelling area are adjacent to each other, a single fixed pipe foam system will be installed to provide coverage to both rooms. This meets the requirements of a fire suppression system for flammable liquid storage areas and service garages as stipulated in the OMR, §28 (2) [R48].
- To fight a fire in a waste-filled emplacement room, mine rescue teams (see Section 7.2) will erect a temporary barrier wall over any openings in a shielding wall, or over the entire drift cross-section, to isolate the oxygen supply to the fire so it will burn out. In the event that a fire occurs near the entrance of an emplacement room, it may be necessary to construct a barrier wall in the emplacement room panel access tunnel. Exhaust ducting from each emplacement room will be equipped with a fire rated damper than can be closed off remotely from the DGR control room once the mine rescue team have assessed the situation, accounted for all personnel underground and indicated it is safe to do so. Installing fire suppression equipment in the emplacement rooms would be ineffective due to the size of the rooms and the storage arrangement of packages. In addition, it would not be practically possible to maintain any fire suppression equipment installed inside the emplacement rooms once it is filled and a shielding wall is erected.
- A portable, skid mounted dry chemical system will be provided to aid mine rescue teams in fighting fires underground. The dry chemical system will be stored underground and moved into place using a forklift when required.
- All diesel equipment will be equipped with automatic, foam-based fire suppression systems. These systems are mandated for diesel-powered equipment operating underground and will be triggered on detection of any fire on the vehicle.

In addition to fire suppression systems, fire doors will be installed at the Main Shaft station, the maintenance facility and the fuel storage and fuelling area, in compliance with §39 of the OMR [R48]. A normally open, manually operated fire door will be installed on each side of the Main Shaft station as shown in Figure 7-1. These doors will be closed by the mine rescue team if required. The maintenance facility and the fuel storage and fuelling area will each have a fire rated, overhead, roll-up door that will automatically close when a fire is detected. Each of these roll-up doors will also have a fire rated man door installed adjacent to it to ensure personnel are not trapped in the room if the overhead door were to close.

7.1.3 Emergency Ventilation Controls

Ventilation fans and dampers underground will be controlled remotely from surface. For safety reasons, no alteration or disruption to the ventilation system would occur until all underground workers are accounted for and the mine rescue team has assessed the situation. If, after reviewing the situation with appropriate personnel, it is decided that adjusting the ventilation system will aid in the rescue of personnel or controlling the fire, underground fans and dampers will be operated from surface. However, standard procedure will be to leave the ventilation system untouched in an emergency situation. For further details on the operation of the ventilation system during normal operation, refer to Section 5.1.

7.1.4 Refuge Stations

The first line of protection for underground workers is refuge stations. There will be two permanent refuge stations in the Shaft and Services Area, one in the West Services Tunnel and the other off the Main Shaft Access Tunnel near the ramp to shaft bottom (see Figure 7-1 and Figure 7-2). There will always be two escape routes for any worker to reach a refuge station in the Shaft and Services Area.

Within the emplacement panels and rooms there is only one exit route to reach the shafts. Therefore, to provide the same level of protection, a portable refuge station will be positioned close to the far end of each panel access tunnel (see Figure 7-2), which will again provide any workers with two routes of escape to a refuge station. As the access tunnels are advanced during development, these portable refuge stations will also be advanced beyond the opening of the furthest developed emplacement room. The refuge stations will never be located close to any significant combustible mass, so that any fire will not reach the proximity of the refuge station and cause any risk to the protection of workers inside the station. It is good underground practice to ensure that the location of all refuge stations takes this need into account, and areas around these installations will be demarcated to prevent such a situation.

In total there will be two permanent and two portable refuge stations.

Each refuge station will be sized to accommodate the maximum expected number of employees and visitors underground, and will be designed to be compliant with the requirements of the OMR [R48]. Fire clay will be stored in each refuge station and will be used to seal doors from the inside to prevent the ingress of smoke and gases during a fire. Refuge stations will also be equipped with a communication line to surface, a compressed air supply and a supply of bottled potable water. With these measures, the refuge stations will meet the requirements set out in the OMR, §26 [R48].

Refuge stations will also be equipped with radiation protection equipment for monitoring and decontamination of staff in the event of an accidental radiation release from any waste packages, if one should occur.

Refuge stations will be designed to accommodate up to 25 persons, allowing for about 15 underground workers during construction or 10 during operation, plus any potential visitors. A general arrangement of the permanent refuge stations is shown in drawing H333000-WP402-05-042-0001.

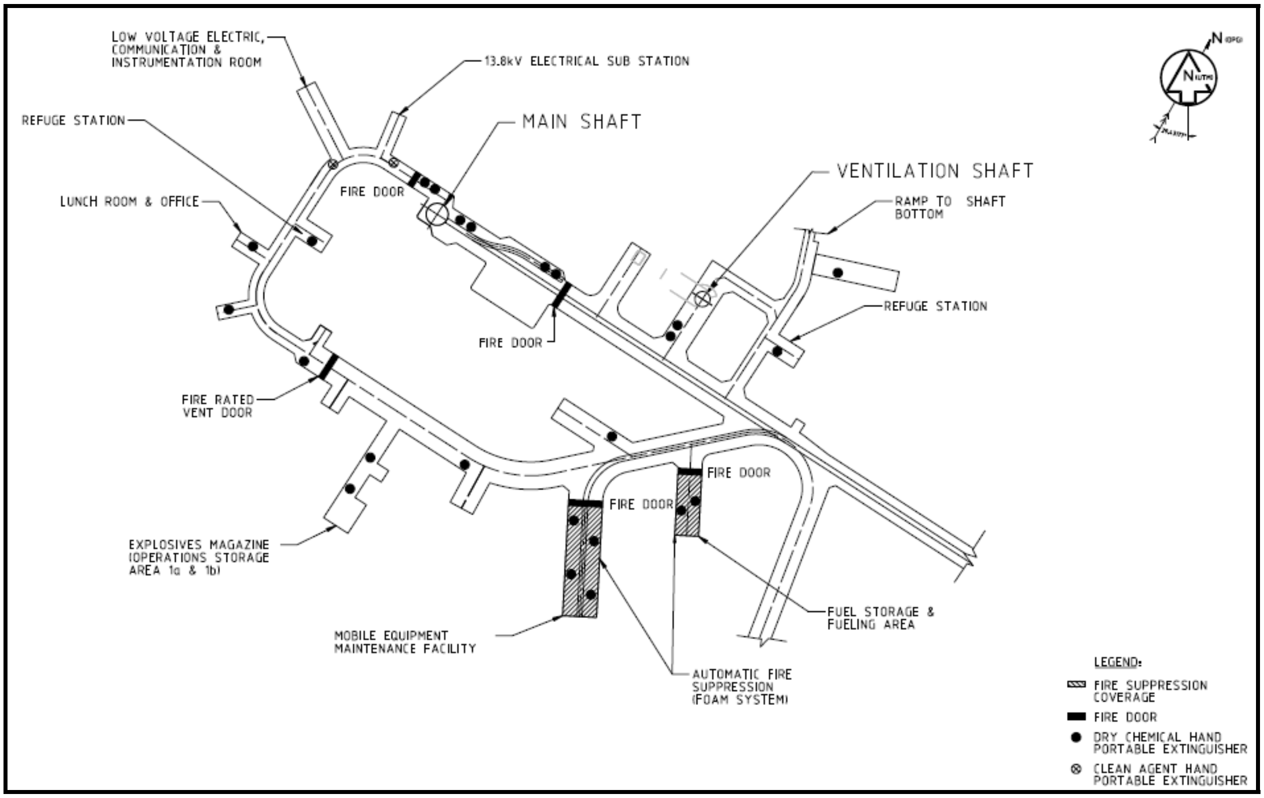

Figure 7-1 – Locations of Fire Protection Equipment in the DGR Underground Service Area

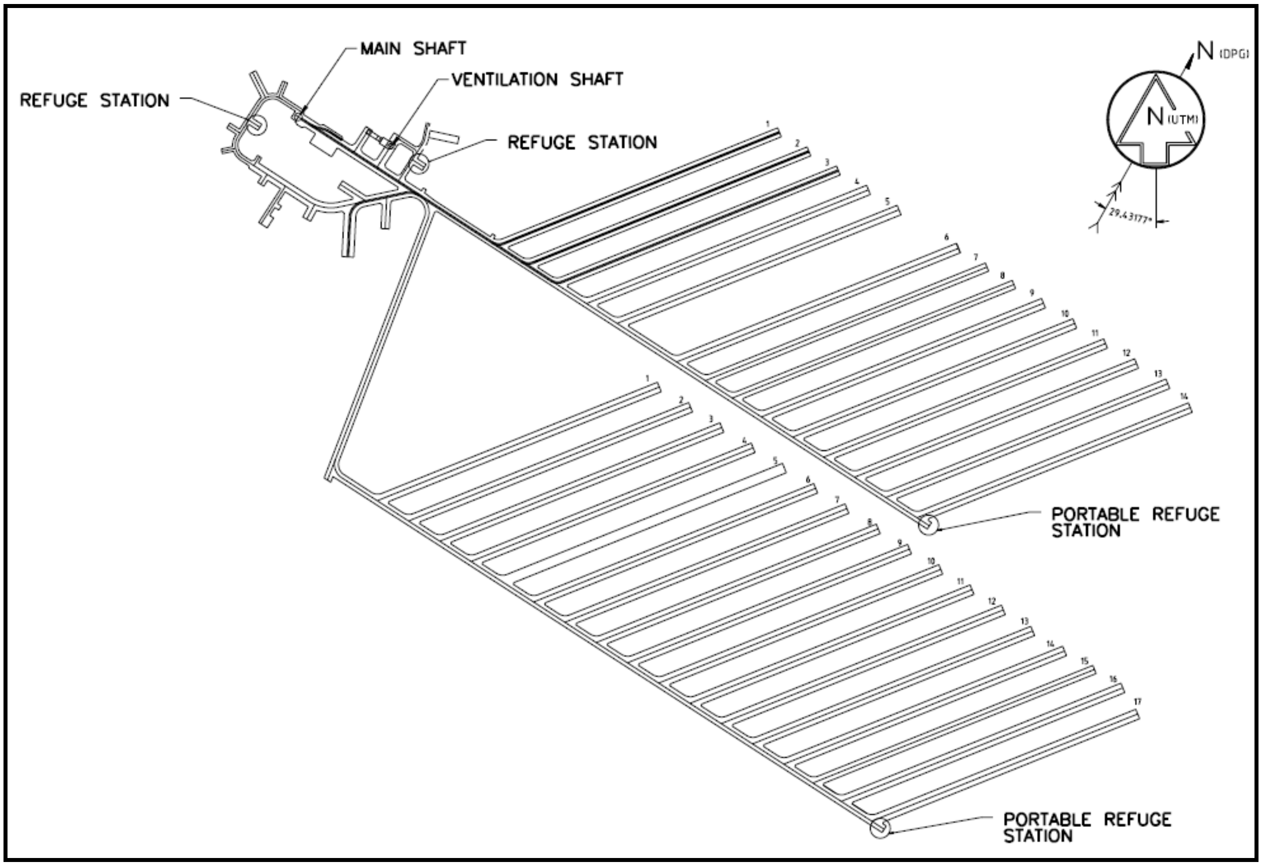

Figure 7-2 – Refuge Station Locations

7.2 Emergency Response

For the purpose of this report, this sub-section only covers emergencies that require personnel to evacuate to assembly areas or refuge stations. More detailed procedures for dealing with other emergency situations, such as personnel injuries, will be developed in later stages of engineering. The emergency response plans are summarised in this section and will also require further refinement in later stages of engineering.

Three general types of events which could occur that will require a planned emergency response are:

- Fire.
- Rock fall.
- Radiological contamination.

The DGR will require a Mine Rescue Team to respond to fire and rock fall events. Because of the anticipated low work force at the DGR, there may not be enough personnel on surface to constitute a Mine Rescue Team. Therefore, arrangements will be investigated for the Bruce Power ERT to serve as the Mine Rescue Team for the DGR site. The Mine Rescue Team will be provided with special training from the Ontario Mine Rescue division of the Mines and Aggregates Safety and Health Association (MASHA) six times per year. The DGR Mine Rescue Team will have its own equipment so that it can immediately respond to a fire or other non-radiological emergency. Mine rescue policy requires a back-up team to be on site before the first team is sent underground, and a third team must be on site before the second team can go underground, in accordance with the MASHA Mine Rescue Handbook [R59]. Therefore, reliance on the neighbouring mines (salt mine rescue teams) in the region will be necessary. This network is the basis upon which mine rescue works with any team from any mine in Ontario being available if required.

DGR personnel will be expected to respond to radiological contamination events as described in Section 7.2.3.

7.2.1 Fire

For the purpose of this report, the following events have been grouped together under a fire event as they will have the same emergency response procedure:

- Fire.
- Explosion.
- CO alarm.
- Explosive gas monitor alarm.

7.2.1.1 Surface

In the event of a fire alarm on surface, all personnel will evacuate the buildings to the nearest assembly area outside. The Bruce Power ERT will be dispatched to the site to evaluate the situation and fight the fire if required.

During a fire event on surface, personnel underground will be instructed to report to the refuge stations to ensure all personnel are accounted for and in case action is required by the personnel.

7.2.1.2 Underground

Immediately on initiation of a fire alarm (or carbon monoxide or explosive gas alarm), all workers will report to a refuge station. Any workers in the vicinity of a visible fire who are in a position to assess the risk and use the nearest available fire extinguisher, while remaining upstream of the fire, will do so if it can be safely done. If the fire cannot be extinguished promptly or safely, these worker(s) should also report to a refuge station.

The repository controller will call out the Mine Rescue Team and the nearest off-site Mine Rescue unit, with whom the DGR is affiliated. No workers would leave the refuge stations until the rescue team has determined that it is safe to do so, either by extinguishing a fire or by identifying a safe route to whichever shaft is in the fresh air supply and uncontaminated by any combustion products.

7.2.2 Rock Fall

In the unlikely event of underground workers trapped by a rock fall or other extraordinary event (e.g. any shaft conveyance event that renders the personnel cage inoperable) management of the facility will coordinate the response and utilise the mine rescue teams to assess the situation and recommend a recovery strategy depending on the circumstances.

7.2.3 Radiological Contamination Event

It is expected that the existing OPG Spill Management and Response Procedure [R60] will be updated to include the DGR facility. This procedure will require that trained DGR personnel, with the use of appropriate PPE (in most cases, protective suits and breathing air, which will be available on surface for the team), execute any clean up procedures as required. A separate procedure will need to be developed for an underground radiological contamination event due to the risk of contamination being spread downstream by the ventilation system and the need to evacuate personnel to surface.

7.2.3.1 Surface

When radiological contamination is found or detected on surface, personnel in the area will move away from the location to minimise exposure. A trained clean-up crew, consisting of DGR personnel, will be dispatched to contain and clean the contamination following the Spill Management and Response Procedure [R60].

7.2.3.2 Underground

A radiological contamination event is of a greater concern underground due to the enclosed nature of the facility and the potential for contamination to be spread downstream in the ventilation air stream where personnel may be exposed.

The ventilation system is active and could pick up radioactive particles (e.g. ash) from a spill. In a contamination event, such as a dropped box, the workers will evacuate the area (upwind, if possible) to a refuge station. A plan for evacuation of the personnel and clean-up will be developed (similar to, or within an updated version of, the Spill Management and Response Procedure [R60]). It is anticipated that DGR staff from surface, with protective suits and breathing air and directed by the health physicist, would travel underground to evaluate the extent of the contamination and to identify a safe evacuation route for personnel in refuge stations. Once personnel are safely evacuated to surface, clean-up will commence. In a situation where an evacuation route is not available, clean-up procedures would commence first. Where necessary to prevent the further spread of contamination, the DGR controller may adjust the ventilation system after all personnel have been accounted for and it is safe to do so.

7.3 Zoning

The transfer of waste from its current storage locations to the DGR will be handled in a controlled and safe manner at all times. Existing WWMF site procedures will be modified to add the steps necessary to move the waste from current locations to the DGR WPRB and DGR specific procedures will be developed for transfer of waste to the DGR operating level, transfer to the emplacement rooms and emplacement. Waste containers will be inspected on arrival at the WPRB to ensure that the containers are free of surface contamination and that the radiation field is within the applicable limits [R37]. Containers that do not meet the requirements will be returned to the point of origin for rectification. A system of radiological monitoring and controls will in place at DGR facility to protect the health and safety of workers.

7.3.1 Radiological Control

OPG's system for managing health and safety includes a set of documents intended to guide management action and control facility operations:

- Level 1 Policy on Health and Safety heads this set of documents.
- Level 2 Policies on Leadership, Assessment, Exposure Management, Hazard Management and Information Management provide further corporate direction.
- OPG's Radiation Protection Policies and Principles [R61] is a concise set of objectives, principles, responsibility statements and policies that govern radiation protection at OPG. It is the controlling document for all other radiation protection-related documents in the corporation and is intended for use by OPG staff responsible for preparing or issuing policies, practices and information related to radiation protection. It also applies to those who are responsible for making decisions that may impact on radiation protection and for which more detailed instructions do not exist.
- OPG's Radiation Protection Requirements [R62] for general use and OPG's Radiation Protection Regulations. Both documents are referred to by the acronym RPRs.

The RPRs comply with the NSCA [R51] and its associated regulations. OPG's RPRs apply the intent of the principles and recommendations established by the International Commission on Radiological Protection (ICRP). They also take into account the knowledge gained through OPG's long experience in designing, constructing and operating a nuclear-electric generation program. At all stages of the life cycle, documents subsidiary to the Radiation Protection Policies and Principles and the RPRs will be developed to specify local application and practice. The Radiation Protection Policies and Principles and the RPRs, and their subsidiaries, stand in addition to and are not substitutes for documents of similar purpose governing conventional health and safety. These guidance principles will be directly applied to the operation for the transfer, handling and emplacement of the low- and intermediate-level waste in the DGR.

A key practice in maintaining control of radiation exposure and contamination is through the use of zoning. The following excerpt from OPG's RPRs [R62] defines the zones that will be applied to the DGR facility:

> *"5.1.3 Zone 1*
>
> *Zone 1 is a clean area which is not a radiological zone and may be considered the equivalent of a normal public access area.*
>
> *5.1.3.1 Zone 1 shall not contain radioactive sources other than those found in normal industrial establishments, or those specifically approved for use in applications such as training and demonstrations.*
>
> *5.1.3.2 Fixed contamination levels in Zone 1 shall not exceed the established contamination limit for Zone 1 surfaces [4.8.2]. No detectable loose contamination shall be permitted in Zone 1 [4.8.2].*
>
> *5.1.3.3 Zone 1 shall have a very low probability of cross-contamination from adjacent areas and shall have a low general radiation background, not exceeding the established limit [4.7.1.1].*
>
> *5.1.4 Zone 2*
>
> *Zone 2 is a radiological zone that is normally free of contamination but is subject to infrequent cross-contamination due to the movement of personnel and equipment from contaminated areas.*
>
> *5.1.4.1 Zone 2 is normally free of radioactive sources other than those found in normal industrial establishments, or those specifically approved.*
>
> *5.1.4.2 Zone 2 shall have a low general radiation background.*
>
> *5.1.4.3 All materials being moved from Zone 3 to Zone 2 should be monitored.*
>
> *5.1.4.4 Where appropriate, local containment systems shall be used when radioactive systems in Zone 2 are opened or leaking.*
>
> *5.1.4.5 If local containment systems are not used, a rubber area shall be established when radioactive systems in Zone 2 are opened or leaking, and it shall be removed promptly when work on the system is complete.*
>
> *5.1.5 Zone 3*
>
> *Zone 3 is a radiological zone which contains systems and equipment which may be sources of contamination.*
>
> *5.1.5.1 Areas of Zone 3 which are normally frequented should have no detectable loose contamination [4.8.3.1]. When loose contamination is detected, decontamination shall be considered in light of factors such as occupancy levels, degree of hazard and probability of spread. Decontamination should be carried out at the discretion of either line management or the Responsible Health Physicist or delegate."*

Figure 7-3 – Radiological Zoning for DGR (from OPG's RPRs)[13]

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[13] All section references in Figure 7-3 refer to the section numbers within [R62].

The preliminary design of zoning for the DGR is based on the following guidance:

- Zoning a facility has to take into account the transfers and movement of personnel and materials and work activities associated with the DGR. Although zoning of the surface and underground sections of the DGR will be finalised at a later stage of the design with involvement of the appropriate Health Physics personnel, it is important to consider zoning within this report to determine its impact on the overall facility design.
- All spaces within the DGR facility perimeter will be classified in accordance with criteria for potential contamination in OPG's Radiation Protection Requirements for Nuclear Facilities [R62].
- Appropriate personnel and materials / equipment monitoring devices are required at each inter-zonal boundary.
- Movement from the existing storage areas at the WWMF to the WPRB buildings takes place through a Zone 2 area of the WWMF.
- As required by the DGR WAC [R37], waste packages will be delivered to the DGR without any loose contamination on the exterior of the packages.
- The DGR zoning proposed in the following Sections 7.3.2 and 7.3.3 was requested by OPG during the OPG design review with NWMO of the preliminary DGR facility design held in March 2010.

7.3.2 Zoning – Surface

The proposed zoning of the DGR surface facilities and the surface Amenities Building are shown in Figure 7-4 and Figure 7-5, respectively. In general:

- All surface facilities within the fenced perimeter of the DGR, including the Amenities Building, Offices & Main Control Room, will be classified as Zone 2.
- The lamp room and decontamination room in the Amenities Building will serve as the main entrance from the WPRB. A whole body monitor (WBM) and small articles monitor (SAM) will be located in the lamp and monitoring room.

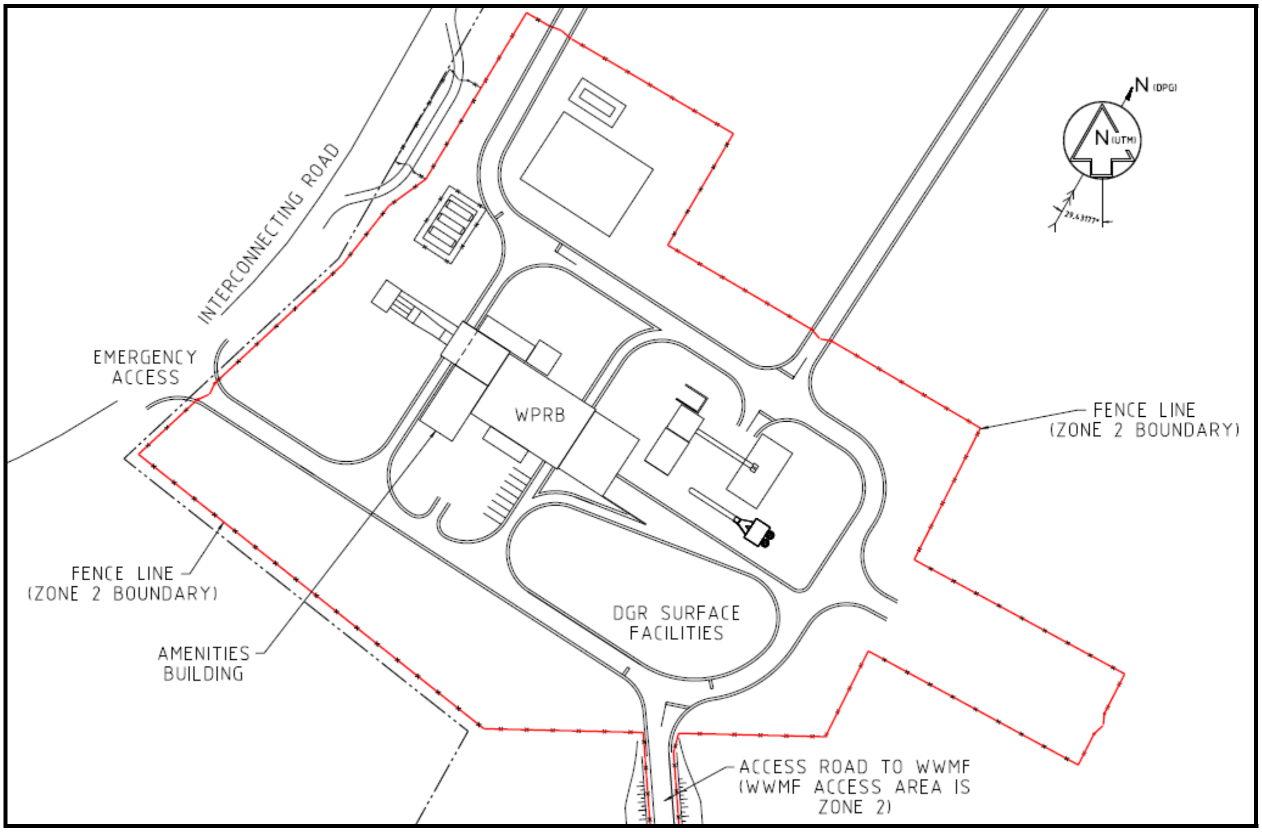

Figure 7-4 – Plan of DGR Surface Facility Showing Radiological Zone 2

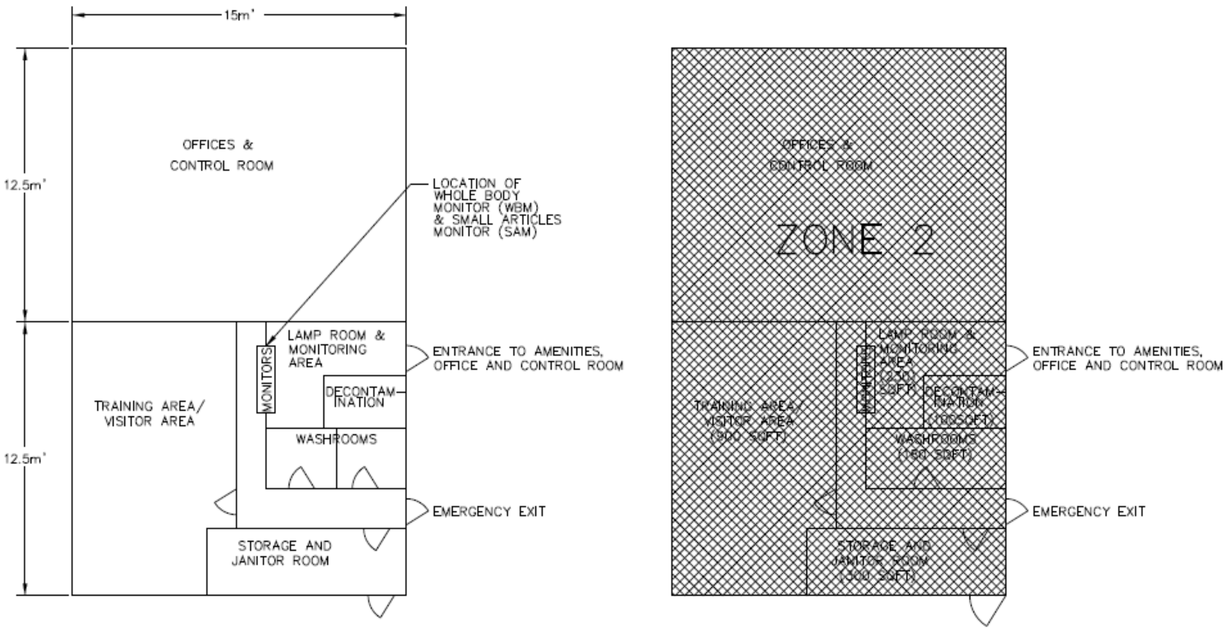

Figure 7-5 – Plan of Amenities Building Showing Radiological Zone 2

All employees and visitors will park and use the change room facilities at the WWMF. After changing into appropriate PPE, employees and visitors will be shuttled to the DGR Amenities Building. Personnel reporting to the Amenities Building, Offices or Main Control Room will use the WBM and SAM to enter this area. All other workers report to their work areas as required. Lockers will be available in the Amenities Building for visitors to store personal items while they go underground. Personnel may exit the DGR facility and return to the WWMF without monitoring. Personnel will be shuttled back to the WWMF where they will use the existing monitoring procedures to return to the change rooms and leave the site.

For emergency purposes, the DGR facility may be accessed through the gates in the fence leading from the Interconnecting Road or through the WWMF access road, as shown in Figure 7-4. In such a situation, vehicles will be required to exit the DGR property through the WWMF following existing protocol to ensure the vehicles are not contaminated.

7.3.3 Zoning Underground

The underground Shaft and Services Area will be classified as Zone 2. OPG currently operates Zone 2 Lunch Rooms. Based on this precedent, the underground Lunch Room will be classified as Zone 2. To ensure no contamination enters the underground Lunch Room, a WBM and SAM will be installed outside the entrance, as shown on Figure 7-6. Personnel will monitor all small articles in the SAM and pass through the WBM prior to entering the Lunch Room. Regular checks will also be done within the Lunch Room to test for contamination.

Waste transfer vehicles will enter the Zone 2 at the DGR from the Zone 2 at WWMF and the Zone 2 in the Shaft and Services Area will be an extension of Zone 2 at the surface.

The two panels of emplacement rooms will be classified as Zone 3. The proposed boundary between Zone 2 and Zone 3 is shown on Figure 7-6; it will be a "virtual" boundary in that there will no physical barriers at this location. The location of this boundary may be adjusted in the future to a more optimal location. All equipment and personnel moving from Zone 3 back into Zone 2 will be checked for contamination. A WBM and SAM will be located at this boundary. A portable, hand-held device will be used to check for contamination on equipment.

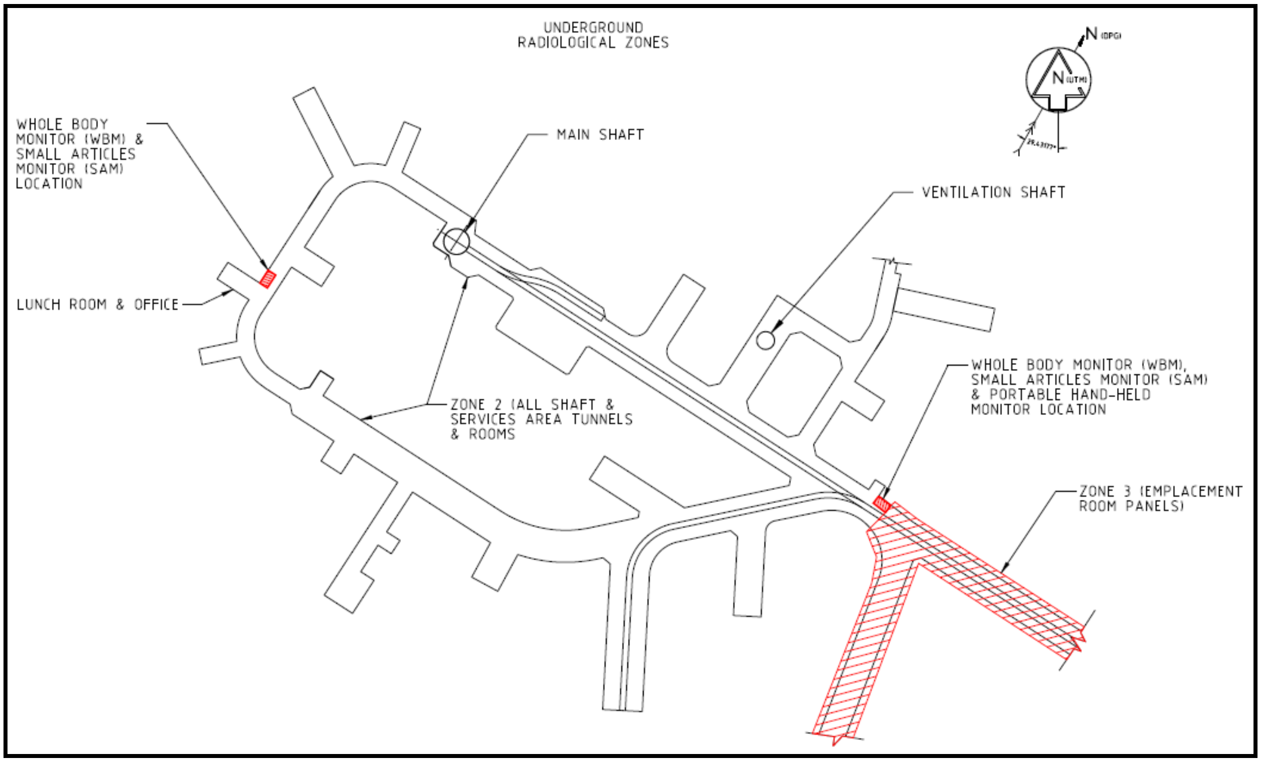

Figure 7-6 – Plan of Underground Service Area Showing Radiological Zones

7.3.4 Control of Radionuclides in Air During Operations

The ventilation system is designed to ensure that the airborne contamination of radionuclides from the waste and any naturally occurring gaseous radionuclides (i.e. radon) are maintained sufficiently low within the access tunnels and the emplacement rooms, both those being filled with waste packages and those that are shielded, to ensure a safe working environment.

Additionally, all air that has passed over waste packages in the emplacement rooms will be captured in steel ducts that run all the way back to the upcast Ventilation Shaft, into which they will discharge the used air. In this way, all areas of most frequent occupancy (i.e. access tunnels, non-operations rooms and the front sections of emplacements rooms being filling with waste packages) will always be in a clean air stream.

The Main Shaft Headframe will be under positive pressure relative to the Main Shaft. One of the benefits of having a positive pressure imparted to the Main Shaft Headframe is to prevent contamination from a spill at the collar from entering the Main Shaft and being drawn in the underground excavations.

Fresh air will enter the underground facilities through the Main Shaft. The ventilation system will direct the air flow around the West and South Services Tunnels, away from the waste package staging area, and into the emplacement room access panels and emplacement rooms. A small quantity of fresh air will be directed through the waste package staging area, exhausting directly into the Ventilation Shaft via the access tunnel to the shaft bottom ramp. All exhaust air will be ducted back to the Ventilation Shaft. Thus, any potential airborne contamination in the tunnels will be directed away from the Main Shaft and all exhaust air that has passed through emplacement rooms will be contained in duct work, minimising the risk of exposure to personnel. The underground duct work will be under negative pressure relative to the tunnels, thereby preventing any potential contamination from leaking out of the ducting. The exhaust air from the Ventilation Shaft will be monitored for contamination at surface. For more details on the design and operation of the ventilation system, refer to Section 5.1.

7.3.5 Decontamination

Routine decontamination of underground equipment is not anticipated since one of the key DGR WAC [R37] is that there shall be “no loose contamination” on waste packages. In the event that decontamination underground is required the following facilities will be provided:

- The maintenance facility will contain materials and equipment that can be used to decontaminate forklifts or other mobile equipment that is discovered to be contaminated underground.
- Materials will be provided next to the WBM underground that will be used to contain contamination so that personnel may be transported to surface to the decontamination facility.
- The refuge stations will be equipped with radiation protection equipment for monitoring and decontamination of staff in the event that an accidental radiation release from any waste packages should occur.

Detailed procedures for decontamination underground will be developed in future stages of engineering.

7.4 Radiation Monitoring

Radiological monitoring will be provided at the DGR facility to ensure radiation levels in air and water are within regulatory limits. The monitoring program would be designed to periodically measure the air and water concentration of one or more of the following parameters: tritium, carbon-14 and / or gross beta / gamma. Air monitoring would take place at strategic locations underground to confirm air concentrations of radionuclides are below acceptable limits at various work locations (e.g. shaft service area, access tunnels, active emplacement rooms). Air monitoring would also occur at key exhaust air points (e.g. within ducts at exit from waste-filled rooms and at Ventilation Shaft exhaust location at surface) to ensure release of radioactivity into surface air environment is below acceptable limits.

Water monitoring would take place at strategic locations underground and at surface to confirm water concentration of radioactivity is below acceptable limits. For example, the concentration of radioactivity could be monitored in the underground shaft sump water and in the run-off from the SSFA (see Section 4.2.3.10.2). The underground waste water, that would be delivered to surface in totes (see Section 8.1.2), would be sampled and analysed for radioactivity, as necessary, to ensure proper treatment and disposal of this wastewater.

Reference should also be made to Section 8.12 for additional information about overall environmental monitoring program. The details of the radiological monitoring requirements, including monitoring parameters, locations and frequency of measurements, will be detailed in the next stage of engineering.

7.5 Underground Air Quality Monitoring

Air quality in the underground DGR will be monitored to ensure that the health and safety of personnel within the DGR is not compromised. The monitoring system will ensure:

- Levels of noxious gases do not exceed regulatory limits.
- Levels of explosive gases do not exceed explosive limits.
- Temperature and humidity of the DGR remains acceptable for both personnel health and infrastructure integrity.
- Airflows remain adequate in active work areas.

During construction, an air monitoring station will be installed at the base of the Ventilation Shaft to measure levels of carbon monoxide (CO), nitrogen dioxide (NO_2), methane (CH_4) and air flow volumes from all ducting and access tunnels exhausting into the Ventilation Shaft. Since propane is being used as the medium for combustion, CO will be monitored on surface at the discharge of Main Shaft Heater House. In addition, the temperature (wet bulb and dry bulb) of air entering the intake air plenum at the Main Shaft will be monitored. All measurements will be monitored remotely on surface and will also be available to be monitored underground by hooking up to the system at the Low Voltage Electrical, Communication and Instrumentation Room, if required.

During operations, air monitoring will be installed as shown in drawing H333000-WP402-75-042-0001. Airflow, CO and NO_2 measurements will continue to be taken at the Ventilation Shaft. Explosive gas monitors will also be installed to monitor a range of potential gases, including methane and hydrogen. The monitoring installed at the Main Shaft during construction will also be left in place for operations. In addition, a monitoring station will be installed at the base of the Main Shaft to measure temperature (wet bulb and dry bulb) and RH. Emplacement room exhaust air ducting will be equipped with combustible gas monitors to monitor a range of potential gases, including methane and hydrogen. All measurements will be monitored remotely on surface and will also be available to be monitored underground, if required.

Propane, which has a similar agent to the stench gas used to alert underground workers of an emergency, will be used on surface at the supply air heaters. In the event of a significant release of propane that enters the shaft ventilation system, workers will smell the propane and will not be able to differentiate it from stench gas. In this event, workers would proceed to the positively pressurised refuge stations where no gas will be able to accumulate, providing a safe refuge from the gas. The likelihood of a large amount of propane going down the shaft is low since most of the gas from any propane leak will likely be burned at the Heater House burners.

At times, dust may be liberated during construction and operation of the DGR. Both area (stationary) and personal gravimetric monitoring for dust will be undertaken at intervals and locations to be determined.

8. Support Services and Infrastructure

This section describes the support services for surface and subsurface facilities, and infrastructure that will be provided to facilitate both DGR construction and operations activities.

8.1 Underground Dewatering

The goal of dewatering systems is to carry away water as it collects in the underground sections of the DGR and discharge it to surface into the DGR storm water management system. The below-grade nature of underground workings necessitates that all dewatering infrastructure be configured to handle water ingress from:

- Construction water used during the underground openings development cycle.
- All operations and maintenance activities such as dust suppression and water from washing equipment.
- Leakage of groundwater into the two shafts.
- Groundwater ingress into tunnels and emplacement rooms on the DGR horizon (expected to be very low volume due to low permeability of host rock).
- Condensation water from exhaust air.

The dewatering infrastructure must also be capable of handing the potentially large water inflows due to the following malfunction scenarios:

- Rupture of water pipes in Main or Ventilation Shafts.
- Failure of shaft liner.

Groundwater ingress into the shafts will largely depend upon the performance of the shaft liner in the upper 200 m of each shaft (see Sections 2.5.2 and Section 4.3.6.1.4). Although the design goal for this liner will be a dry shaft, some minor leakage is still to be expected. The dewatering system has been designed based on an assumption that there would be a small steady-state leakage into each shaft.

The condensation water from exhaust air is a potential water source caused by adiabatic decompression and associated cooling of humid air as it is drawn up the Ventilation Shaft. The actual volume of water collecting at the Ventilation Shaft bottom will be dependent upon several factors, including ambient surface humidity and temperature conditions and the intensity of underground humidity sources.

The potential volume of water resulting from a ruptured pipeline will be minimised through the use of excess flow control valves installed in the water handling lines feeding the shafts. These valves are used to detect a flow condition associated with a ruptured pipe and will automatically shut off the flow in the unlikely event of a pipe rupture.

To ensure a robust design of the dewatering system, the following features will be included in the dewatering systems:

- Redundancy of systems such as power systems, pumps, and pipelines.
- Sump capacity to allow temporary build-up of water.
- Sump overflow configuration to allow non-critical sumps to discharge in a controlled manner to other sumps.
- Sufficient spare capacity to handle the sum of all foreseeable ingress scenarios.

8.1.1 Repository Development and Construction

The dewatering system will be implemented in stages as the DGR is constructed. Water collected for discharge during construction activities can be typified as containing suspended solids, dissolved solids, and petroleum residues as a result of the operation of mechanised drilling equipment and rock blasting. All underground discharge water will be sent for appropriate treatment at the available surface facilities.

During shaft sinking, permanent dewatering infrastructure is not available and it will be necessary to handle rock excavation and ingress water in the sinking buckets (see Section 4.3). Dewatering activities will occur on an as-required basis, depending on the realised inflow rates and activities at the given time. At surface, water from buckets will be pumped into a truck or discharge line for appropriate treatment.

Upon completion of the vertical development, the shaft dewatering pipelines will become available for use and the sinking buckets will no longer be used for this purpose. At this time the permanent dewatering pumps will be installed and commissioned for use during lateral development. They will be positive displacement plunger-type pumps and are, thus, suitable for pumping dirty construction water discharge.

While performing lateral development of the DGR, temporary sump facilities will be utilised by the contractor to allow some degree of settling and removal of the larger rock particles. Removing a large portion of the settled material underground will minimise wear and maintenance of the dewatering pumps and clogging of surface treatment facilities. The relatively low volume of these collected fine rock particles will be handled by dumping them into the development waste rock stream.

8.1.2 Operations

During repository operations, the dewatering system will have two separate streams. The first will handle wash-down water from the Wash Bay sump, which may be contaminated with oil, soap and other petrochemicals. Due to the relatively clean nature of the underground spaces during the operations stage, the wash bay is expected to be used relatively infrequently. This water will be pumped from the wash bay’s local sump into totes and taken to the surface via the Main Shaft cage and sent for treatment.

The second stream will handle all other water. This includes water flowing from the Main Shaft, Ventilation Shaft, Panel 1, Panel 2 and the Shaft and Services Area as depicted in the repository dewatering collection and handling schematic in Figure 8-1. Any water collected in sumps at each of these locations will be pumped to the Dewatering Sump, located on the DGR level near the Ventilation Shaft and then pumped to the surface via a positive displacement pump through the Ventilation Shaft discharge column. A back-up discharge column will also be provided in the Main Shaft. More details are shown on the Drainage and Dewatering System Process Flow Diagram (refer to drawing H333000-WP409-50-030-0002).

To minimise potential contamination, the underground mobile equipment maintenance workshop and the Fuel Storage and Refuelling Bay will each be equipped with a containment sump instead of gravity draining into the Services Area collection sump. These sumps will be suitable for containing any accidental fluid spills, such as fuel, oil, or engine coolant. After a spill, any captured fluids would be pumped into a tote on the DGR level and then taken in the Main Shaft cage to surface for appropriate treatment.

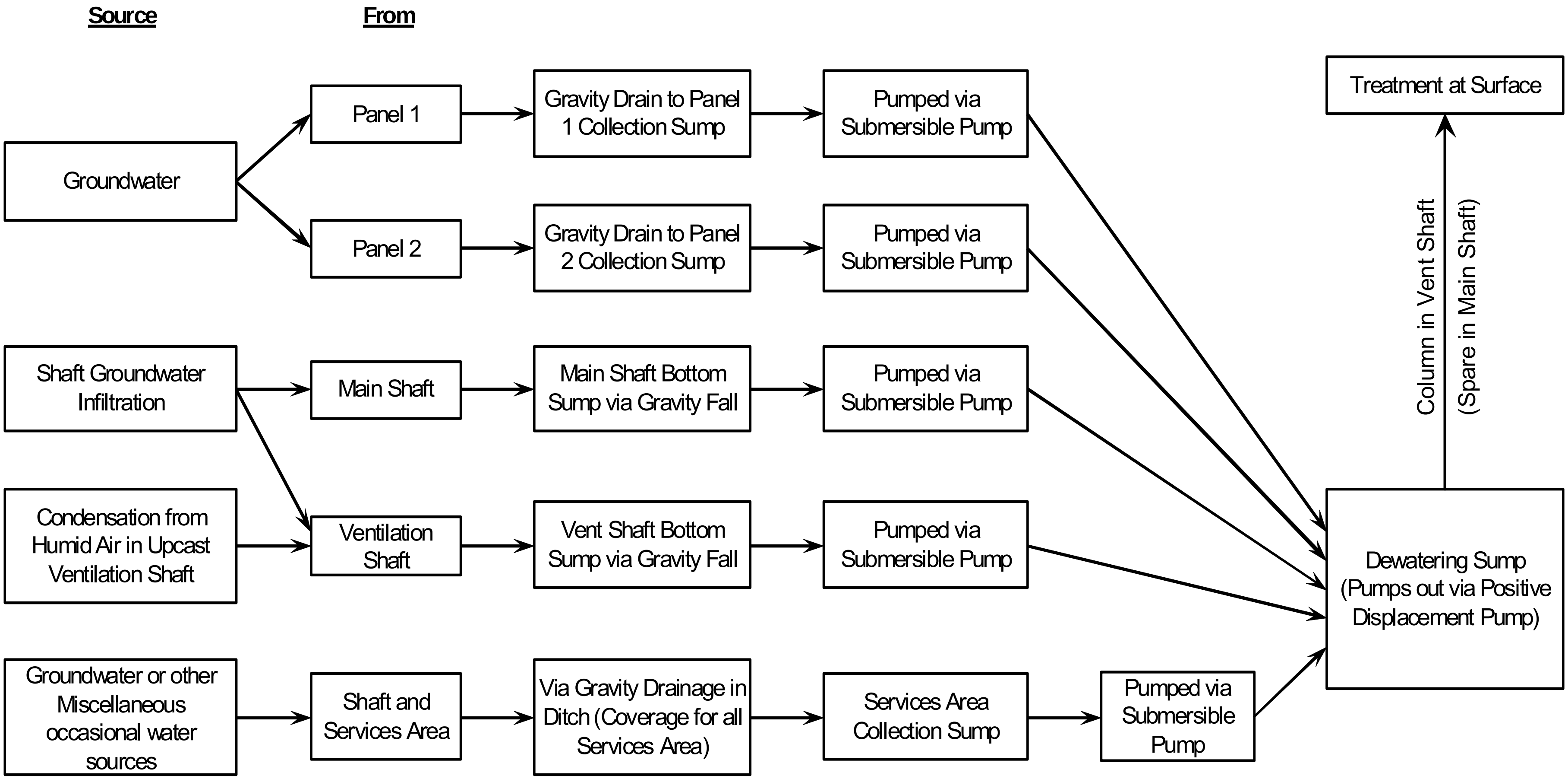

Figure 8-1 – Repository Dewatering Collection and Handling Schematic for Operations

8.1.3 Flow Rates

The design flow rates are the estimated normal maxima and do not include for any inrush volumes caused by cracking of a shaft liner, pipe column failure, or other emergency event.

During construction, the maximum flow rate is expected to be approximately 5.4 L/s, and made up of:

Infiltration from groundwater into two shafts	1.3 L/s
Condensation in the Ventilation Shaft (after DGR ventilation circuit establishment)	1.0 L/s
Water from lateral development mining	3.1 L/s

During operations, the maximum flow rate expected is estimated at 2.3 L/s, made up of:

Infiltration of groundwater into the two shafts, and collection in Main and Ventilation Shaft Sumps	1.3 L/s
Condensation water collected in the Ventilation Shaft Sump	1.0 L/s

- Water infiltrating into underground openings at repository level and collected in Shaft and Services Area, Panel 1 and Panel 2 Collection Sumps (very low volume assumed).

The aforementioned condensation water rates are considered to be conservative.

The DGR dewatering infrastructure design allows for an inrush event of up to 15 L/s and any amount in excess of this is considered to be very unlikely. In the remote event that one of the shaft liners fails and there is large inflow, the dewatering system will have sufficient capacity to handle inflow at rates up to 15 L/s, until repair work can be performed to reduce inflow rates below the design rate.

On the basis of a 20% utilisation during construction and 10% utilisation during operations, it has been assumed that wash-down water collected at the Wash Bay Sump will amount to a maximum of 1,700 L/day during construction and 850 L/day during operations. This wash-down water would be handled in totes and kept separate from water collected in Dewatering Sump.

8.1.4 Sump and Pump Design

The Dewatering System consists of seven separate sumps. Table 8-1 lists the minimum sump capacities required. The sump capacities listed do not incorporate the water in-rush scenario; however, the capacity of the shaft bottoms and the shaft bottom ramp can be used for emergency and temporary water storage in the remote event of a major in-rush, which would provide considerable storage volume.

Each sump will have a “live volume” and an “emergency capacity” associated with its design. The live volume of each sump refers to the volume of water that will collect and be pumped during the typical pumping cycle, noting that the sump does not need to be full before the pump is initiated. The “emergency capacity” refers to the total water holding capacity of the sump, which would only be used if the pump was unable to keep up with the water inflow rate for some reason such as electrical or mechanical failure.

Name	Location	Water Sources	Sump "Live" Volume (L)	Minimum Emergency Capacity (L)
Ventilation Shaft Sump	Bottom of Ventilation Shaft	• Infiltration from groundwater. • Condensation in Ventilation Shaft.	32,000	141,000
Main Shaft Sump	Bottom of Main Shaft	• Infiltration from groundwater.	32,000	55,000
Panel 1 Collection Sump	Panel 1 Entrance	• Groundwater from Panel 1.	335	670[14]
Panel 2 Collection Sump	Panel 2 Entrance	• Groundwater from Panel 2.	335	670[14]
Wash Bay Sump	Shaft and Services Area	• Wash-down water from the Wash Bay.	3,000	N/A
Services Area Collection Sump	Shaft and Services Area	• Gravity Drainage Ditch from Shaft and Services Area.	335	670[14]
Dewatering Sump	Top of Ramp to Shaft Bottoms	• Ventilation Shaft Sump. • Main Shaft Sump. • Panel 1 and Panel 2 Sumps.	32,000	196,000[15]

Table 8-1 – Summary of Sump Capacities

Each sump will be equipped with redundant water level instruments, which will transmit the level of water in the sump to the Main Control Room. The pumps will be arranged to run automatically, but may also be manually started from the control room or locally.

The sump design will take into consideration the cleaning of collected sediments and thus all sumps will be accessible and maintainable. The sump being cleaned will need to be pumped empty and the incoming line will be locked out as required. To handle sediment material, manual cleaning via pressure washer and industrial vacuums will be used as appropriate.

The Main Shaft and Ventilation Shaft bottoms will each be connected by a cross-cut to the ramp from the DGR level, at which a sump will be constructed to collect any groundwater ingress, which will be pumped to the Dewatering Sump. Each shaft bottom sump will be equipped with one operating and one stand-by submersible pump configured to allow quick change over (i.e. turn of a switch). The Ventilation Shaft bottom sump will also collect any condensation that forms within the shaft.

Sump pumps will run once the sump level reaches its sump "Live" capacity. In the remote event of an inrush scenario, a single Main and a single Ventilation Shaft pump would direct flow to the Dewatering Sump where the two positive displacement pumps would work in parallel to transfer water to the surface. The design capacity for the pump flow required for the Main Shaft, Ventilation Shaft and Dewatering Sump pumps will be based on the amount needed to accommodate a 15 L/S flow in addition to the normal flow. The design flow rates for the main pumps are given in Table 8-2.

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[14] The 670 litre capacity is considered a minimum practical size for this sump.
[15] This sump will be designed to overflow to the Main Shaft and Ventilation Shaft bottom sumps in a safe manner.

Any groundwater coming from the emplacement rooms will gravity drain into the Panel 1 and Panel 2 Sumps where the fluid will be pumped out with a submersible pump to the Dewatering Sump.

The Services Area collection sump will handle miscellaneous occasional water sources that collect in the general gravity drainage Shaft and Services Area ditch. A submersible pump will be used to pump any water that may collect to the Dewatering Sump.

Pump Name	**Number of Pumps Running**	**Pump Design Flow (L/s)**
Main Shaft Sump	One	20
Ventilation Shaft Sump	One	20
Panel 1 / 2 Collection Sump	One	1
Services Area Collection Sump	One	1
Main Dewatering Sump	One	11
	Two	22

Table 8-2 – Pump Design Flows

The Dewatering Sump's pumps will be installed on permanent concrete foundations. The two pumps will be positive discharge plunger pumps, such as Gardner-Denver GD-205T models, which are ideally suited to this high-static head application. One pump will normally operate with the second acting as a stand-by in the event of failure of the first pump or to supplement pumping capacity to clear any excessive short-term in-flow of water. Each pump will be rated to pump at a rate of 11 L/S. The full pumping capacity of each system with both pumps operating in parallel would be 22 L/S, which will provide adequate capacity for the estimated water inrush event.

The submersible pumps at the shaft bottoms, panel collection, and wash bay sumps are typical to industrial and mining applications. These relatively small and rugged pumps have integral motors, frames, and inlet screens. These pumps are simply lowered directly into the sump using an overhead winch and they are easily replaced as required.

8.2 Potable / Industrial Water

Water connection to WWMF for operations has not yet been confirmed. A nominal 600 m distance has been assumed at this level of study to cover the estimated distance required.

Industrial water is required at the underground Repository for the following uses:

- Construction activities including drilling, dust suppression, and wash-down.
- Operations activities, primarily wash-down at various areas of the Repository.

Industrial water will be supplied to the underground using a heavy-wall 100 mm diameter steel pipeline in the Ventilation Shaft. A spare column will be installed in the Main Shaft for use as a backup during maintenance. At the base of the shaft, a pressure reducing valve (PRV) will be used to reduce the static pressure to a safe working pressure. Steel pipes with a nominal diameter of 50 mm will then carry the water around the Shaft and Services Area and through each panel access tunnel. Water will be provided in the emplacement rooms during construction stages and then removed before operations commence. Down-pipes will be provided at regular intervals and at each ancillary room to provide access for hose connections as required.

Potable water will be made available in bottles or jugs to all personnel in the underground areas for both drinking and hand washing. Bottled water will be available at various locations including the lunchroom. The underground hand washing stations will be similar to those used in mining operations, where the washing stand is integrated with a small reservoir, pump, and water heater. The reservoir filled using typical 18.5-litre drinking water jugs.

8.3 Compressed Air

One Air Compressor Plant building will be constructed on surface to provide compressed air to the DGR site, both for surface and underground during operations. The plant will include two 186 kW constant speed rotary screw air compressors. The compressors will be electrically powered and air cooled. Associated with the compressors are a wet air receiver, pre-filters, desiccant dryers, after-filters, dry air receivers and condensate treatment oil separators. Desiccant dryers will be installed in order to help prevent moisture and corrosion issues in the compressed air distribution system.

One compressor will operate to meet demand[16] at any given time and one compressor will be on stand-by. The two compressors will be set at lead-lag sequence of operation and will automatically rotate as the lead compressor periodically. The air quality is suitable both for the refuge station emergency use and for air tools under cold weather conditions. One compressor will be available to be driven by the Emergency Diesel Generator power during an electrical power disruption.

Energy saving skids will be installed on each of the two compressors to collect heat from cooling exhaust air for plant heating during the winter heating season.

The compressors will be housed inside an acoustic enclosure in order to reduce the environmental noise level. Spread footing foundations will be suitable for the Air Compressor Plant. Compressed air lines will be buried between the Air Compressor Building and both the WPRB and the Ventilation Shaft Headframe.

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[16] Compressor capacity will be 0.52 m^3 of atmospheric air per second at 830 kPa.

Compressed air will be supplied to the underground repository from the surface compressors, at a nominal pressure of 830 kilopascals. Redundant 150 mm pipes will be used (one in each shaft) with a receiver unit near the shaft stations. A 100 mm pipeline with frequent down-pipes will service both the underground Shaft and Services Area and each panel access tunnel, allowing compressed air to be used at any of the ancillary rooms and at the entrance to any emplacement room. This steel pipeline will be securely hung to minimise the potential for movement, even in the event that it is accidentally struck by equipment. All components of the compressed air system will be accessible for inspection and replaceable if required. Water traps and purge valves will be fitted at suitable points close to a sump to allow maintenance personnel to purge any water that accumulates in the system underground.

8.4 Electrical

8.4.1 Electrical System Description

Class 4 electrical power will be supplied to the facility by a 44 kV high voltage transmission line originating from the Hydro One substation at Douglas Point. The 44 kV transmission lines will terminate at the main substation located at the north corner of the DGR Surface Facility.

The main substation will contain incoming 44 kV protection, redundant 44 kV / 13.8 kV step down transformers and 13.8 kV distribution equipment. Each transformer will be capable of supplying the full operational load of the DGR. The 13.8 kV distribution equipment will be designed as a main-tie-main arrangement so that it will have the ability to isolate one transformer for maintenance or failures and still power the full operational load of the DGR via the other transformer. The 13.8 kV distribution equipment will be the primary distribution point for 13.8 kV to major loads located on surface and underground.

The Main Shaft hoist, Ventilation Shaft hoist and large power distribution transformers are major surface loads and will be supplied at 13.8 kV. The large distribution transformers will step down 13.8 kV to 600 V. The 600 V system will supply the surface MCCs. Among other electrical power users, the surface MCCs will feed:

- Mine air Intake Fans.
- Mine air Exhaust Fans.
- Air compressors.
- Overhead electric cranes.
- Surface workshop and offices.
- Small power distribution transformer for lighting, receptacles, and other facility service loads at 110 VAC.

Power will be fed down the two shafts at 13.8 kV and will terminate at the shaft substation on the repository level. Shaft power cables will be redundant Hi-Tensile Verlok® (or Client approved equivalent), which meet the Insulated Cable Engineers Association (ICEA) mining standards' safety factors and are approved for shaft use by CSA (Canadian Standards Association) and MASHA. Each cable consists of three individual stranded copper conductors, which are shielded and insulated with cross-linked polyethylene (XLPE). The full cable is armoured with interlocked galvanised steel and encapsulated with a flame-retardant polyvinyl chloride (PVC) outer sheath suitable for hazardous locations to provide protection from mechanical damage, prevent electrical discharge and minimise the fire risks.

The shaft substation will distribute 13.8 kV to portable MPC's and the repository level double-ended substation. Two portable MPC's will be installed at appropriate positions in the DGR and moved as excavations advance and as operations retreat back towards the shaft substation. Portable MPC's are used to minimise voltage drops over long distribution distances in underground openings and step the voltage down from 13.8 kV to 600 V. The 600 V system will be used to power the mine development equipment and emplacement room lighting skids. The double-ended substation will power large 600 V loads and will feed the underground MCC. Among other electrical power users, the underground MCC will feed:

- Auxiliary ventilation fans.
- Sump pumps.
- Dewatering pumps.
- Small power distribution transformer for lighting and receptacles.

Lightning protection will be designed and installed according to CSA standards as stipulated in the national building codes. The requirements for lightning protection on the NWMO site will be determined according to CAN/CSA-M421-00 "Use of Electricity in Mines" and CAN/CSA-B72-M87 "Installation Code for Lightning Protection Systems".

8.4.2 Electrical Power Loads

The connected loads are given in Table 8-3 for both surface and underground power users. The total connected load for the facility is estimated to be approximately 9,965 MVA.

Surface		**Underground**	
Main Shaft Hoist	3,300 kVA	Shaft Sump Pumps*	80 kVA
Ventilation Shaft Hoist*	1,700 kVA	Dewatering Pumps*	250 kVA
Main Shaft Aux Hoist*	160 kVA	Underground Ventilation Fans	540 kVA
Mine Air Intake Fans	100 kVA	Jumbo Drilling Machines	450 kVA
Mine Air Exhaust Fans	240 kVA	Rock Bolting Machines	225 kVA
Air Compressors*	430 kVA	Shotcrete Machine	100 kVA
Lighting and Misc Low Power Equipment (*50% Emergency)	100 kVA	Lighting and Misc Low Power Equipment (*50% Emergency)	60 kVA
Misc 600V Loads	350 kVA	Misc 600V Loads	200 kVA
20% Growth Factor	1,300 kVA	20% Growth Factor	380 kVA
Total Surface Connected	7,680 kVA	Total Underground Connected	2,285 kVA
Total (Surface & Underground): 9,965 kVA			

*** indicates loads that are connected to the diesel generator**

Table 8-3 – Electrical Power Loads

8.4.3 Emergency Power

An Emergency Diesel Generator, complete with load bank, will be installed to assure safety in the event of a grid power failure. Preliminary calculations indicate a generator capacity of approximately 1,750 kW to serve the site loads that are essential for personnel safety and to maintain overall conditions in a satisfactory state. The rating of the diesel generator will be finalised in future stages of engineering to be adequate for all emergency loads. The diesel generator will be located at the surface substation and will feed equipment through the cables and switchgear used for normal operations. The diesel generator will not support continued waste transfer and emplacement operations. The only loads that will be served by the diesel generator are:

- Ventilation Shaft hoist at a reduced speed of 3 m/s, which will be used as the second egress to remove personnel from underground to surface.
- Main Shaft Auxiliary hoist.
- Main Shaft Koepe friction hoist brakes and controls to allow for controlled lowering of the cage via gravity and brakes and not by the motor. It should be noted that because the Koepe is a ‘balanced hoist’, such gravity winding is only possible in the event the cage is ether lightly loaded (with only personnel) or fully loaded with a heavy waste package load.
- Sump and dewatering pumps.
- One air compressor.
- Emergency lighting and communications in the repository and on surface.

Diesel powered emergency generators are commonly used at underground mining operations in Ontario. This generator will power up critical components within 30 seconds of an unscheduled power outage. Capacity for the diesel fuel storage system for the Emergency Diesel Generator is driven by the risk of any sustained severe weather occurrence, but may be minimised with the 10,600 litre tank, which is part of the generator installation, and a secondary fuel supply available at the WWMF or elsewhere on the Bruce nuclear site. Specialised controls and switchgear are used to initiate the generator start up and shed non-critical loads during an outage, as well as allowing an uninterrupted switchover when the supply grid is re-energised.

During a utility power outage, only one hoist would be allowed to run at any one time to limit the rated power of the installed generator. All such heavy power users would request power from the Surface Control Room Operator, who would sequence usage of power. This method of control during power interruptions is common practice in mines.

Only one diesel generator will be provided. Mines do not normally have more than one emergency generator, as this provides the redundancy necessary to guard against electrical power supply failures. Having two generators would be providing triple redundancy; risk assessments for mines have not found this to be necessary.

Major maintenance on electrical systems and the Emergency Diesel Generator will normally be carried out during off shifts (e.g. weekends and afterhours). Minor maintenance can be performed during working hours if easy and quick reconnection and start up can be achieved. Additionally, the generator will be tested off line regularly, and at least once per year the mains power would be deliberately disconnected and the generator used to prove running of the relevant hoists, pumps and fans using the generator power supply system.

8.5 Building HVAC

The heating, ventilation and air conditioning (HVAC) systems for the surface buildings will be designed for local climatic conditions as specified in the National Building Code or as defined by Environment Canada databases, whichever is the more adverse. Heating or cooling of underground air is covered in Section 5.

8.6 Propane Storage

Propane will be the primary method of heating the air that is supplied to the underground infrastructure. In the colder period of the year the ventilation air will be heated in the Heater House building located at surface upstream of the Main Shaft, where the air is distributed by forced draft underground. It is currently assumed that electric heating will be used in the various surface buildings including the Amenities Building and Offices & Main Control Room.

Three 50,000 litre propane tanks will be provided to supply liquid propane for heating of underground ventilation air. These propane tanks will provide eight to nine days of fuel for ventilation air during the heating season. It is proposed that propane will be regularly delivered to the tank farm by propane tanker truck. A propane filling station will be located outside of the DGR fence line so that delivery personnel will not need to enter the DGR facility. The supply lines to the storage tanks and discharge lines to the heater building are buried to provide protection. Adequate valving and a fire arresting system will be installed to avoid any back flow from the heater building to the storage tanks.

The propane tank farm will be protected against damage from traffic by bollards placed around the perimeter. A substantially constructed and firmly anchored fence with a minimum height of 1.8 m will surround the propane tanks. Lockable gates will provide proper access to the propane tank, valves and filling station. The propane storage tanks will installed in a concreted area, bermed to contain an accidental rupture of all three propane tanks. The propane tanks are located at sufficient distance from the WPRB to avoid the possibility of a propane tank explosion causing damage to the WPRB or Main Shaft Headframe. Location of tanks may be changed in next stage of engineering to a more optimal location. The location of the propane tanks is shown on the general arrangement of the SSFA (refer to drawing H333000-WP403-10-042-0001).

8.7 Diesel Fuel

8.7.1 Surface

During operations diesel fuels are not stored on surface at the DGR site, with the exception of the diesel tank for operating the emergency generator (see Section 8.4 above). Diesel dispensing and lubrication will be provided by supply truck from WWMF to the DGR facility as needed. Totes will be filled at the WWMF fuelling station and brought to the WPRB.

8.7.2 Underground

For the underground repository, a Fuel Storage and Refuelling Bay is included at the services area. It will provide fuelling facilities for both construction and operations stages. The 5,400 litre diesel fuel storage tank will be an integrated unit with built-in leak containment and fire suppression system, such as the “Satstat” systems commonly used in the mining industry. The dispensing unit will be air-powered with a retractable hose.

The underground diesel fuel storage unit will be re-charged on a weekly or as-required basis using forkliftable metal fuel totes. After delivery to the WPRB, the totes will be loaded onto rail carts using the light duty forklift and transferred in the Main Shaft cage. Fuel totes will be never transferred in the Main Shaft cage at the same time as waste packages are delivered underground.

Both surface and underground fuel storage areas will be provided with sump capacity to collect accidental spillage that could occur during fuel transfer or leakage from any tanks or pipes. Berms will be constructed as needed to ensure that any spillage of fuel or lubricant will be retained within the storage and refuelling areas. Space for only a single piece of mobile equipment will be provided in the underground refuelling station to reduce any risk of a fire incident. Fire detection, suppression and emergency response systems for the refuelling system are described in Sections 7.1.1.2 and 7.1.2.2.

8.8 Communications

The DGR communications system includes the surface and underground infrastructure required for:

- Telephones.
- Wireless Radios.

- Business Network.
- Process Control Network.

The system architecture diagram for the DGR is included in Figure 8-2. The system described in this diagram is the permanent configuration that will be installed and commissioned during DGR construction and then utilised during operations.

The communications system does not include the infrastructure for fire detection and suppression, and hoist control. These two systems will utilise exclusive signal transmission infrastructure that will be supplied by the respective vendors for those systems. However, outputs from these systems can be accepted by the DGR communications system for inclusion on the operator's control screens.

8.8.1 Communications Network Backbone Technology

The communications infrastructure at the DGR will utilise Gigabit Ethernet-based equipment linked over a fibre optic network. To provide redundancy, a fibre cable will be run in both the Main Shaft and the Ventilation Shaft. This equipment will be used for local switching and as an overall link to the main OPG network. The Gigabit Ethernet technology is proven in industrial environments and will be configured for appropriate redundancy. This infrastructure will be installed during DGR construction.

8.8.2 Telephone System

Ethernet-based IP telephone (i.e. Voice over Internet Protocol (VoIP)) technology will be used for both surface and underground telephone service. It will be connected via fibre optic link, for access to external lines and OPG internal phone network. This reliable and well-established technology will eliminate the need for a Voice network separate from the Data network infrastructure.

Additional cellular infrastructure will not be provided at the DGR site.

8.8.3 Emergency Analogue Phones

Hard-wired emergency phones will be installed at the surface control room, at the Main Shaft and Ventilation Shaft stations, and at each refuge station. The phone system will be connected by twisted pair cable which is installed in a ring between each of the phones. These emergency phones are intended for emergency communications in the event of failure of the other voice communications systems (VoIP phones and radio). Because the system uses a separate, isolated infrastructure, it provides an extra layer to emergency communications redundancy at relatively low cost. Because power is carried in the copper (twisted pair) phone lines, an interruption to the underground power grid will not affect these phones.

8.8.4 Radio

Wireless voice coverage will be provided for the underground repository, Main Shaft and Ventilation Shaft, and the surface control room using “leaky feeder” technology. Leaky feeder is a simple and robust analogue system that utilises a simple coaxial antenna cable. This cable is simply hung throughout the underground tunnels using hangers and can easily be removed from emplacement rooms as they are filled with waste. A separate channel will be provided for in-shaft work, as this is required to ensure uninterrupted communications between shaft workers and the hoist control person, particularly during maintenance and shaft inspections. Each underground worker will either carry a portable radio or work in equipment that has radio hardware installed.

Although alerts of fire or other emergency conditions will be made via the radio system, the primary system of notification to the underground DGR will be the stench gas system, which is described in Section 7.1.1.2.

The leaky feeder radio system will also be used to carry monitoring signals from remotely installed instrumentation. The leaky feeder will carry cable modem terminal services (CMTS) connectivity to support Ethernet data communications requirements in remote areas of the underground installation. The CMTS communications will be tied into the fibre / copper process control network (see Section 8.9).

8.8.5 Business and Process Control Networks

The data communications system will be segregated into business and process data network.

The business network will provide access for business computers to e-mail, internet and other network services at all appropriate locations at surface and underground. The IWTS will be accessible through this network. The VoIP telephone system and the closed circuit video systems will also utilise the business network. There will be main business switches located at the surface Offices and Main Control Room and network drops to the required locations.

The process control network will carry all signals for monitoring and controlling systems at the DGR both on surface and underground. This network is provided in the key locations where connectivity between instrument and equipment is required. There will be main process network switches installed in the main or central control room.

8.9 Control and Monitoring

8.9.1 Offices & Main Control Room

The DGR will have a centralised control room (MCR), which is located adjacent to the WPRB, and single-operator approach to operations, with the exception of the shaft hoisting equipment, which will be separately controlled from work stations in the hoist room. This approach has been adopted across many industries as a safe method of achieving efficient operations. The DGR Operator will be enabled to make decisions and take remote control of components while being informed of the status of all DGR systems. This control room will have both closed circuit video monitors and a human machine interface (HMI). The HMI will allow the operator to view custom-configured control screens that display equipment and system status and allow inputs to be executed through a mouse / keyboard interface.

8.9.2 Secondary Control Room Locations

In the off-shift hours, the DGR Operator will not be required to staff the Offices & Main Control Room. The control room at the WWMF will be modified to include an interface to the DGR video screens and HMI, allowing this operator to respond to any alarms that may be encountered during this period.

A SCR will be established in the underground Refuge Station 1, located in the underground Shaft and Services Area as indicated on drawing H333000-WP408-20-042-0003. The purpose of this interface is to allow emergency control over critical systems in the event that personnel are confined to refuge station and communications between the surface control room and the underground systems is lost. To enable control from this secondary location, the primary control room would need to assign temporary permission. Alternatively, if communications between the underground control system and the primary control system is lost, the control permission at the SCR would be enabled automatically. The HMI will be adapted to reduce the number of screens at this location.

8.9.3 Control Platforms

PLCs or distributed control systems (DCSs) will be necessary on the surface (at the Offices & Main Control Room) and the repository level (at the Low Voltage Electrical, Communication and Instrumentation Room) to control and monitor equipment. This control system will handle the local automation necessary to maintain proper function of the equipment in question and will transmit monitoring data to the rest of the control network.

Monitoring and control will be available underground through a remote HMI station at the SCR (see Section 8.9.2). This will allow for supervisory operation of the control systems from underground, should the redundant fibre links to the surface be severed.

The underground control system processor will be installed within the Low Voltage Electrical, Communication and Instrumentation Room. It will interface directly with the equipment in the Shaft and Services Area. Remote input/output (I/O) panels will be used to interface with equipment in the access tunnels.

8.9.4 Equipment Control Communications

The central processing units (CPUs) will be connected to one another underground, with the SCR HMI (see Section 8.9.3) and with MCR at the WPRB on surface via Ethernet. Using industrial Ethernet as the link layer for the control communications will allow for the project to leverage the planned network infrastructure rather than requiring the installation of separate infrastructure or media converters to communicate between underground and surface.

The following underground equipment will be monitored and controllable from the HMI:

- Dewatering pumps.
- Power distribution facilities including motor starters and some switchgear.
- Ventilation fans and air heaters.

The following equipment will provide only operating status to the control HMI screens. This equipment either does not require control, will be controlled locally or will be managed by a separate, isolated framework or infrastructure (such as the fire detection and suppression system):

- Fire detection and suppression system.
- Uninterruptible power supplies (status monitoring).
- Temporary (construction) ventilation fans.
- Water contamination monitoring if required.
- Air quality monitoring as required.
- Ground support monitoring as required.
- Hoist system monitoring:

Fundamental control of all facilities will be managed locally at the control racks. Control from the WPRB, WWMF or SCR will be at the supervisory level (i.e. changing process set points and switching between process operation modes) and in the event of a communications failure, the local control systems will maintain operation of the controlled systems at the last established settings.

8.9.5 Control Applications

All of the above listed control applications, dewatering, power distribution and ventilation, will be controlled using drives, MCCs and switchgear situated within the Electrical Substation and other areas of the services area of the underground repository. The primary control CPU located within the communication and instrumentation room will interface with this equipment to facilitate network connectivity with the process control network.

8.9.6 Monitoring Applications

Much of the monitoring instrumentation will be installed within the underground Shaft and Services Area of the repository. This instrumentation will be connected to the primary control panel in the Low Voltage Electrical, Communication and Instrumentation Room. Any monitoring equipment within the services area that is Ethernet-enabled will be provided the requisite connectivity.

The remainder of the instrumentation is remotely located (in either of the emplacement access tunnels) and will be connected to secondary control panels or remote I/O panels. This instrumentation will consist of air and ventilation monitoring equipment installed at the ventilation ducting outside each emplacement room and potentially various ground control instrumentation.

The control and monitoring system will allow for connection and activation of alarm devices to notify personnel of abnormal or unsafe conditions. Alarm notification devices are expected within the control rooms and as necessary underground.

8.9.7 Video Systems

The DGR facility will have a video monitoring system throughout the surface facilities and at key hoisting system locations. Closed circuit cameras will be used and the video data will be carried over business network to the control room where the operator will be able to monitor these areas via multiple screens.

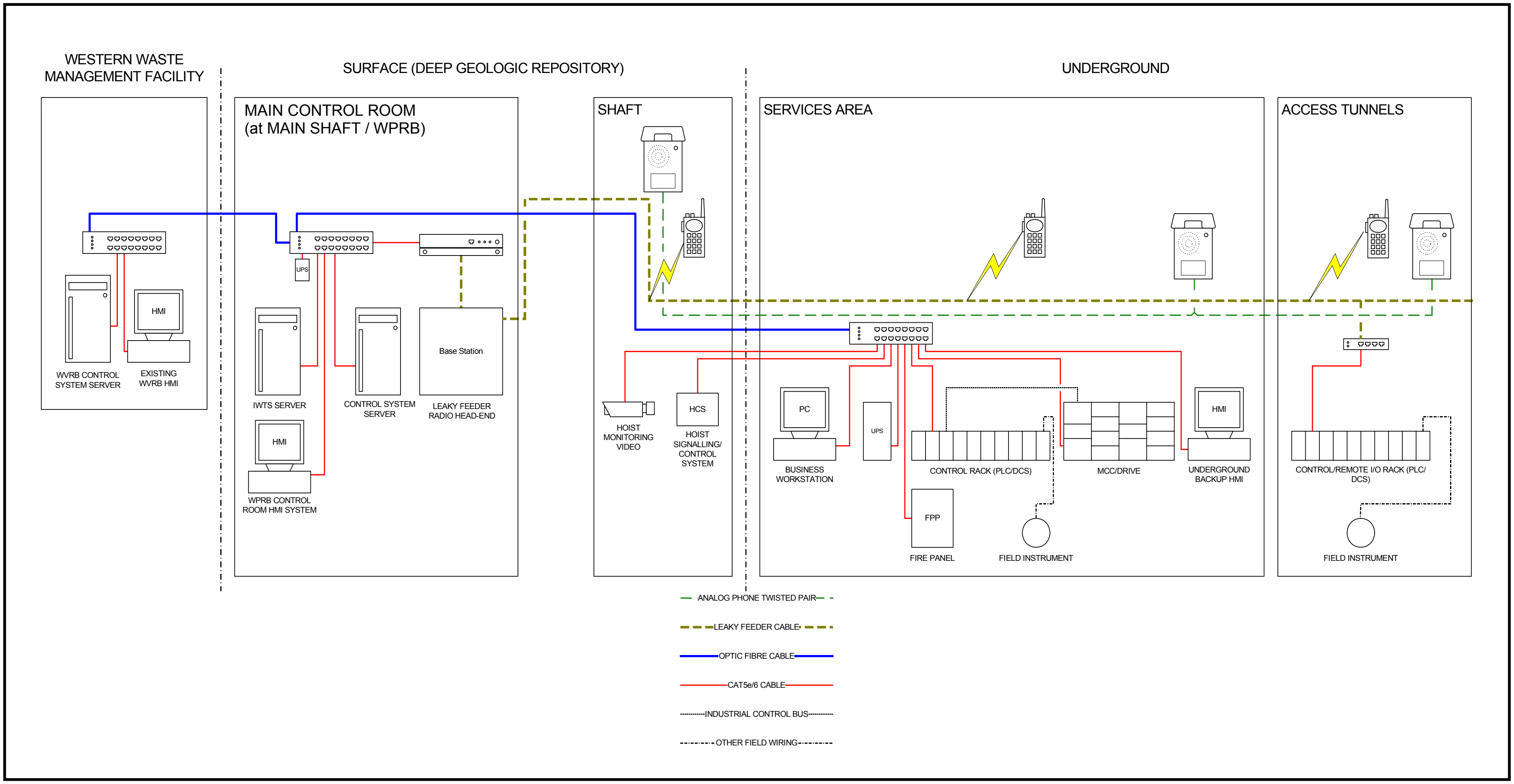

Figure 8-2 - System Architecture Diagram

8.10 Hazardous Materials and Waste

8.10.1 Storage

A number of materials that are explosive or flammable in nature are required to construct and operate the DGR facility. This will include diesel fuel and lubricants to operate the mobile equipment, and explosives for rock excavation (construction phase only).

During construction, diesel will be supplied either by each contractor independently, or by one contractor supplying to all contractors, or by OPG with a suitable system of back charging each contractor. During operations, diesel will be supplied from the WWMF.

Demand will be greatest during construction when consumption of diesel fuel is estimated to be approximately 5,000 litres per operating 8 hour shift for both surface and underground construction activities. An underground storage capacity of 5,400 litres will be installed with replenishment every few days from a tank (on a rail cart) that is refuelled on surface and transported underground via the Main Shaft cage. During facility operation replenishment would only be expected to occur on a weekly basis. Containment and fire protection systems are described in Sections 8.7.2 and Section 7 respectively.

Lubricants and materials (e.g. mops) used to clean up spills will be stored in the maintenance shop adjacent to the WPRB. A ‘waste’ bin will be provided at the Main Shaft area for temporary, but immediate disposal of any used clean-up materials.

A maximum underground explosive storage capacity of 1,500 kg is expected to be sufficient for the construction phase.

Explosives may be delivered on a day-basis directly to the surface headframe area by the explosive supplier and moved underground immediately, with no explosives being stored on surface or underground. Alternatively, a dedicated magazine may be established at the DGR site, which would allow less frequent explosives deliveries, thus reducing construction schedule risks during severe weather and improving security by having less deliveries.

During facility operations, it is not expected that explosives would be required. Special projects requiring miscellaneous rock excavation would have specific procedures in place with day-of-use delivery of explosives. There are also several commercially available, non-explosive products for splitting rock that could be considered for small projects.

8.10.2 Conventional and Hazardous Waste Management

Conventional and hazardous waste is produced during construction and the operation period of the DGR facility. These will consist of consumable material, namely rags and coveralls used in maintenance and clean-up operations, and solids generated from underground sanitary facilities (see Section 8.10.3). Other solids waste, such as pipes and steel structures, produced during maintenance and decommissioning can be considered to be contaminated with radioactive material and will be handled on a case by case basis. In any event, it is assumed that all steel structures will be left in place underground as apart of the decommissioning process.

All consumable waste materials will be stored in waste bins located at the Main Shaft area. These bins will be sent to the WWMF at regular intervals for treatment and disposal.

Waste rock produced from the excavation of both shafts will be removed by trucks and stored in the WRMA on the DGR site as described in Section 4.2.3.

8.10.3 Sewage System

In the underground areas, toilets will be provided at the two sanitary facilities. These “mine toilets” are typical to underground mining applications and use compressed air to function as simple, small-scale sewage treatment plants. This allows the self-contained toilet / reservoir units to function for 18 months before a fluid clean-out is required. These will be forkliftable units and will be taken to surface for the clean-out work to be completed.

Grey water from hand washing stations will be collected via gravity drain into tanks. This water will be pumped out as required to the same totes used for handling water collected at the wash bay.

8.10.4 Liquid Wastes

Apart from sewage, liquid wastes underground will consist of diesel fuel, oils and lubricants resulting from spills and maintenance. These liquids will be handled through the dewatering system and are described in Section 8.1.

8.11 Fencing and Security

The DGR facility will be located within the Bruce nuclear site and will be encompassed by the larger security system for the site. It is assumed that the Bruce nuclear site security system will be in place during DGR construction and operations.

The Bruce nuclear site is entirely surrounded by a perimeter fence that restricts access to the site via land or water. The only access to the site is via controlled checkpoints. Only authorised personnel and vehicles are allowed on the site. Security clearances are obtained for all employees and contractors.

8.11.1 Construction

During construction, the entire construction island including the WRMA will be surrounded by a fence (refer to drawing H333000-WP403-10-042-0002) to isolate the DGR from other OPG and Bruce Power facilities. A separate gated entrance to the DGR site will lead directly off the “Interconnecting Road” or the road to the east of the project site. During construction there will be no access via the WWMF. Security on the DGR site during the construction phase would be the responsibility of the individual site contractors.

8.11.2 Operations

The surface structures of the DGR, including the Main and Ventilation Shaft complex and the road and crossing connection to the WWMF, will be encompassed by a secure fence. The DGR Shaft Service Facilities’ Area (SSFA) will be connected to the WWMF via the crossing (refer to drawing H333000-WP403-10-042-0001). It is currently envisaged that the fencing around SSFA will be linked to the WWMF fencing, thereby allowing easy traffic flow between these two facilities. Incoming and outgoing vehicles and traffic will pass through existing WWMF main access gate, immediately adjacent to WVRB, and then drive over the new crossing, to reach the DGR SSFA. DGR traffic would pass through the WWMF main gate using same procedures as currently used by WWMF traffic.

8.12 Environmental Monitoring Program

The DGR operations may have potential air quality impacts due to flow of air from underground ventilation system exhaust, surface water quality impacts due to storm water run-off, and possible impacts on ground water. The likelihood and potential significance of these effects will be described in the environmental impact statement for the DGR project (to be prepared by NWMO). Where appropriate, an environmental monitoring program will be established to characterise the concentration of air-borne and water-borne contaminants relative to acceptable limits and assess the effectiveness of mitigation measures.

Full scope and details of the monitoring program (sampling location, frequency, methods, equipment and monitoring parameters) will be established in next phase of design. Some possible elements of the surface water and ground water monitoring programs are described in Sections 4.2.3.4 and 4.2.3.10. Air quality monitoring of exhaust ventilation air is briefly discussed in Sections 7.3.5 and 7.5.

9. Repository Development and Construction Phases

9.1 Approach to DGR Development

9.1.1 Geotechnical Investigations

NWMO is currently completing a comprehensive GSCP at the Bruce nuclear site (see Section 2.3.2). These investigations have been complemented by a field and laboratory testing program that includes a suite of geomechanical laboratory tests. All borings have been conducted beyond the periphery of the DGR and outside the planned footprint of the underground repository.

In geotechnical engineering design, calibration between borehole investigations and the observed rock mass behaviour gained on previous projects is invaluable in predicting the means and methods necessary and the cost to implement them on other projects in similar conditions. When such calibrated information is available, the results of current borehole investigations can be compared to results of similar borehole investigations on previous projects to permit interpolative predictions of the conditions and behaviour for the new work.

The engineering design basis for the emplacement rooms and access tunnels has been significantly enhanced by results from the current DGR site investigations. However, it has been necessary to make significant behavioural assumptions based on extrapolated data from other projects in similar rock formations in order to perform the geotechnical design of the DGR underground openings (e.g. excavation methods and rock support requirements). A list of projects considered is given in Section 2.5. In particular, assumptions had to be made about the following key aspects of the site:

- In-situ stress measurements – these measurements cannot be performed reliably at this depth through boreholes drilled from surface in sedimentary rock formations.
- Nature of vertical and inclined discontinuities (such as spacing, bedding planes, joint sets, joint orientation, width, spacing, infilling and pervasiveness) – these features are difficult to assess at depth from boreholes.

9.1.2 Management of Geotechnical Risk

To increase knowledge about deep geotechnical conditions at the DGR site and to mitigate the level of geotechnical related risk for the DGR project, the activities described in the following section will be considered in the next phase of engineering.

9.1.2.1 Geotechnical Risk Register

Risk registers are living documents that are commonly used for design development on large underground projects. A risk register identifies and evaluates project risks (design, construction and other), their probability of occurrence and their potential impact. A scoring system is then used to assess the need for mitigation. Once a risk is identified as requiring mitigation, potential mitigation methods are identified and the process is repeated to assess their effectiveness.

To manage geotechnical risks associated with the engineering design and construction of the DGR, the project should implement a dedicated Geotechnical Risk Register for the geotechnical design aspects of the repository. A key feature of a risk register is that it would document and provide a record of the rationale for implementation of required investigations and design decisions.

9.1.2.2 Geotechnical Baseline Report

A Geotechnical Baseline Report (GBR) should be prepared to establish a quantifiable contractual statement or “baseline” of the geotechnical conditions anticipated to be encountered during underground construction. Such a statement allocates construction risk between the owner and the contractor – risks associated with conditions consistent with or less adverse than the baseline are allocated to the contractor and those significantly more adverse than the baseline are accepted by the owner. The GBR would be included in contract bid documents.

9.1.2.3 Geotechnical Investigations and Testing Prior to Lateral Development

Borehole investigations should be conducted down the centre-line of each shaft prior to shaft sinking. The purpose of these holes is to confirm conditions at the DGR as observed through existing DGR investigation boreholes (see Section 2.3.2). These holes would also be used to identify any potential anomalous conditions that would not have been discovered by the aforementioned DGR boreholes. The boreholes, if drilled, would provide an additional opportunity to confirm the engineering characterisation of the rock mass.

Due to the necessary assumptions made to establish the geomechanical basis for design and construction of access tunnels and emplacement rooms, it is considered essential that confirmatory geotechnical investigations be conducted at repository level prior to performance of excavations associated with the main lateral development of the DGR. This will provide direct observations and measurements on a full scale basis of the rock mass behaviour in response to the work. These investigations would be largely conducted in the Cobourg Lower Member and would likely include, but not necessarily be limited to, the following:

- Geologic mapping of discontinuities, rock mass quality, bedding plane thickness and distribution.
- Measurement of in-situ stresses including overcore or hydraulic fracturing in vertical and horizontal boreholes advanced from the advance works.
- Measurement of joint, intact and rock mass strength properties using flat jack and plate load testing methods.
- Measurement of intact and rock mass properties through laboratory testing.
- Measurement of extent of overbreak and damaged rock due to excavation.
- Installation of instrumentation in advance of excavation to measure rock mass behaviour in response to excavation.

The scope of the testing program will be further defined in the next stage of engineering.

9.1.2.4 Geoscience Facility and Storage Areas

As outlined previously, continued mapping, sampling, testing and monitoring of the rock mass will be an integral part of the DGR development to confirm assumed behaviour. The Geoscience Facility and Geoscience Laboratory & Storage area in the underground Shaft and Services Area will help achieve this by facilitating the following activities:

- Geotechnical mapping.
- Testing of intact rock samples.
- Long term rock property testing under DGR conditions.
- Sample storage and preparation equipment.
- Instrumentation monitoring and interpretation.
- Storage of field records and data.

9.2 Surface Facilities

Most of the surface facilities will be constructed during the initial construction phase. For shaft sinking this includes the two headframes, complete with the permanent Ventilation Shaft Hoist House, Exhaust Fan building and waste bin with airlock for waste rock dumping. Temporary hoist houses for the Main Shaft sinking hoist and both sets of sinking winches (Main and Ventilation Shafts) would be installed. Additionally, as the shaft sinking would be planned to occur on a 24 hour / 7 day / 350 days per year basis, a temporary heating and fan house and equipment would be installed to provide controlled air temperatures to the shaft sinking crew.

The layout of these surface facilities during construction of the DGR is shown at a high overview level in Figure 9-1 and, for preliminary comparative reference, Figure 9-2 shows the surface layout during the operational phase. The main structures or areas are numbered in these two figures and colour-coded to identify whether they will be re-used as is or modified following completion of the Construction Phase, would be replaced or newly constructed for the Operations Phase. Drawings H333000-WP403-10-042-0002 and -0001 respectively show these two arrangements in the full site context.

The construction layout is arranged to form a “construction island”, in which all facilities will be grouped in relatively close proximity around the construction site. This arrangement will be fenced off from the rest of the Bruce nuclear site and allows for controlled access and security at the site. Access will be primarily from the Interconnecting Road on the western side of the DGR Site, with an alternative gate on the south-east leading to the road running along the eastern boundary of the project site via the abandoned railway bed.

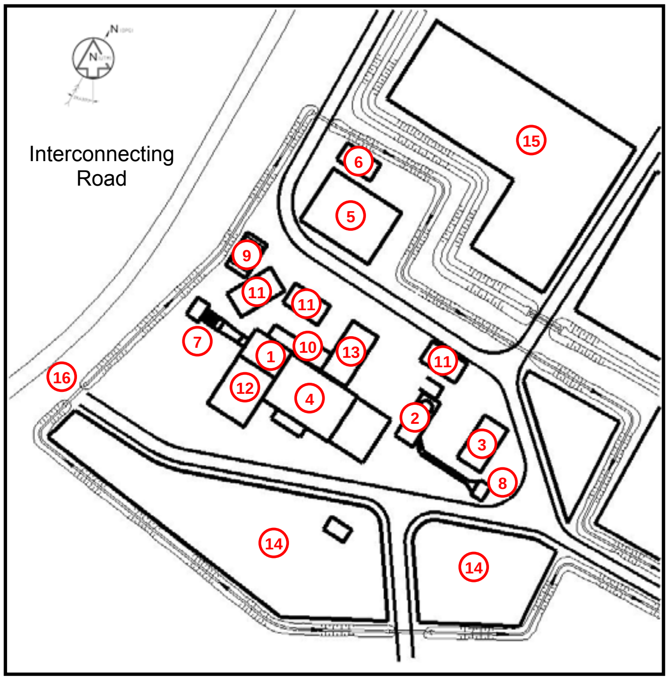

Figure 9-1 – Surface Layout – Construction Phase

Item	Description
1	Main Shaft Headframe
2	Ventilation Shaft Headframe, Collar House & Rock Dump
3	Ventilation Shaft Hoist House
4	Sinking Maintenance Shop & Stores
5	Electrical Substation
6	Emergency Diesel Generator
7	Intake Fans & Heater House
8	Exhaust Fans
9	Propane Tank Farm
10	Electrical Room & Air Compressors
11	Sinking Hoist Houses
12	Main Shaft Rock Dump
13	Freeze Plant
14	Contractors' Facilities
15	Construction Laydown Area
16	Construction Site Access

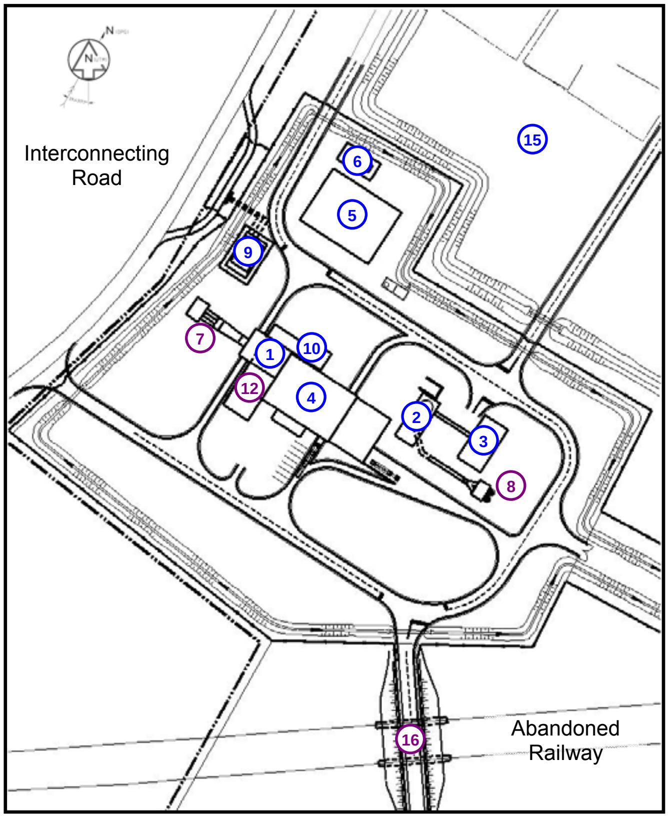

Figure 9-2 – Surface Layout – Operations Phase

Item	Description
1	Main Shaft Headframe
2	Ventilation Shaft Headframe, Collar House & Rock Dump
3	Ventilation Shaft Hoist House
4	WPRB
5	Electrical Substation
6	Emergency Diesel Generator
7	Intake Fans & Heater House
8	Exhaust Fans
9	Propane Tank Farm
10	Electrical Room & Air Compressors
11	-
12	Amenities Building, Offices & MCR
13	-
14	-
15	WRMA
16	DGR Access from WWMF

Colour Key: **Blue** items were erected prior or during Construction Phase, although some may require refitting for Operations Phase; **Purple** items will be new or replacements for construction items; **Grey** indicates items are not required for Operations Phase.

The Main Shaft will interface with the surface facilities through the WPRB. In effect, this building will serve as a collar house facility where maintenance activities and material deliveries are staged. To this end, the overhead crane and off-loading bays can be used. The Offices & Main Control Room facilities attached to the WPRB cannot be used during the construction stage, as this area will be required as a mucking bay for dumping of rock excavated out of the Main Shaft. Trailer buildings will be used as offices and a control room for both planning and supervision personnel during construction. The control room will house system control interfaces and screens for the construction systems such as hoisting and ventilation. The permanent Offices & Main Control Room buildings play a key role in DGR operations, and thus are more fully described in Section 4.2.

The Ventilation Shaft Headframe will be used for both shaft sinking and permanent arrangements. This steel structure will provide the required framework for hoisting equipment such as rope sheaves, conveyance guides and rock skip dump hardware. It will be fully clad and insulated, noting that particular attention will be given to covering the rope passage openings, using curtains to provide protection against cold winter conditions and discharge chute locations using a gate to provide an ‘airlock’ seal to prevent short-circuiting of air once the repository flow through ventilation system is commissioned.

The waste rock generated during the repository construction will be hoisted up the Ventilation Shaft using two skips. The discharge from either of the two skips will be diverted to a muck bay located outside of the headframe via a chute. A common chute will be used for both skips. At the exit point of the chute two layers of conveyor belt strips will be installed to help control the air draft and associated dust. At the completion of construction, this chute will be sealed to reduce heating costs in the headframe building. This chute and associated muck bay are shown on drawing H333000-WP406-20-042-0010.

The Ventilation Shaft Collar House will be used to support shaft-related maintenance activities. This structure will also be subjected to the air pressure differential (negative pressure) generated by the Exhaust Fans. This is due to the direct connection to the Ventilation Shaft at the collar. It will be possible to use the shaft safety doors[17] to temporarily seal the shaft from the headframe. This would temporarily relieve the negative pressure created by the running Exhaust Fans from acting on the headframe and collar house. If the hoisting system is required for use (i.e. secondary egress) at this time, the Exhaust Fan speed would be minimised to allow the doors to be opened.

The construction roads have been designed to accommodate heavy construction traffic and maximise construction laydown areas, including a concrete batch plant. Construction roads will be granular.

For the construction period of the project, main access will be via the existing Interconnecting Road on the west side of the construction site. Secondary construction site access may also be provided to the east as shown on drawing H333000-WP403-10-042-0002.

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[17] Safety doors are horizontal gates installed near the top of a shaft during shaft sinking to protect workers; primarily by blocking any object dropped in the collar area or headframe from falling down the shaft.

The Ventilation Shaft Collar House will be of insulated and clad steel-framed construction. The internal dimensions of the collar house will be approximately 15.0 metre (m) long by 10.0 m wide by 5.0 m high. The width will be the same as the Ventilation Shaft Headframe with a length to suit a concrete transmixer truck plus 4 m (2 m on either end of the truck). The height of the collar house is 3.8 m to account for the truck height plus 1.2 m of additional clearance to accommodate a monorail crane and lighting.

One steel sectional overhead door (4.0 m wide x 4.5 m tall) rated for the pressure differential between the interior and exterior of the building will be provided. To prevent short circuit in the ventilation system, this overhead door would not be used while the Exhaust Fans are running, unless the safety doors in the shaft are closed. During operations, the overhead door would be kept closed most of the time, thus allowing full use of the hoisting system. An airlock chamber will be provided to allow personnel to access the building at all times. The general arrangement for this building can be found on drawing H333000-WP406-20-042-0010.

This collar house will have a collection sump for drainage and the concrete floor will be sloped appropriately. Sources of liquids would be minor in terms of volume and include water or ice brought in by incoming trucks or forklifts, periodic floor washing and potential oil or fuel spills from equipment. Similar to what is used at the WVRB at the WWMF, this will be a "dead sump" and will require periodic pump-out. This minimises the complexity and cost of the system while preventing the need to monitor "automatic" discharges for contamination.

The muck bay will be open on the top with a concrete wall on three sides and will be accessible from one side. Embedded concrete rails will provide a digging surface for the loader and impact protection from the falling waste rock. A siren and strobe light will be operated to warn before skips dump to the chute, but as a passive safety feature, the back wall of the bay will be located close enough to the chute so that the cab of a loader will not be directly under the chute during mucking.

Because the Ventilation Shaft hoisting system is ground-mounted, a hoist house will be provided both in the DGR construction and operations stages. This building will contain the Ventilation Shaft hoist motor and drums, as well as local hoist controls hardware. The Ventilation Shaft sinking stage winch house will be utilised for construction only and then removed. This structure will be located directly adjacent to the hoist house.

9.3 Shafts and Underground Repository Development Phase

9.3.1 Shaft Construction Methods and Sequence

The proposed construction methodology for the Main Shaft and Ventilation Shaft is presented herein. This section includes a description of the proposed ground improvement, excavation method and rock support techniques. Due to the varied nature of the stratigraphy at the site, the shaft construction methodology is presented according to the four stratigraphic reaches described in Section 2.3. The geotechnical basis for the design of the shaft liner and rock support is presented in Section 4.3.6.1.

Shaft sinking methods and initial support design are considered to be at a conceptual level of design and will be developed in more detail in the next phase of design. The detailing of the initial support and final lining may need to make allowances for time dependent deformations (swelling) to occur without undue distress to the initial support.

9.3.1.1 Shaft Sinking Requirements and Sequence

Excavation of the shafts through hard rock will be accomplished using drill and blast excavation techniques. Drill and blast has been proven to be a suitable excavation technique in similar rock conditions during shaft sinking operations [R29]. Diligent enforcement of controlled perimeter smooth wall blasting will be required to limit overbreak of the shaft walls and limit rock damage. Even with these measures in place, a depth of damaged rock (HDZ and EDZ) will occur during drill and blast excavation. This damaged rock will likely require removal at the time of shaft sealing to achieve the required bulk hydraulic conductivity value for the overall shaft sealing system (see Section 11.2).

Ability to minimise the depth of rock damage will be a key consideration in the assessment of various construction methods and the selection of a preferred method. Confirmatory analyses will be performed in future phases of engineering to predict the depth of damage rock in the context of the proposed construction means and methods. This assessment will be on the basis of sinking productivity (advance lengths), rock support, final liner requirements and requirements of the shaft sealing system.

The anticipated shaft sinking sequence and ground improvement methods for the Main Shaft of the DGR are described in Table 9-1. A similar procedure will be followed for the Ventilation Shaft.

Reach	Sinking Activity	Ground Improvement
Pre-Sink Surface, Reach 1, Reach 2a	1. Site preparation (shaft area only). 2. Install shaft sinking ground water treatment facilities. 3. Install sinking shaft piles outside of shaft area. 4. Pre-sink: a) Reach 1 – secant pile wall around shaft and plenum. b) Reach 2a (top 20 m) – surface grouting. c) Excavate Reach 1 within secant pile structure. d) Excavate 20 m of Reach 2a using drill and blast (D&B).	A structural cut-off system constructed using secant piles will be used through Reach 1. Formation grouting from the surface to be used for top 20 m of Reach 2a as part of pre-sink.
	5. Build concrete head frame and collar. 6. Assemble sinking hoists. 7. Install sinking Galloway (three stages with Cryderman mucker).	
Reach 2a Sink	8. Sink to bottom of Reach 2a. • Install initial support (leaky shotcrete & steel dowels). • 0.3 m added to the shaft excavated diameter as overbreak. • Three stage Galloway, with Cryderman mucker. • Drill probe holes 25 m – maintain 7 m ahead of bottom. • Supplemental grouting as directed through Reach 2a if required. • 3 m bench (advance). a) Survey & drill pattern. b) Load holes, back out Galloway & crew. c) Shoot round and clear blasting fumes. d) Reset Galloway & muck out bottom. e) Install initial rock support on upper decks – bolts & shotcrete.	Freezing (or possibly grouting) used to bottom of Reach 2a (~190 mBGS) – drill probe holes ahead of bottom to confirm effectiveness of ground improvement, employ supplemental methods as required.
Reach 2b Sink	9. Sink to bottom of Reach 2b. • Install initial support (leaky shotcrete & fibre-glass dowels). • Use same sequence described in Reach 2a sink.	Drill probe holes ahead of bottom to confirm effectiveness of ground improvement, employ supplemental grouting as required.
	10. Stop sinking & set-up for installation of horizontal ring barrier.	
	11. Install horizontal shaft ring barrier.	
	12. Set-up to install permanent shaft liner to surface.	
	13. Install shaft lining to surface (slip form from Reach 2b / 3 contact), actual concrete placement period based on 6 m/day advance rate.	
Reach 3 & 4 Sink	14. Set-up to continue sinking through Reach 3 & Reach 4.	Probe ahead of shaft bottom, grout as required (not expected to be necessary).
	15. Sink through Reach 3 & Reach 4 to DGR horizon. • 3 m bench (advance). a) Survey & drill pattern. b) Load holes, back out Galloway & crew. c) Shoot round and clear blasting fumes. d) Reset Galloway & muck out bottom. e) Install initial rock support on upper decks – bolts & shotcrete. 16. Shaft Lining – slip form from bottom or concurrent with shaft sinking (to be determined).	
	17. Excavate initial DGR level stations.	
	18. Sink to shaft bottom (Main Shaft).	
	19. Sink to loading pocket level in the Ventilation Shaft.	
	20. Utility & steel installation – productivity, 30 m/day.	
	21. Install instrumentation and monitoring for each shaft.	

Table 9-1 – Anticipated Ground Improvement and Sinking Sequence

9.3.1.2 Reach 1: Overburden Sinking Methodology

The excavated diameters for the Main and Ventilation Shafts Reach 1 Overburden material will be 9.4 m and 7.7 m respectively. While the depth of overburden at site varies (refer to Section 2.3.4), the assumed sinking depth through Reach 1 is 18 m.

Shaft excavation through the lower portion of the overburden will likely be accomplished using a small backhoe and muck skips hoisted to the surface by a crane or possibly using a clamshell, depending upon the contractor’s selected means and methods.

9.3.1.2.1 Reach 1: Ground Improvement Methods

The pre-sink through Reach 1 will be through predominantly cohesive glacial till material but will intersect the basal sand and gravel layer directly above the bedrock and may intersect thin sand layers. Being below the water table, these soil units will exhibit flowing behaviour and will likely transmit significant volumes of groundwater if not improved in advance of excavation.

To reduce groundwater inflows through Reach 1, a secant pile perimeter wall is proposed around the perimeter of each shaft collar and plenum. To construct this wall, augers will be used to excavate a series of 1.2 m diameter holes down to and socketed into bedrock. The primary holes will be drilled on 2 m centres and filled with concrete. After the primary holes are complete, secondary holes (with a diameter of 1.2 m) will be augered between the primary holes to provide a 0.1 m interlock between each pile. The secondary holes will be reinforced with rebar or steel cage before being filled with concrete. The bedrock plug ahead of the socket will then be formation grouted from the surface to seal the Reach 1 / 2a contact and the planned pre-sink depth in Reach 2a.

9.3.1.2.2 Reach 1: Initial Support

In addition to reducing groundwater inflows, the secant pile wall will also act as a structural element providing initial support during sinking. A reinforced collar beam at the soil / rock interface is recommended to stiffen the initial support, permit transition into a shotcrete lined rock excavation and to provide a groundwater dam to collect and channel groundwater inflows at the contact. This feature results in the larger excavated diameter in the overburden relative to the underlying rock.

The permanent shaft headframe base and collar will be constructed on bedrock within the secant pile structure before sinking into Reach 2a.

9.3.1.3 Reach 2: Dolostones Sinking Methodology

The minimum excavated diameters (no allowance for overbreak) for the Main Shaft and Ventilation Shaft will be 7.85 and 6.15 m, respectively. A portion of Reach 2a (approximately 20 m) will be excavated during the pre-sink, while the rest of Reach 2 will be excavated during the full sinking period.

Given the elevated hydraulic conductivities in the Reach 2a dolostones and certain units within Reach 2b, it is assumed that ground improvement will be required to control water inflows and permit safe excavation under dry conditions. Ground improvement will also be required to reduce the risk of flooding during DGR operations by limiting groundwater inflow from Reach 2a and permeable units in Reach 2b in the remote event of a shaft liner failure.

The following sections describe the proposed methods of ground improvement and initial rock support design in the Reach 2 dolostones. The final liner design is described in Section 4.3.6.1.

9.3.1.3.1 Reach 2a Pre-sink: Ground Improvement Methods

Formation grouting from the surface would be used during the pre-sink phase to control potential groundwater inflows for the top 20 m. To accomplish this, a ring of grout holes will be drilled around the proposed shaft excavation, extending from surface to a depth of 20 m into Reach 2a. These holes would then be pressure grouted to inject cementitious material into joints and fractures that have been intersected by the holes, reducing the overall hydraulic conductivity of the rock mass.

The effectiveness of the grout will be tested from surface using probe holes before sinking is initiated. If additional grout is required, a second ring of grout holes would be drilled.

9.3.1.3.2 Reach 2a Sink: Ground Improvement Methods

The ground improvement program through Reach 2a is intended to create a relatively impermeable annulus around the shafts to limit lateral groundwater flow from the permeable dolostones into the excavation. This can be accomplished from surface through either freezing or grouting.

Ground freezing is considered to be the reference method of ground improvement through Reach 2a at this stage of design. Grouting from the surface may also be possible, however, future investigations and studies are necessary to assess this method. These options will be assessed in the next phase of engineering.

These options would be performed concurrently with the pre-sink to reduce any impact on schedule. Supplemental formation grouting can be used as required during sinking in zones where surface ground improvement is ineffective and to address any vertical flow through the plug.

Each of these options is described in the following subsections.

9.3.1.3.2.1 Ground Freezing

Ground freezing is accomplished through vertical holes drilled from the surface around the perimeter of each shaft. Circulation pipes (denoted as freeze pipes) are installed in each drill hole to permit flow of low temperature coolant (brine or liquid nitrogen). As the coolant circulates within the closed loop freezing system (all coolant is contained within the loop), it lowers the temperature of the groundwater outside of the pipe until it freezes.

The freezing operation effectively solidifies the groundwater in the rock joints, making the ground mass impermeable. In addition, a key advantage of this method is its ability to self-heal after loosening due to rock blasting. Verification of the effectiveness of the freeze in the shaft excavation area is accomplished using probe holes prior to sinking and periodically during sinking ahead of the advancing shaft bottom.

Freezing has been used successfully to achieve effective water cut-off and rapid shaft sinking rates at several shaft sinking projects. At the Goderich salt mine, ground freezing was used during sinking of Shaft No. 3. This method was chosen as it was felt that the length of freeze time could be more reasonably calculated than the amount of grout required, as grout has the potential to migrate during injection. Migration was a major issue during the sinking of Shafts No. 1 and 2, resulting in significant project costs and sinking delays. The use of freezing resulted in significantly faster shaft sinking rates, subsequently resulting in cost savings.

The freeze hole pattern at the DGR will be designed to create a virtually impermeable frozen ring around each of the planned shaft excavations. Probe holes will be drilled ahead of the advancing shaft bottom to verify the effectiveness of the freeze in Reach 2a and to assess the inflow potential in Reach 2b. The results of the probe holes will be used to direct the implementation of supplemental formation grouting.

9.3.1.3.2.2 Surface Grouting

Grouting involves injecting cement or chemical grouts into the surrounding rock mass to fill in fractures. This method has been used extensively during shaft sinking in a variety of rock types and provides the following:

- Control of seepage into the excavation during shaft construction; and
- Improved hydraulic properties of the rock (i.e. grouting of major fracture zones).

At the DGR, this method would be accomplished by drilling a ring of grout holes around the shaft from surface to the top of Reach 2b. These holes would then be pressure grouted to inject cement into any fractures that have been intersected by the holes, reducing the overall hydraulic conductivity of the rock mass.

To determine the success of the grout, probe holes would be to drilled ahead of the excavation. If groundwater flow rates are still considered to be too high, additional grout rings can be drilled. This process can result in a significant reduction in hydraulic conductivity depending on the size of the fractures / openings and the degree of connectively between these features.

In construction practice, the effectiveness of a grouting program may be reduced by factors such as the tortuosity of the fractures, presence of fracture infillings, presence of intersecting fractures and the grout pressures required for penetration. In order to accurately predict the grout volume required, the grouting extent and the interconnectivity of fractures will need to be estimated. As grout can migrate through several paths, this can affect both the schedule and the cost certainty of a project.

9.3.1.3.3 Reach 2b: Ground Improvement Methods

As shown in Section 2.4, DGR site investigations indicate that only two units in Reach 2b (the upper 4 m of the Salina A1 carbonate and the Guelph Formation) display elevated hydraulic conductivities similar to those in Reach 2a. Correspondingly, it is believed that supplemental formation grouting while sinking will be appropriate for Reach 2b. This method may also be used in portions of Reach 2a if freezing is ineffective at certain places.

During sinking, supplemental formation grouting would be accomplished using a drilled hole pattern to inject cementitious grout into rock discontinuities. This creates a low permeability zone around the ground to be excavated and maintains a full face grouted plug ahead of the advancing face. Cementitious grout using micro-fine cement or chemical grout using sodium silicate suspension will be injected through blind drilled holes or through a sleeve port grout pipe (SPGP) system that facilitates multiple grouting stages through the same grout holes depending upon observed performance. This grouting will also limit groundwater inflow into the shaft through the initial support system.

The proposed arrangement consists of 25 primary and 25 secondary grout holes extending 25 m in front of the shaft face. Secondary grouting will be directed on the basis of inflow criteria applied to observed inflows from a second probe hole advanced after primary grouting is completed. The grouting sequence (shown in Figure 9-3) will be repeated, as required, through permeable units in Reach 2b.

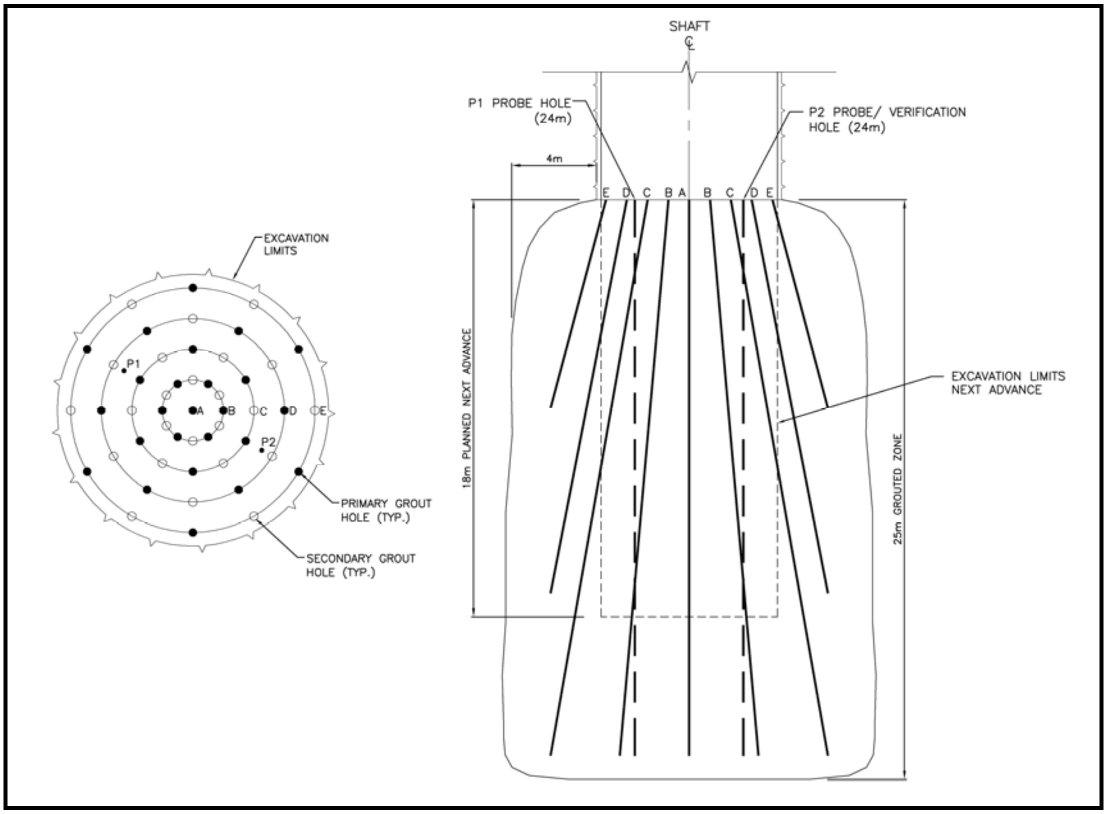


Figure 9-3 – Possible Reach 2 Supplemental Grouting Arrangement

9.3.1.3.4 Reach 2: Initial Support

For the purposes of preliminary design, it is assumed that initial support for Reach 2a will be provided by 1.5 m long, 25M steel dowels at 1.0 m spacing (vertically and circumferentially) with 150 x 150 x 10 mm base plates. Successive bolt pattern arrays should be staggered relative to the previous array during sinking. Bolts may require mechanical anchorage instead of grout in the frozen ground.

The need to effectively seal both shafts at the time of repository closure will likely require the removal of damaged rock prior to placement of sealing materials. During excavation of Reach 2b, the extent of rock damage must therefore be minimised and rock support must be installed to facilitate removal of damaged rock in a controlled manner. As such, initial support in Reach 2b will consist of 3 m long fibreglass dowels with 1.5 m spacing (vertically and circumferentially). Fibreglass dowels have been selected as they are easier to remove than steel dowels.

The base plates will be covered with a 75 mm fibre-reinforced shotcrete layer, which will provide additional support and protect against rock falls. To prevent groundwater pressure from building up behind the shotcrete, panning is to be placed between the rock and the shotcrete and weepholes will be placed through the shotcrete. This design is shown in Figure 9-4.

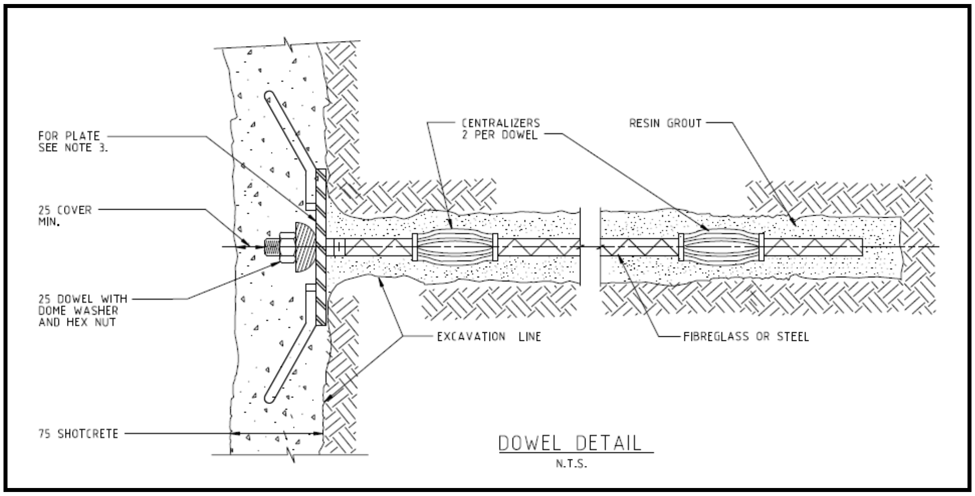


Figure 9-4 – Initial Support Details for Reaches 2, 3 & 4

9.3.1.4 Reach 3 Shales and Reach 4 Limestones: Sinking Methodology

The excavated diameters (no allowance for overbreak) for the Main and Ventilation Shafts in the Reach 3 Shales and Reach 4 Limestones will be 7.85 and 6.15 metres respectively.

9.3.1.4.1 Reach 3 and Reach 4: Ground Improvement Methods

Ground improvement methods are not anticipated through the Reach 3 shales or the Reach 4 limestones. Probing and grouting (if necessary) similar to that identified for Reach 2b units may be required in the upper units of Reach 3 and to provide greater certainty and safety during sinking through there units.

9.3.1.4.2 Reach 3 and Reach 4: Initial Support

Similar to Reach 2b, the extent of rock damage needs to be minimised through Reach 3 and Reach 4 to effectively seal both shafts at closure. To facilitate removal of initial support and damaged rock during sealing, fibreglass dowels will be used. The 3 m long, 25M fibre-glass dowels will be spaced at 1.5 m (vertically and circumferentially) with 150 x 150 x 10 mm base plates. The dowels will be covered with a 75 mm fibre-reinforced shotcrete layer (see Figure 9-4).

Panning is to be placed between the rock and the shotcrete and weepholes will be placed through the shotcrete.

9.3.2 Underground Repository Development

9.3.2.1 Room Excavation Method

9.3.2.1.1 Excavation Methods

During earlier stages of design, traditional drill and blast and mechanical excavation using a roadheader were the excavation methods that were considered for construction of access tunnels and emplacement rooms.

While both methods are considered viable at this stage of design, NWMO has indicated a preference to consider drill and blast as the reference method for excavation of the DGR at this time. Correspondingly, drill and blast methods have been assumed as the reference method for the purposes of preparing cost estimates for the DGR.

The use of mechanical excavation methods (i.e. roadheader) will continue to be considered in discussions regarding the recommendation of a preferred method of excavation. Each method is believed to have potentially significant cost, schedule and technical advantages that need to be assessed more fully.

For more information on possible excavation methods, the reader is referred to [R49].

9.3.2.1.2 Excavation by Drill and Blast Methods

Underground excavation by drill and blast methods involves the drilling of a series of parallel horizontal holes (vertical holes for shaft sinking) in a predetermined pattern and length. An example of this is shown in Figure 9-5 and Figure 9-6.

After drilling is completed, each hole is packed with explosives and a time delayed detonator, often referred to as a blasting cap. To fire the round and hence fracture the rock, the detonators in each hole are connected together using either electrical wire or non-electric shock cord. Once connected, the entire pattern or “round” is detonated from a safe distance using a blasting machine that initiates all in-hole detonators in a defined sequence to control fragmentation. Use of delays is important to attain the required fragmentation of the blasted rock, control vibrations and thus achieve smooth wall blasting.

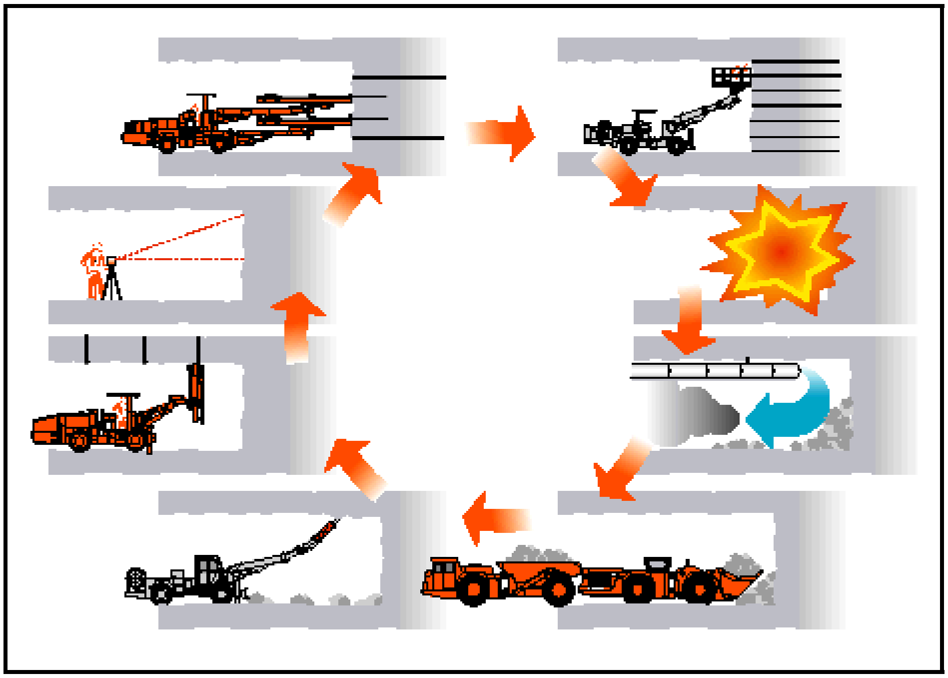


Figure 9-5 - Typical Drill and Blast Excavation Cycle

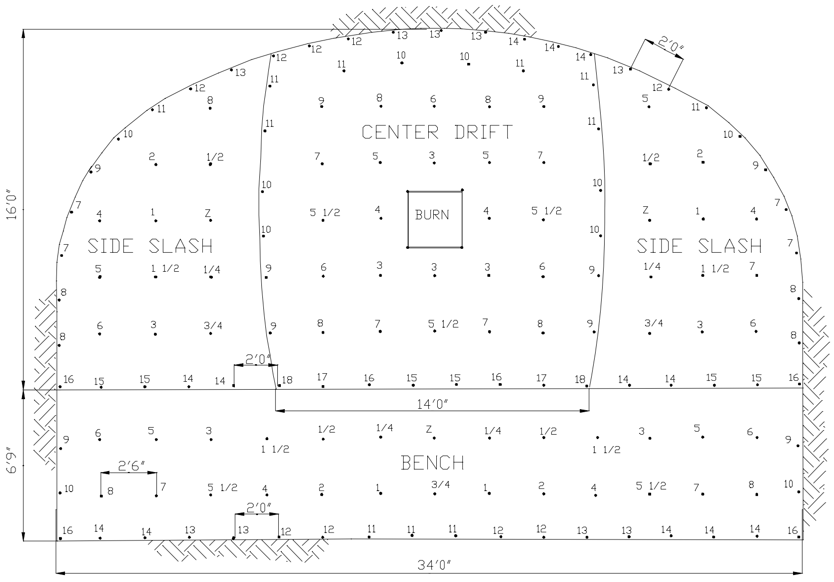


Figure 9-6 - Typical Drill Hole Pattern for Drill and Blast Rock Excavation of Similar Size and Shape to DGR Emplacement Rooms

9.3.2.1.2.1 Overbreak using Drill and Blast Methods

By its nature, blasting results in overbreak (excavation beyond the intended excavation design lines) and the development of an extended fracture zone in the rock around the excavation perimeter.

The amount of overbreak will typically be in the range of 150 mm to 300 mm depending on the amount of control used during blasting. Control of overbreak can be accomplished through the use of strict and diligent enforcement of smooth wall blasting methods. Smooth wall blasting techniques involve the simultaneous detonation of closely spaced and lightly charged perimeter holes that are designed to create a clean separation surface between the rock to be blasted and the rock which is to remain. These perimeter holes are shot in the final delays of each round. Successful implementation requires experimentation and continual adjustment in response to observed rock mass conditions and blasting performance.

Strict limits on blasting patterns for vibration control and diligent monitoring and enforcement will be required to ensure that vibration limits and tight tolerances on overbreak are met. Failure to meet the overbreak requirements will result in over-excavation beyond the emplacement room limits and will therefore impact the recommended room pillar width. See Section 4.5.1.4 regarding discussion of the pillar width requirements.

9.3.2.2 Assumed Excavation Sequence

During each underground excavation advance, in-situ rock stresses redistribute themselves around the opening, the magnitude of which depend upon the size of the opening created. If the opening is too large, the rock stresses result in overstressing or fracturing of the rock mass leading to rock fallout and potential instability. Smaller openings and advance lengths reduce the stress redistribution that occurs and due to reduced mucking volumes, allow a more timely installation and a reduction in the amount of the support that is required.

Practical advance lengths and excavation opening sizes have been selected, which will permit an efficient excavation and support sequence. For project planning purposes, it is currently assumed that full-width excavation will be used for development of the emplacement room and access tunnel excavations and that advance lengths will be on the order of 4 m. In some areas, partial-face excavation methods will be required to reduce risk of rock falls on workers in larger excavations. Partial-face excavation can be achieved by limiting the height and/or width of the excavation face. The excavation sequence in the larger DGR excavations will be considered in greater detail in the next phase of engineering.

Given the size of the openings for the DGR, rock support will be required between advance lengths in the DGR. The timing and magnitude of that rock support will depend upon in-situ stress levels, their orientation relative to the excavation opening, strength properties of the rock mass around the excavation, the size of the excavation and the time available for its installation. For a number of reasons, the most important of which is worker safety, timely installation of overhead rock support is required.

Drawings H333000-WP408-20-042-018 and H333000-WP408-20-042-019 show more details on the proposed excavation sequence for the access tunnels and emplacement rooms respectively.

9.3.2.2.1 Heading and Bench

The full height of excavations for the emplacement rooms and access tunnels vary between 7.0 and 8.5 m high which is considered to be too high at these stress levels to permit safe work beneath prior to rock support installation. Thus, a heading and bench advance as shown in Figure 9-7 should be used to limit the height of the initial excavation (refer to drawing H333000-WP408-20-042-0018 for qualifying note).

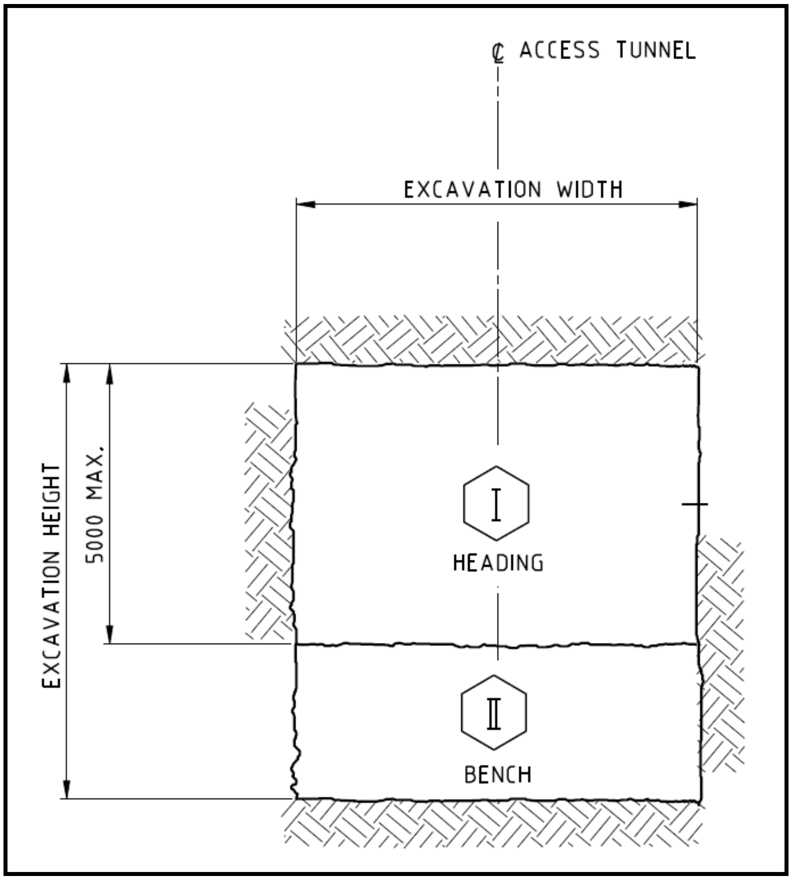


Figure 9-7 – Proposed Heading and Bench Sequence to be Used for Access Tunnels

Use of a heading round followed by rock support installation (and prior to the bench round) limits the vertical span of excavated walls and reduces the risk of rock failure in pillar walls between rooms. Use of a bench would minimise the volume of rock to be mucked out (and hence time required) before bolting can commence. Full face excavation will likely be possible for smaller openings.

Due to the combination of in-situ stresses and rock strength parameters at the DGR site, rock bolts and other support such as shotcrete are necessary to hold overstressed and fractured material in place so that it cannot loosen and destabilise. There are a number of reasons for this:

- Due to concerns with respect to potential roof slabbing and worker safety, it is important to install rock support as soon as possible after detonation of the blasted round. Use of a bench will minimise the volume of rock to be mucked out (and hence time required) before bolting can commence. While bolting could be done from the muck pile, this will make this operation less efficient and more difficult.
- Failed rock in the pillar walls between rooms is proportional to the height of the exposed wall. This rock will be fractured and rock support will be necessary to hold it in place. Use of a heading round followed by support installation prior to the bench round limits vertical span of excavated walls prior to installation of rock bolts and shotcrete along the walls.
- To reduce the room height relative to room width for each blast round. A full face excavation (versus a full width heading followed by bench) potentially puts workers at greater exposure to side-wall rock fall out. It should be noted that in order to maintain the efficiency of the work cycle, shotcrete installation on the roof and walls would occur several rounds behind the face.
- Bench excavations can be accomplished beneath fully supported back and walls allowing longer advance lengths for the bench and hence efficiency.

While full-face excavation methods were achieved in both Darlington NGS Cooling Water Intake and Discharge Tunnels for similar size excavations and rock strength conditions, it should be noted that these were accomplished under considerably reduced in-situ stress conditions. Correspondingly, full-face excavation methods may not be possible in DGR access tunnels and emplacement rooms.

This benching requirement may be revisited and relaxed in areas of higher strength rock, where measured stress levels are low enough, and in smaller opening sizes. Full face excavation will likely be possible for smaller openings such as ancillary rooms, shaft walkway access and the shaft bottom access ramp.

9.3.2.2.2 Full-Width / Part Width Excavation

The maximum advance length that can be safely achieved for full width excavations was assessed using three dimensional numerical modelling [R50]. Modelling results such as rock stress failure condition and convergence were examined as the simulated excavation face approached, reached and passed relative to a particular section of the model. To determine the maximum safe advance length using the model, the results were reviewed to predict the length of full-width excavation that could be achieved in an unsupported roof before a predicted fallout mechanism would develop.

Application of the modelling over the full range of expected, credible rock mass strength and in-situ stress conditions permitted an assessment of the maximum advance length applicable to each condition. If the modelling of a full-width excavation showed that a 4.0 m advance length could be achieved without fall-out for a given stress / strength condition, then a full-width excavation was considered practical. The probability of occurrence of each rock mass condition allowed assessment of the likelihood of achieving a 4.0 m long advance over the range of conditions. If this advance length could not be achieved, then a part-width excavation was deemed necessary.

The results of the modelling indicate that part-width excavation sequence is expected to be required for up to 25% of the emplacement rooms (7.25 equivalent room lengths).

For access tunnels, the use of a heading and bench sequence to reduce the height of the excavation taken in each advance combined with engineering judgment allowed the full-width excavation sequence shown on the design drawings. Additional confirmatory modelling will be performed in the next stage of engineering to assess excavation sequence in access tunnels including the need for a heading and bench.

9.4 Development and Construction Schedule

The creation of the DGR is a multi-year project, which will begin with basic site preparation, including drainage and containment and progress through establishing key building foundations and their erection, sinking two shafts, connecting the shafts at the DGR level to establish a ventilation circuit, development of a ramp to the shaft bottoms, lateral and vertical development, construction of selected underground infrastructure items and development of the emplacement rooms. Following this construction period, certain temporary construction facilities will be demolished or removed and other permanent facilities will be constructed.

9.4.1 Construction Approach

The development and construction objective is to complete these activities for the DGR in a reasonable and efficient timeframe. To achieve this objective, the sinking of the shafts will be undertaken as parallel activities. The lateral development of the DGR underground level and construction of the underground facilities will utilise the multiple headings and workplace opportunities to the fullest extent possible.

The first stage focuses on the construction of headframe and building foundations, shaft collars, pre-sink and ground freezing to facilitate the sinking through the permeable Reach 2a Dolostones. During this time the site will be cleaned and graded suitable for construction and the main site electrical substation will be built. Power for the initial construction activities will be supplied from an existing Hydro-One substation, which is around 500 m from the DGR Project Site. This early availability of power will enable construction activities to commence promptly after approval to proceed with the DGR construction is given.

The second stage of construction focuses on the erection of the headframes and most of the permanent buildings. The temporary sinking hoist and winch houses will also be constructed along with all the hoist installations for the sinking phase.

Once the facilities are commissioned for sinking, the shafts will be sunk approximately in parallel to the DGR horizon at about 686 m BC. The Main Shaft would excavate the proposed geoscience sub-drift in the Reach 3 shales as the shaft passes this level (see Section 4.3.6.4). Once at the DGR level, both shafts will shift to lateral excavation of the shaft stations and facilities that are required for lateral development of the DGR after the shaft sinking. The shafts will then continue to the bottom and the shaft bottom ramp will be driven.

The shaft lining is installed in two segments: first the Reach 2 section will be constructed after the bentonite seal is constructed at the Reach 2b / Reach 3 interface and the Reach 3 and 4 section after the sinking and initial development is complete. The shaft steel and equipping installations will follow the lining.

The Main Shaft will then be changed over to the permanent configuration with the two Koepe friction hoists and cages being installed in the concrete Main Shaft Headframe. The Ventilation Shaft will change over to the skipping configuration and complete the installation and commissioning of the loading pocket and rock handling facilities. During this transition period, close coordination of the short-term scheduling will be required to ensure continual primary and secondary access to the DGR and shaft bottom levels to maintain pumping.

This time period will also facilitate a window of opportunity to conduct geotechnical studies and drilling prior to undertaking the full lateral development program. The initial lateral development work will provide ample tunnel length away from the shafts to mobilise diamond drills.

The initial DGR construction will commence with the Main Shaft and utilise two construction and equipping crews to build the permanent electrical, communications, rock handling, refuge station and pumping facilities. The main lateral development equipment will be mobilised to the DGR level near the end of this construction stage.

At this stage, lateral development will commence with a progressive build-up of equipment as space becomes available. The construction of the remaining Shaft and Services Area facilities will be completed as soon as possible to provide support to the ongoing development program.

Once Panel 1 emplacement room development has progressed adequately to allow a continuous construction program to be implemented, the construction of the rooms will commence. This work, which includes installation of concrete floors, piping, cabling, lighting and other services, will follow closely behind the mining development, completing shortly after the development. The access tunnels are constructed on a retreat basis to ensure the concrete floors are not damaged by ongoing development haulage activities.

Figure 9-8 through Figure 9-12 provide a graphic depiction of the shaft sinking and DGR lateral development at key points in the DGR development.

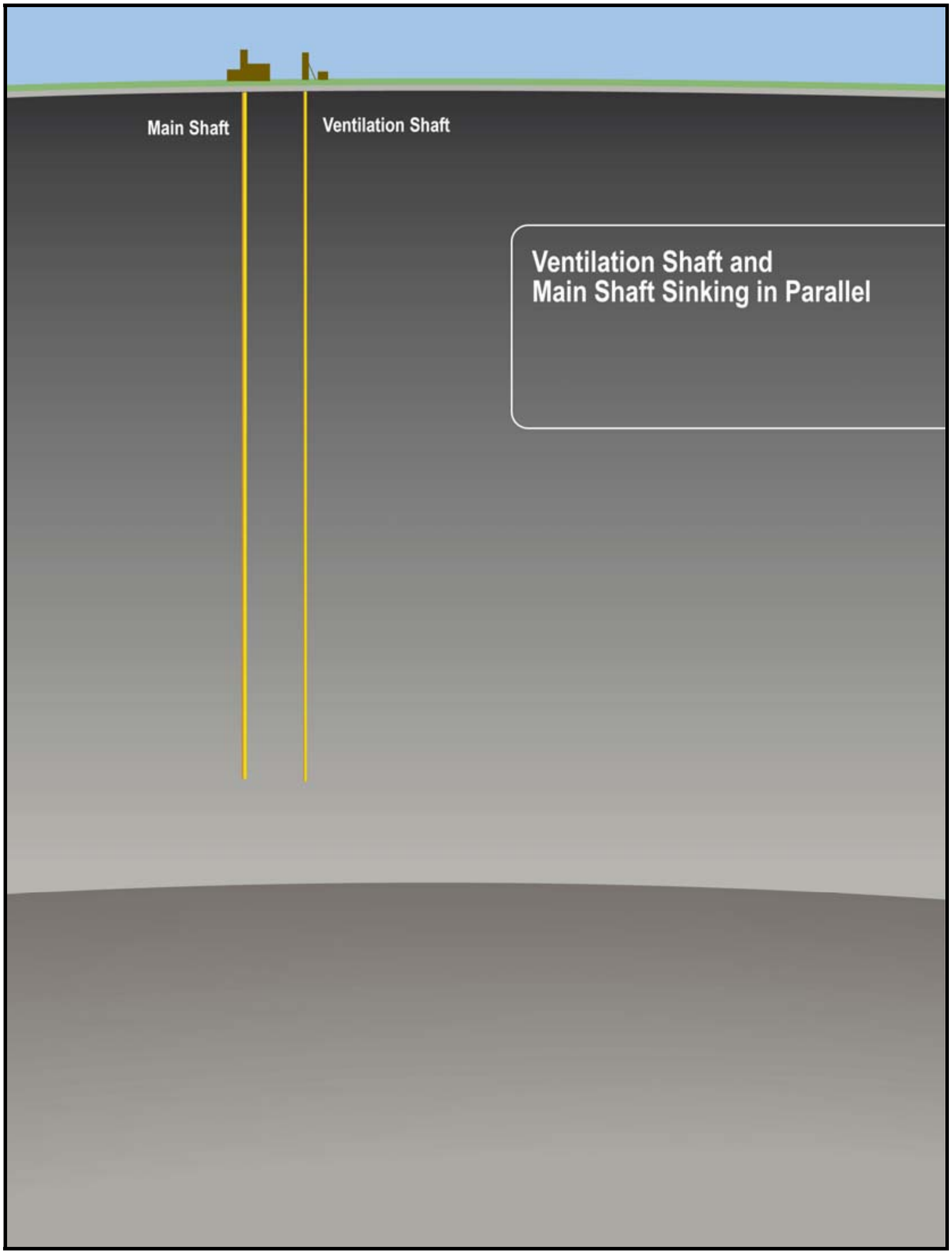


Figure 9-8 - Shaft Sinking – Stage 1

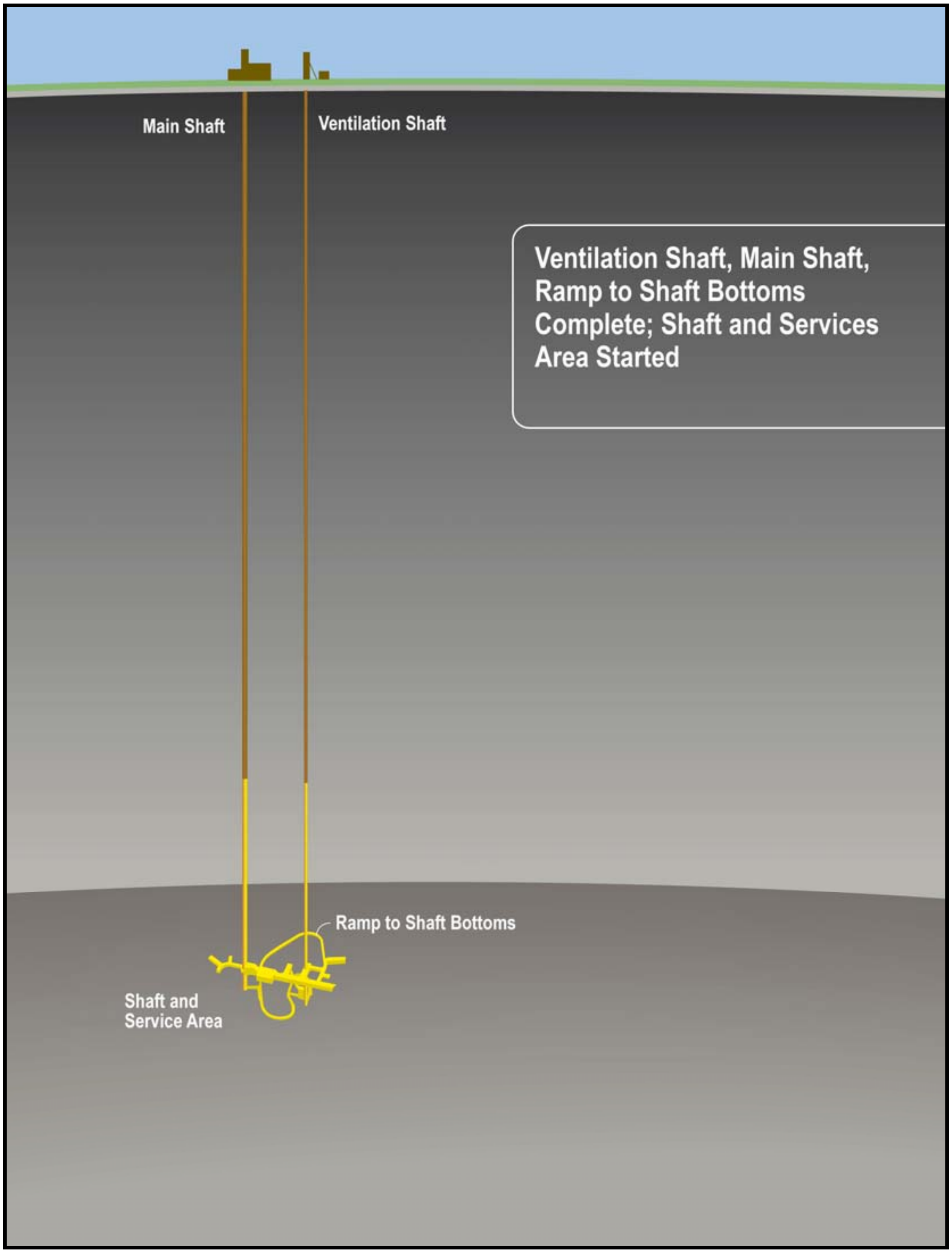


Figure 9-9 - Shaft Sinking and Initial DGR Development– Stage 2

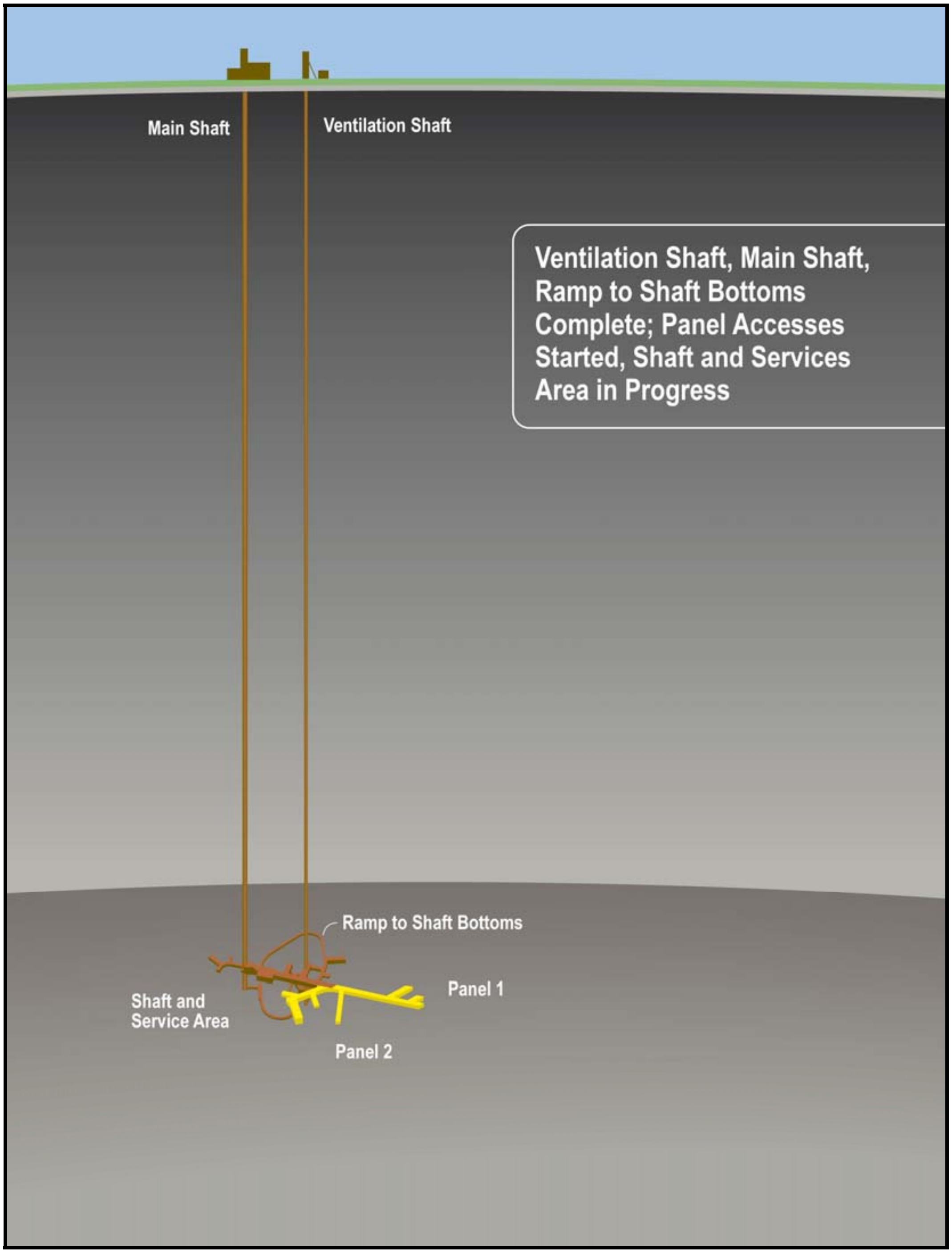


Figure 9-10 - Initial DGR Lateral Development – Mobilising

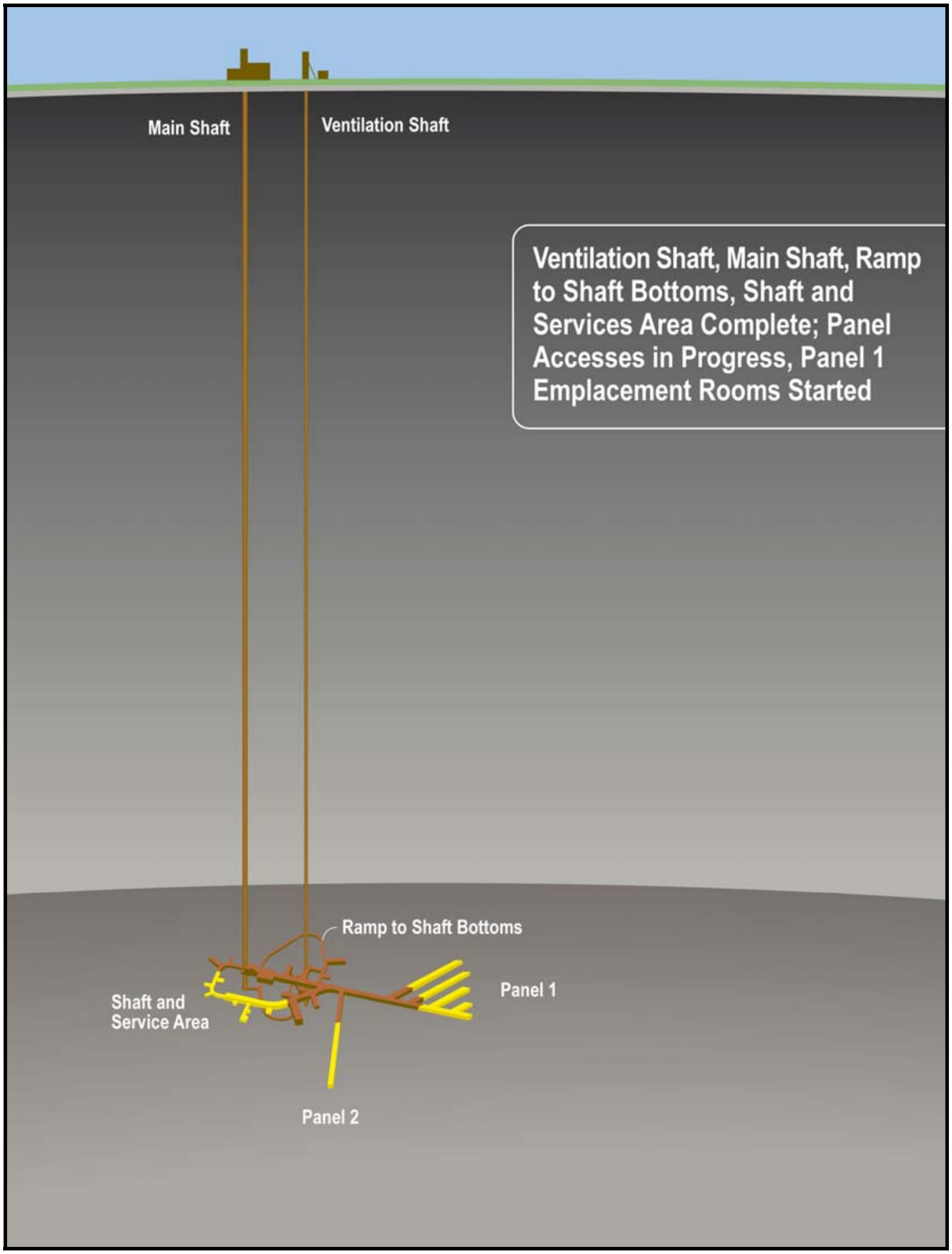


Figure 9-11 - Ramp-Up of Lateral Development – Multiple Workplaces

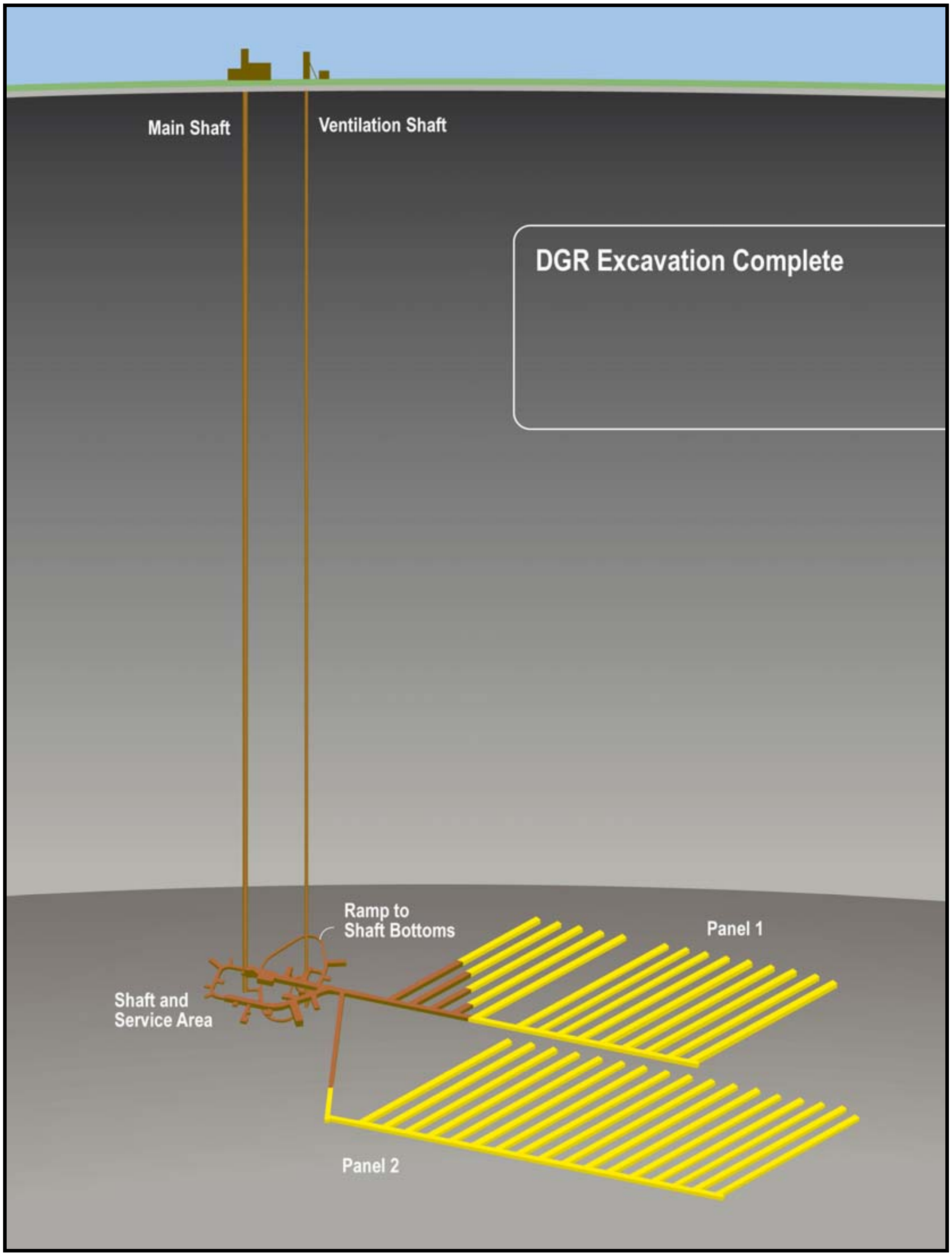


Figure 9-12 - DGR Development Complete

9.4.2 Critical Path

The ground freezing and primary foundations are critical for both shafts and thus have a crew dedicated to each for drilling of the ground freezing boreholes and constructing the headframe and building foundations.

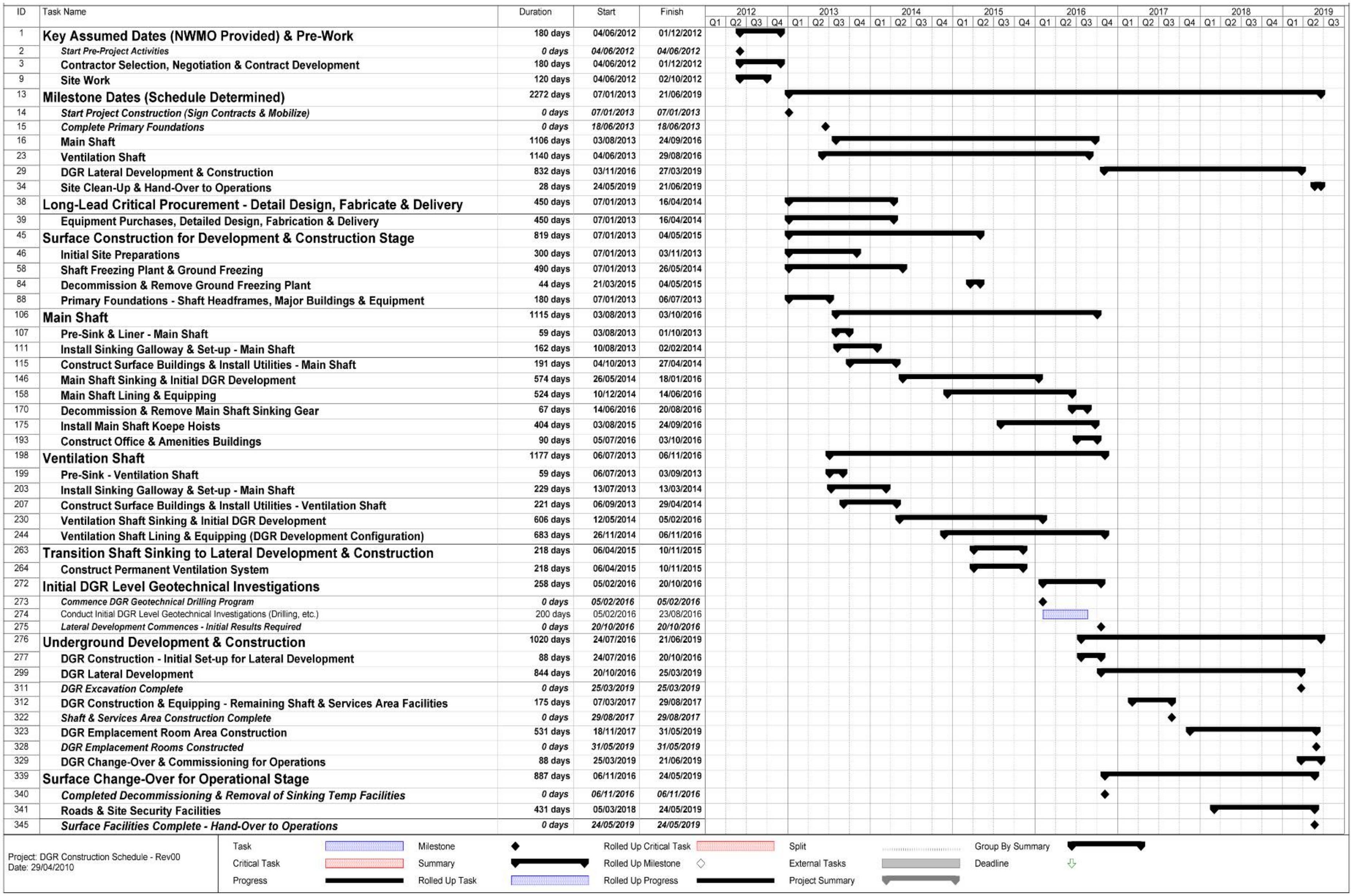
The Main Shaft sinking bucket hoist, Ventilation Shaft hoist and the surface substation electrical equipment are all close to critical path and will be dependent on confirmation of the currently assumed fabrication and delivery durations.

For the Main Shaft, the critical path flows through the pre-sinking and headframe construction. There are several parallel activities to erect and install the sinking hoist, Electrical Room for the low voltage switchgear and MCCs, Air Compressor Plant and each of these are on or close to critical. Once the shaft sinking equipment is commissioned for sinking, the shaft and initial DGR lateral development fall on the critical path.

For the Ventilation Shaft, the critical path is the erection of the headframe followed by the construction and installation of the hoist building and hoist installation. Also, as with the Main Shaft, once the sinking equipment is commissioned for sinking, the shaft and initial DGR lateral development will be on the critical path.

The development of the underground Shaft and Services Area and emplacement rooms provides multiple workplaces and, therefore, there is no one specific critical path. Instead there are a couple of critical processes that will require similar levels of focus: the rock handling and skipping system, the development jumbo and the rock bolter. The emplacement room construction will follow behind the development with free float; however, the last emplacement rooms, the Panel 2 access and South Access Tunnels become critical path to complete the facilities.

A high level summary of the schedule is given in Figure 9-13. Completion of the project construction and commissioning, and hand-over to operations is forecast for mid 2019, which assumes a commencement of site construction in January 2013. At the level of this preliminary design, this date is considered to be realistic. However, it is noted that there are opportunities for shortening the project duration and possibly meet the current assumption of a start of operations in 2018 (refer to Section 10.1). Activities that present the opportunities are the initial shaft set-up and pre-sink prior to full shaft sinking, sequencing of the ramp development, and possible greater rock hoisting capacity during lateral development.



ID	Task Name	Duration	Start	Finish
1	**Key Assumed Dates (NWMO Provided) & Pre-Work**	180 days	04/06/2012	01/12/2012
2	*Start Pre-Project Activities*	*0 days*	*04/06/2012*	*04/06/2012*
3	Contractor Selection, Negotiation & Contract Development	180 days	04/06/2012	01/12/2012
9	Site Work	120 days	04/06/2012	02/10/2012
13	**Milestone Dates (Schedule Determined)**	2272 days	07/01/2013	21/06/2019
14	*Start Project Construction (Sign Contracts & Mobilize)*	*0 days*	*07/01/2013*	*07/01/2013*
15	*Complete Primary Foundations*	*0 days*	*18/06/2013*	*18/06/2013*
16	Main Shaft	1106 days	03/08/2013	24/09/2016
23	Ventilation Shaft	1140 days	04/06/2013	29/08/2016
29	DGR Lateral Development & Construction	832 days	03/11/2016	27/03/2019
34	Site Clean-Up & Hand-Over to Operations	28 days	24/05/2019	21/06/2019
38	**Long-Lead Critical Procurement - Detail Design, Fabricate & Delivery**	450 days	07/01/2013	16/04/2014
39	Equipment Purchases, Detailed Design, Fabrication & Delivery	450 days	07/01/2013	16/04/2014
45	**Surface Construction for Development & Construction Stage**	819 days	07/01/2013	04/05/2015
46	Initial Site Preparations	300 days	07/01/2013	03/11/2013
58	Shaft Freezing Plant & Ground Freezing	490 days	07/01/2013	26/05/2014
84	Decommission & Remove Ground Freezing Plant	44 days	21/03/2015	04/05/2015
88	Primary Foundations - Shaft Headframes, Major Buildings & Equipment	180 days	07/01/2013	06/07/2013
106	**Main Shaft**	1115 days	03/08/2013	03/10/2016
107	Pre-Sink & Liner - Main Shaft	59 days	03/08/2013	01/10/2013
111	Install Sinking Galloway & Set-up - Main Shaft	162 days	10/08/2013	02/02/2014
115	Construct Surface Buildings & Install Utilities - Main Shaft	191 days	04/10/2013	27/04/2014
146	Main Shaft Sinking & Initial DGR Development	574 days	26/05/2014	18/01/2016
158	Main Shaft Lining & Equipping	524 days	10/12/2014	14/06/2016
170	Decommission & Remove Main Shaft Sinking Gear	67 days	14/06/2016	20/08/2016
175	Install Main Shaft Koepe Hoists	404 days	03/08/2015	24/09/2016
193	Construct Office & Amenities Buildings	90 days	05/07/2016	03/10/2016
198	**Ventilation Shaft**	1177 days	06/07/2013	06/11/2016
199	Pre-Sink - Ventilation Shaft	59 days	06/07/2013	03/09/2013
203	Install Sinking Galloway & Set-up - Main Shaft	229 days	13/07/2013	13/03/2014
207	Construct Surface Buildings & Install Utilities - Ventilation Shaft	221 days	06/09/2013	29/04/2014
230	Ventilation Shaft Sinking & Initial DGR Development	606 days	12/05/2014	05/02/2016
244	Ventilation Shaft Lining & Equipping (DGR Development Configuration)	683 days	26/11/2014	06/11/2016
263	**Transition Shaft Sinking to Lateral Development & Construction**	218 days	06/04/2015	10/11/2015
264	Construct Permanent Ventilation System	218 days	06/04/2015	10/11/2015
272	**Initial DGR Level Geotechnical Investigations**	258 days	05/02/2016	20/10/2016
273	*Commence DGR Geotechnical Drilling Program*	*0 days*	*05/02/2016*	*05/02/2016*
274	Conduct Initial DGR Level Geotechnical Investigations (Drilling, etc.)	200 days	05/02/2016	23/08/2016
275	*Lateral Development Commences - Initial Results Required*	*0 days*	*20/10/2016*	*20/10/2016*
276	**Underground Development & Construction**	1020 days	24/07/2016	21/06/2019
277	DGR Construction - Initial Set-up for Lateral Development	88 days	24/07/2016	20/10/2016
299	DGR Lateral Development	844 days	20/10/2016	25/03/2019
311	*DGR Excavation Complete*	*0 days*	*25/03/2019*	*25/03/2019*
312	DGR Construction & Equipping - Remaining Shaft & Services Area Facilities	175 days	07/03/2017	29/08/2017
322	*Shaft & Services Area Construction Complete*	*0 days*	*29/08/2017*	*29/08/2017*
323	DGR Emplacement Room Area Construction	531 days	18/11/2017	31/05/2019
328	*DGR Emplacement Rooms Constructed*	*0 days*	*31/05/2019*	*31/05/2019*
329	DGR Change-Over & Commissioning for Operations	88 days	25/03/2019	21/06/2019
339	**Surface Change-Over for Operational Stage**	887 days	06/11/2016	24/05/2019
340	*Completed Decommissioning & Removal of Sinking Temp Facilities*	*0 days*	*06/11/2016*	*06/11/2016*
341	Roads & Site Security Facilities	431 days	05/03/2018	24/05/2019
345	*Surface Facilities Complete - Hand-Over to Operations*	*0 days*	*24/05/2019*	*24/05/2019*

Figure 9-13 - Schedule for the Repository Development

9.5 Changeover Following Completion of Underground Development

Following the completion of the underground lateral development and the departure of the contractor's development equipment, the final processes to complete the preparation of the DGR for waste emplacement will commence. These activities will take place in two geographical areas, on surface and underground and the activities are described in the subsequent two sub-sections.

9.5.1 Underground

Underground construction activities will be carried out in parallel with lateral development in the emplacement panels and, by the completion of the lateral development, most construction work will be completed. Panel 2 will have approximately a third of the emplacement rooms at the end of the panel farthest from the shaft, the Panel 2 Access Tunnel and South Access Tunnel, which will require final work on the ventilation ducting, permanent services and concrete floors left to complete.

In addition to these activities, the waste rock handling system will have to be put into a state suitable for extended care and maintenance from the dump through to the loading pocket. As part of future engineering, consideration should be given to the support requirements for the dump raise to ensure that this system is capable of being reactivated, should it be required either for excavation maintenance or for potential future expansion of the repository.

The concrete / shotcrete system in the Ventilation Shaft will be required for the final emplacement room and access tunnel construction activities. It will likewise be cleaned up and prepared for extended care and maintenance for any potential future expansion of the repository, should this occur.

The operating underground fleet of equipment for emplacement will be brought underground and assembled as required by a joint Contractor and Operations Group to familiarise the latter with the correct procedures to move their equipment in and out of the repository. This includes both the rubber tired and rail-bound units. It is assumed that the contents of the various offices, geotechnical laboratory and the workshop in the underground Shaft and Services Area and any small equipment for the emplacement rooms will be brought down as one of the first tasks in Operation's tenure and would not include any work by contractor crews.

It is assumed that any monitoring or control data from the various systems will be being stored on Operation's servers to establish monitoring baselines by this point and no transfer of such data will be required.

Following these last tasks, the repository will be ready for emplacement to commence from spatial, services and equipment perspectives.

9.5.2 Surface

By the time underground development is completed and the development contractor is demobilised, there will be minimal work remaining to be performed on surface. The only major item remaining will be to remove the temporary construction roads and yards, recondition and re-grade the site and prepare and lay the final road surfaces for operations. Material storage areas for key materials such as spare shaft sets, spare hoist ropes and reels and the one removed Ventilation Shaft skip, which will have been replaced by a cage, will have to be established as part of the surface yard restructuring. Several gate closures will be required to direct traffic flow through the WWMF and over the railway ditch crossing to the DGR instead of using the direct access to the isolated construction island, which had been previously employed during construction.

9.6 Construction Labour Requirements

During construction there will be changes in the number and types of labour as activities occur and interact. The labour profile is based on a three shifts per day rotation during construction and is specified in Table 9-2.

The following assumptions were considered in determining the labour requirements of the project:

- Surface labour requirement are assumed for a 8 h/d, 5 days/week work plan.
- Shaft sinking labour requirements are indicative of both shafts being sunk concurrently. Therefore, quantities have been doubled to account for both. Shaft sinking labour requirements assumes three shifts at 8 h/d, 7 days/week. Quantities indicated are per work shift, not work day.
- Lateral Development labour requirements assume three shifts at 8 h/d and 7 days/week. Quantities indicated are per work shift, not work day.
- No allowance is made for additional labour that is required to cover rotation, vacation and sick time for all 24 h / 7 d activities.
- The peak loading will occur during weekday shifts when all management and support personnel will be on site. During afternoon, night and weekend shifts, these persons would not normally be expected to be on site.

Peak Man Power by Activity					
Surface Work	**#**	**Shaft Sinking**	**#**	**Lateral Development**	**#**
Project Management	6	Project Management	6	Project Management	6
Site Superintendents	2	Site Superintendents	2	Site Superintendents	2
Engineering Support	3	Engineering Support	4	Engineering Support	4
PM Office Support	6	PM Office Support	8	PM Office Support	8
Contractor Office Support	8	Contractor Office Support	8	Contractor Office Support	8
Foremen	5	Foreman	4	Foreman	2
Carpenters	24	Shaft Leader	2	Tunnel Leader	1
Labourers	22	Clam Operator	4	Jumbo Operator	1
Iron Workers	18	Shaft Miner	12	Shotcrete Pump Operator	2
Millwrights	12	Shaft Labour	8	LHD Operator	1
Pipefitters	6	Jumbo Operator	2	Truck driver	2
Operators	8	Bolter Operator	2	Small Backhoe Operator	2
Electrician / Technician	6	Shotcrete Pump Operator	2	Tunnel Miner	6
		LHD Operator	4	Tunnel Labour	4
		Truck driver	6	Hoist Operator	2
		Tractor / Backhoe Operator	2	Deck Man	2
		Small Backhoe Operator	2	Electrician / Technician	1
		Remixers Operator	6	Mechanic	2
		Explosive Loader Operator	2	Welder	1
		Loading Pocket	2	Loader Operator	1
		Hoist Operator	2	Dozer Operator	1
		Deck Man	4	Fork Lift Operator	2
		Electrician / Technician	2	Yardman	1
		Mechanic	4	Drill Doctor	1
		Welder	2	Dryman	1
		Loader Operator	2		
		Small Loader Operator	2		
		Dozer Operator	2		
		Fork Lift Operator	4		
		Cherry Picker Operator	4		
		Surface Truck Operator	4		
		Yardman	1		
		Drill Doctor	1		
		Dryman	1		
Total Man Power	**126**		**123**		**64**

Table 9-2 - Construction Labour

9.7 Construction Equipment Requirements

During construction, it is assumed that the various contractors will provide the majority of their own equipment, both fixed and mobile. This includes everything from small hand tools up to major items like sinking winches and galloway equipment. Several key exceptions to this are the Ventilation Shaft hoisting plant, the main site electrical substation and the concrete batch plant.

Diesel equipment has been extensively used in underground mining and civil projects with many years of successful operational experience. Ventilation for the facility has been designed to meet the required legislation for diesel use underground as defined in [R48]. Diesel equipment allows for greater flexibility and range and does not require extensive electrical services for tethering or battery charging stations that other options would require. As a result, it is particularly well suited to multi-heading work areas, which will be present during development of the repository.

Some of the key equipment that would be used during construction and their basic specifications have been listed in Table 4-11. The development equipment fleet would include Load-Haul-Dump (LHD) and haul trucks, which are large and may set excavation dimensions. In addition to this development equipment, there will be a number of other types of underground mobile equipment including, but not limited to, computerised electro-hydraulic drill jumbos, mechanised bolters, shotcrete sprayers, etc. and surface loaders and haulage trucks, etc. Table 9-3 below provides the anticipated fleet makeup. For those pieces which operate underground, an assumed engine power rating for a single unit is presented consistent with ventilation system assumptions.

Equipment	Number of Units	Rated Power (kW)
Drill Jumbo (E/H)[1]	2	58 (Moving)
LHD	2	200
Bolter (E/H)	2	55 (Moving)
Shotcrete Sprayer (E/H)	2	142 (Moving)
Shotcrete Transmixer	4	179
Haul Trucks	4	304
Backhoe Tractor	1	51
Explosives Carrier	1	179
Ramp LHD	1	72
Personnel Carriers	3	97
Fixed Rockbreaker (E/H)	1	
Surface Loaders	2	
Surface Haul Trucks	4	
Surface Forklift	1	
Ramp LHD	1	

[1] Denotes electric / hydraulic equipment which is moved by diesel power

Table 9-3 - Anticipated Construction Mobile Equipment Fleet

9.8 Construction Facilities and Services

The following facilities will be provided to the contractors working in the DGR construction island and will apply to both surface construction and underground contractors following initial site preparation by a third party contractor:

- Site access to the fenced and gated construction island.
- A levelled, graded and drained yard area with temporary construction roads in place for trailers and material storage.
- Power for all equipment at 13.8 kV, 4160 kV and 600 kV at the main electrical substation, which will be installed upon project approval.
- Process water connection point – common for all construction users.
- Communication connection point - common for all construction users.

All other facilities and services will be provided by the respective site contractors. A connection to existing sewer lines will not be provided during construction. The exact distribution of shared services such as road maintenance, snow removal, etc., will be determined in later engineering study.

9.9 Commissioning

Commissioning of the DGR facilities will likely present one of the most intensive periods of activity in the DGR as a result of the interaction of facilities and the various duty configuration changes, which will occur. Commissioning will also be required during construction not only for the permanent facilities, which are installed to support construction, but also for the temporary facilities installed by the construction contractors. Having a consistent commission plan with well documented protocols and procedures will ensure a smooth transition from physical completion of facilities through ramp-up to their full operation. Failure to properly plan the commissioning activities will result in increased costs, schedule delays, or compromises in quality and may also impact overall security and reliability of the facilities. The commissioning process is most effective when it begins during construction and follows a well developed plan which considers individual facilities, their interactions from the completion of installation of all components which make up the facility, through testing and verification, initial test operation, operational criteria proving and finally ramp up to normal operations.

In order to accomplish this, an overall approach will be documented at the program level to outline the requirements and define processes, which will be applied at the facility level in the development of facility specific commissioning plans consistent with the guidelines of the commissioning program. The program document and the various facility plans will generally cover the same topics and take the same format although at a different level of detail. This program will affect construction activities and will be detailed in later engineering, but prior to the letting of construction contracts.

The following is an example of the contents of a typical commissioning document which may be used at either the program or facility level. For facilities, it will need to be developed down to the individual facility sub-systems in some cases where complex interactions or staged operation are present. An example of this would be the Ventilation Shaft hoisting system, which will serve as a skip-cage system, a skip-skip system and then a skip-cage system again. The main sections of the commissioning document are listed as follows:

- Introduction of how commissioning fits into the project.
- Extent of work and groups involved.
- Organisation to include Client, engineers, contractors and vendors required.
- Commissioning schedule with sequence of work and key dates.
- Individual equipment testing procedures, including details of tagging safety for equipment commissioning, vendor requirements, performance tests.
- Facility testing procedures to prove process flow operation of combined individual components of facility (e.g. hoisting rock from loading pocket to dumping inclusive).
- Safety requirements over and above those identified by the commissioning team and vendors for individual items of equipment.
- Handover procedure for individual components, separable portions of the facility and the complete facility.

During facility commissioning, appropriate records are to be maintained outlining all activities undertaken against plan, including methods used, checks performed, adjustments made, results obtained and final as-commissioned settings. These records will be compiled into a facility commissioning report so that an archive of commissioning is established and maintained. Compilation of the various facility reports will form the overall commission report.

9.10 Potential for Future Expansion

The System Requirements [R46] for the design of the DGR facility outlines that the emplaced volume of waste packages to be stored is approximately 200,000 m^3 over approximately a 35 year period. This volume assumes ongoing OPG nuclear waste generation at current levels and no plant decommissioning waste has been considered in this volume. At a conceptual level, a repository with the capability of storing 400,000 m^3 of emplaced waste packages was laid out with two additional emplacement panels to the south of those for the 200,000 m^3 case. The panel configuration maintains the basic format of Panels 1 and 2 and they are accessed by an extension of the south Access tunnel past Panel 2. It was assumed that the levels of emplacement activity would be similar to those of Panels 1 and 2 and, therefore, no upgrades or expansion of the infrastructure would be required. This will require further study in future stages of engineering to improve the understanding of the impact of DGR expansion on the current design.

It is key to note, however, that there is to be no concurrent mining and emplacement as outlined in the System Requirements [R46]. Therefore, emplacement activities will have to cease and any clean-up done to the repository to make it suitable to a mining contractor to move in to create new emplacement space. It is assumed that the Ventilation Shaft configuration with a skip and cage would be suitable for the expansion development. However, should it be necessary, the skip used in the initial development period could be re-installed and similar transport protocols reinstated as were used in the initial development campaign. Ventilation to any filled or partially filled emplacement rooms, which are not behind an explosion resistant closure wall would have to be maintained and the exhaust ducting monitored for any damage during mining. Prompt repairs would have to be made in the same manner as when there were emplacement activities occurring.

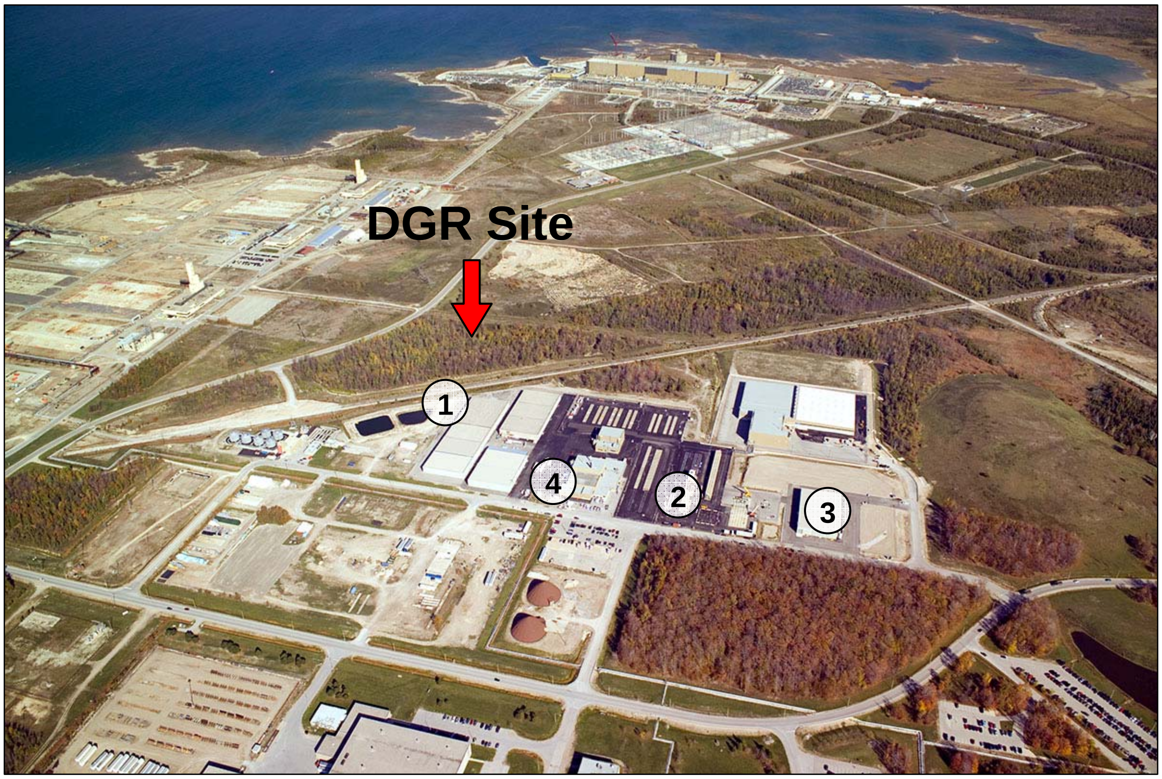
On surface, the waste rock pile could be expanded and increased in height to accommodate both the limestone extracted during excavation of the original 200,000 m^3 waste package capacity DGR and the rock produced as a result of expansion.

10. Repository Operations and Maintenance

10.1 Schedule and Sequence of Waste Transfer and Emplacement

10.1.1 Overview

OPG plans to begin operating the proposed DGR facility in 2018 following the completion of commissioning. It is currently assumed that the DGR will operate for about 40 years and near the end of the facility operations, OPG would seek regulatory approval to decommission the facility and to seal the shafts (see Section 11).



Key: 1) Low Level Storage Buildings (LLSBs)
2) In-ground Containers for ILW
3) Refurbishment Waste Storage Buildings
4) Waste Volume Reduction Building (WVRB)

Figure 10-1 – Aerial view of OPG's WWMF (October 2007)

DGR operations will be integrated with the overall operations of OPG's existing WWMF. All staff and visitors will access the DGR via the WWMF. The DGR will receive all waste through the WWMF, where the existing facilities will be used to process and package the waste prior to transfer to the DGR's WPRB. About 50,000 waste packages will be transferred to the DGR over the operating life of the repository. Figure 10-1 shows the location of various buildings at the WWMF and the proposed location for the nearby DGR surface facilities.

10.1.2 Schedule and Sequence of Waste Package Receipts

The majority of waste packages to be received by the DGR will be in a disposal-ready state as defined by the DGR WAC (see Section 3). The waste packages will be delivered by forklift, covered truck, or flat-bed truck to the WPRB. At the WPRB the waste packages will be off-loaded to a staging area or directly onto self-propelled rail carts for movement into the Main Shaft cage and then transferred underground. Once underground, the wastes will be delivered to appropriate emplacement rooms by either forklift or rail cart (see Section 6).

This design study has assumed that the operation of the DGR will span a period of about 40 years, which will be divided into three distinct phases:

1. Initial Operation Phase – 5-year period when waste packages in the WWMF storage buildings are transferred to the DGR. During this period, some of the wastes that are stored in-ground at the WWMF and new L&ILW (i.e. new waste received at the WWMF after start of DGR operations) would also be transferred to the DGR.
2. Steady-State Operation Phase – 30-year period when the DGR receives new L&ILW as well as smaller quantities of waste packages from various in-ground storage structures.
3. Extended Monitoring Phase – 5-year period following completion of waste emplacement operations when the facility performance will be monitored in preparation for decommissioning and sealing of shafts.

Additionally, three emplacement periods identify the times at which Panel 1 and two portions of Panel 2 are closed off by a closure wall (see Sections 4.5.4, 5.4.3 and 10.5). Emplacement Period 1 covers the Initial Operation Phase, and Emplacement Periods 2 and 3 fall into the Steady-State Operations Phase. These emplacement periods are defined in the context of the rooms they encompass in Table 10-2, and the waste package types and operations phases in Figure 10-2.

The following sub-sections describe the schedule and sequence of waste receipts at the DGR during the Initial Operation and Steady-State Operation phases.

Table 10-1 gives the assumed schedule for retrieval of waste from WWMF storage and Figure 10-2 provides a more detailed schedule showing when various package types would be received at the DGR. Details regarding the allocation of waste packages to various emplacement rooms and stacking arrangements can be found in Section 6.3. The sequence in which emplacement rooms are filled in each panel is shown on drawings H333000-WP408-20-042-0001, -0005 and -0006.

10.1.2.1 Initial Operation Phase

The Initial Operation Phase will span approximately 5 years and during this period approximately 65 per cent of the total waste inventory will be delivered to the DGR. The emplacement rooms in Panel 2 would be filled during this period. At the end this five-year period, a closure wall would be built at the front (west) end of the Panel 2 Access Tunnel to isolate the rooms in Panel 2 and all waste emplacement operations would then move to Panel 1. The closure walls are described in Section 10.5.2.

During this phase, the majority of the waste received at the DGR will be in the form of existing packages that have been retrieved from various WWMF storage structures. There will also be a relatively small number of waste packages delivered to the DGR containing new L&ILW arising from nuclear generating station operations (see Sections 6.1 and 10.1.2.2 for procedures by which these wastes will be received at the DGR). Mainly Group A waste packages will be emplaced in the Panel 2 rooms (see Figure 10-2).

It is expected that the majority of LLW packages retrieved from LLSBs will be transferred “as is” to the DGR. However, all LLW packages will be inspected and if any are found to be damaged, have high radiation levels or are otherwise unacceptable for emplacement in the underground repository, they will be placed into an overpack container. The waste packages will be delivered by forklift or flatbed truck to the WPRB, and then loaded onto a rail cart for transfer into the Main Shaft cage. The rail cart with packages will be unloaded from the cage and then transported by forklift to the LLW emplacement rooms. The LLW packages will be stacked in the emplacements rooms as described in Section 6.3.

ILW is currently stored in the WWMF in-ground structures that provide shielding against gamma radiation. These structures include concrete and steel-lined structures constructed in augured boreholes, concrete-lined and covered trenches and in above-ground concrete structures (these latter two structures are no longer receiving waste). In order to provide continuous shielding for workers during handling, it has been assumed that most ILW storage containers will be placed directly into sacrificial concrete shields after removal from their storage structures. The shields remain in place during movement to the repository, as well as after emplacement. Depending on the type of ILW and the size of the storage container, the full mass of a shielded ILW package is expected to be in the range of 5 to 35 tonnes with many of the packages having a mass in the order of 30 tonnes.

The Refurbishment Waste Storage Buildings at the WWMF currently contain waste materials from refurbishment activities at the Bruce A NGS. The irradiated fuel channel wastes are stored in Retube Waste Containers, which are reinforced concrete containers with inner and outer steel shells. These containers are disposal-ready and weigh approximately 30 tonnes. Steam Generators removed during refurbishment have been transferred intact to a storage building. Because of their mass and size, these Steam Generators will be segmented to allow transfer into the DGR. Further Steam Generators are currently planned to be transferred to the WWMF for segmenting in the future.

Storage Structure	Assumed Retrieval Schedule[18]	Comments
LLSB (DGR-ready containers)	Y1 – Y5	Mix of waste packages retrieved in sequence that they were stored. Packages will be staged, as required in LLSB, so that they are transferred in the correct sequence to DGR.
LLSB (containers requiring overpacking)	Y1 – Y5	Same as above but placement of storage containers into overpacks prior to transfer to DGR. Overpacking is required for ash bins, drums, LL resin boxes, sludge boxes.
Trenches	Y3 – Y12	Retrieval in May to October months only. Weather-related delays may occur.
Quadricell Resin Liners	Y3	
IC-2 & IC-18 Resin Liners	Y4 – Y8	
Tile Hole Liners	Y3 – Y4	
IC-2 & IC-18 T-H-E Liners	Y9 – Y27	
Heat Exchangers	Y4 – Y8	
Refurbishment Waste Storage Buildings – Retube Waste Containers	Y3	Containers will be DGR-ready.
Refurbishment Waste Storage Buildings - Steam Generators	Y3	Assumes that Steam Generators have been segmented and are ready for transfer to DGR.

Table 10-1 – Assumed Schedule for Transfer of Waste from Various WWMF Storage Structures

10.1.2.2 Steady-State Operation Phase

The Steady-State Operations Phase will span a 30-year period and all waste emplacement activities would occur in Panel 2. During this phase the majority of waste packages received at the WPRB will contain new waste arising from operations at the nuclear stations. The balance of waste package receipts will be comprised of the remaining waste in storage at the WWMF. It is assumed that the package delivery rate to DGR will be significantly lower relative to the Initial Operation Phase.

LLW, that is processible, will first be delivered to the WVRB at the WWMF (see Figure 10-1). At the WVRB, the LLW will be processed by either compaction or incineration to reduce volume and space required for disposal in the DGR. As per current practice, the LLW will be placed in stackable carbon-steel containers and these waste-filled containers will then be taken directly to the DGR's WPRB. LLW that can neither be compacted nor incinerated will be placed into metal bins as-received and without processing at either the nuclear generating stations or the WVRB. If packaged at the stations, the non-processible wastes may by-pass the WVRB and be delivered directly to the WPRB. In this case, WAC inspections to verify the packages are DGR-ready and integration into the IWTS will be required at the WPRB.

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[18] "Y1" means "Year 1", etc.

As per current practice new ILW wastes, because of their physical condition and greater levels of radioactivity, will not be processed for volume reduction. The new ILW will consist of ion exchange resins, filters and irradiated reactor core components. It is currently assumed that the new or "fresh" Resin Liners will be delivered directly to the WPRB. The Resin Liners will be delivered in transportation packages on a trailer via the WWMF entrance gate and then taken to the WPRB[19]. Inside the WPRB, the Resin Liners will be off-loaded by the 40-tonne overhead crane into concrete shields as per procedures described in Section 6.1.6. The loaded shields will be prepared for transfer underground inside the WPRB. The filters and irradiated core components will be delivered directly to the WPRB in disposal-ready, self-shielding concrete boxes called "ILW Shields".

It has been assumed that additional OPG-owned reactors will undergo refurbishment during this 30-year Steady-State Operations Phase, and that these refurbishment wastes would be delivered to the WPRB in disposal-ready containers similar to those described in Section 3.6.3.

During the first 15-year period of the Steady-State Operations Phase, nine rooms at the east end of Panel 1 will be filled with waste packages from all groups, except Group B and Group D (see Section 10.1.2.3). When these nine rooms have been filled (Rooms 6 to 14, inclusive, on drawing H333000-WP408-20-042-0005), they will be isolated by a closure wall that is constructed mid-way along the Panel 1 Access Tunnel.

During the final 15-year period of the Steady-State Operations Phase, new waste in the form of Group A Bins, Resin Liners in concrete shields and ILW Shields will be emplaced in two Panel 1 rooms (Rooms 4 and 5 on drawing H333000-WP408-20-042-0005). At the end of waste emplacement operations these two rooms as well as the nearby Group B and D rooms would be isolated by a closure wall.

10.1.2.3 Emplacement of Group B and D Packages

During a 25-year period, currently assumed to start in Year 3, Group B (Heat Exchangers and Shield Plug Containers) and Group D (T-H-E Liners) packages will be emplaced in the Panel 1 rooms with rail-cart access (Rooms 1, 2 and 3 on drawing H333000-WP408-20-042-0005). Because the emplacement of T-H-E liners is not assumed to start until after all Group B packages are emplaced, the gantry crane used in the Group B room (Room 3 in Panel 1) can moved to the Group D room (Room 2 in Panel 1) to handle T-H-E liners.

10.1.3 Planning of Waste Package Emplacement Operations

Although the repository is designed to be able to operate continuously (24/7) for 365 days per year, the facility is only expected to operate on a 5 day per week, single shift per day basis. Taking statutory holidays into consideration, 250 days per year will be available per year for operations. Of this time, 10% has been estimated to be required for daily statutory inspections and maintenance activities (see Section 10.3), and a further 10% is allowed for unplanned outages (breakdowns, delays, etc.), leaving a net utilisation period of 200 days per year.

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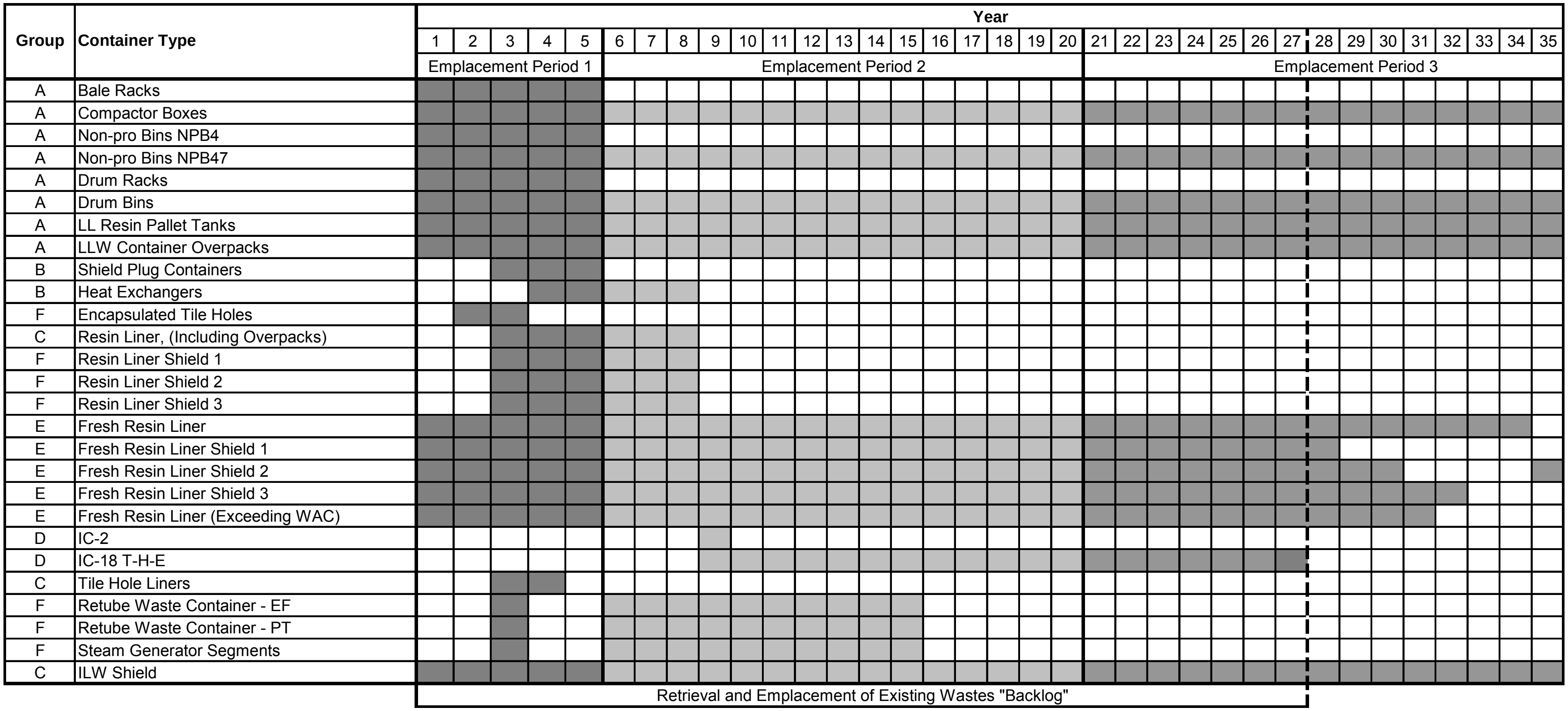
[19] Note that an option to load the Resin Liners into DGR shields at the WWMF instead of the WPRB may be considered in the future.

It is assumed that in an eight hour shift there will be no more than two and a half hours of operating time before and after lunch for a total for five operating hours a day. To ensure full utilisation of DGR resources during this available operating time, a waste package transfer roster should be developed and maintained by a joint WWMF / DGR planning team. The development of the roster would be particularly important for the Initial Operations Phase. This roster would specify the detailed schedule, by which waste packages would be retrieved and transferred to the DGR. A waste transfer roster will ensure a steady delivery of waste packages to DGR and would expedite clearing backlog wastes in storage at WWMF. The roster will prevent package delivery delays and lost time, which may otherwise extend the Initial Operations Phase beyond 5 years. It would also help to minimise the number of emplacement rooms that had to be open at any one time by ensuring that packages arrive in the correct and planned order. For instance, the roster would specify that sufficient numbers of bins with common footprint styles are transferred to fill integer numbers of rows within the emplacement rooms.

When developing the roster, special consideration will be given to transfer of large and heavy objects (e.g. Heat Exchangers, Steam Generator Segments, T-H-E Liners) from storage at WWMF. It is likely that more than half a shift will be used for the transfer of these wastes. However there will still be time left over in the shift, during which bin-type packages could be transferred.

Development and implementation of the waste roster would facilitate efficient DGR operations to ensure that System Requirements 3.3 and 3.4 [R46] for transfer of 24 LLW Bins or 4 Resin Liners per shift can be achieved.



Group	Container Type	Year																																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
		Emplacement Period 1					Emplacement Period 2															Emplacement Period 3														
A	Bale Racks	▓	▓	▓	▓	▓																														
A	Compactor Boxes	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
A	Non-pro Bins NPB4	▓	▓	▓	▓	▓																														
A	Non-pro Bins NPB47	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
A	Drum Racks	▓	▓	▓	▓	▓																														
A	Drum Bins	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
A	LL Resin Pallet Tanks	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
A	LLW Container Overpacks	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
B	Shield Plug Containers			▓	▓	▓																														
B	Heat Exchangers				▓	▓	░	░	░																											
F	Encapsulated Tile Holes		▓	▓																																
C	Resin Liner, (Including Overpacks)			▓	▓	▓	░	░	░																											
F	Resin Liner Shield 1			▓	▓	▓	░	░	░																											
F	Resin Liner Shield 2			▓	▓	▓	░	░	░																											
F	Resin Liner Shield 3			▓	▓	▓	░	░	░																											
E	Fresh Resin Liner	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	
E	Fresh Resin Liner Shield 1	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒							
E	Fresh Resin Liner Shield 2	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒					▒
E	Fresh Resin Liner Shield 3	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒			
E	Fresh Resin Liner (Exceeding WAC)	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒				
D	IC-2									░																										
D	IC-18 T-H-E									░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▓								
C	Tile Hole Liners			▓	▓																															
F	Retube Waste Container - EF			▓			░	░	░	░	░	░	░	░	░	░																				
F	Retube Waste Container - PT			▓			░	░	░	░	░	░	░	░	░	░																				
F	Steam Generator Segments			▓			░	░	░	░	░	░	░	░	░	░																				
C	ILW Shield	▓	▓	▓	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
		Retrieval and Emplacement of Existing Wastes "Backlog"																																		

Figure 10-2 – Preliminary Schedule of Waste Package Emplacement Operations

Emplacement Period	Panel	Room Numbers
1	2	1 – 17
	1	1 – 3
2	1	1 – 3 and 6 – 16
3	1	1 – 5

Table 10-2 – Open Rooms during Emplacement Periods

10.2 Labour Requirements

The number of staff required to operate and maintain the DGR facility will vary over its operating life. During the five-year Initial Operations Phase, the equivalent of 29 full-time staff will be required. Although the operational workload reduces by appreciable percentages over time, many functions will still be required at a similar level of effort over the full life (e.g. statutory inspections and maintenance will not reduce). Thus the reduction in staff numbers will likely not be significant following completion of Initial Operations Phase.

Table 10-3 lists the DGR staff and their responsibilities as well as an estimate of staff numbers during four separate periods in the operating life of the DGR. All staff listed in Table 10-3 would be incremental to personnel working at the WWMF. Allowance has not been made for any additional staff required to cover during vacation, training, sickness and any other leaves of absence. The DGR staff would receive support from various existing management and service functions at the WWMF.

Additional specialised technical expertise would be contracted, as required, to support work of the DGR staff in the areas such as plant and equipment inspection / maintenance, ground support, geosciences and geotechnical engineering, safety assessment, licensing and approvals, analysis of environmental monitoring data, and public affairs.

Category of Labour	**Description of Role**	**Annual Full-time Equivalent (FTE)**			
		Y1 – Y5	**Y6 – Y15**	**Y16 – Y25**	**Y26 – Y40**
DGR Facility – Management and Support Staff					
Section Manager – DGR Operations	Responsible for overall operations of the DGR facility.	1	1	1	1
Work Planner	Plans and schedules all DGR work including receipt and emplacement of waste, and maintenance activities.	0.5	0.25	0.25	0.25
Environmental, Health & Safety Officer	Program and planning work only. Field staff responsible for execution of various activities.	0.5	0.25	0.25	0.25
Field Supervisor (FLMA)	Manages day-to-day work of various field staff.	1	0.5	0.5	0.5
Finance	Financial reporting for DGR operations.	0.25	0.125	0.125	0.125
Buyer	Procurement for DGR operations.	0.25	0.125	0.125	0.125
Administrative Field Support	General administrative support for DGR operations.	1	1	1	1
Subtotal		***4.5***	***3.25***	***3.25***	***3.25***
DGR Facility – Operations Staff					
Hoist Operator	Operates Main and Ventilation Shaft hoisting systems. Monitors and controls various DGR systems.	2	2	2	2
Cage Tender at Collar (Surface)	Operates cage, assists with loading of packages.	1	1	1	1
System Responsible Engineer (SRE)	Supervises and controls maintenance of all systems.	1	1	1	1
Technicians - Electrical & Instrumentation	Inspects and maintains all electrical, instrumentation and control systems (including hoist electrical).	3	3	2	2
Technicians - Mechanical	Inspects and maintains mobile equipment.	4	4	3	3
Technicians - Mechanical	Inspects and maintains, cages, hoisting, pumps and ventilation systems.	2	2	2	2
Field Operator (to supplement WWMF)	Inspects and maintains all surface equipment and facilities. Collects ground water samples and pressure data (US and DGR holes), maintains regional seismic monitoring system, borehole monitoring system maintenance, assists in compilation of data for annual reporting. Collects air and water samples as part of surface and subsurface environmental program, and assists with the compilation of data for annual report.	1	1	1	1

Category of Labour	**Description of Role**	**Annual Full-time Equivalent (FTE)**			
		Y1 – Y5	**Y6 – Y15**	**Y16 – Y25**	**Y26 – Y40**
Radiation Control Technician	Implements radiation protection program for the DGR for the purpose of managing radiological risks that could contribute to occupational radiation doses.	0.5	0.5	0.5	0.5
Subtotal		***14.5***	***14.5***	***12.5***	***12.5***
DGR Facility - Waste Handling Staff					
Surface Material Handlers / Forklift Operators	Operates forklifts in WPRB and loads waste packages onto railcars.	2	2	2	2
Underground Material Handlers / Forklift Operators	Receives railcars at underground shaft station and transfers waste packages by forklift or railcar to emplacement rooms. Includes a spotter for placement of waste packages.	4	3	3	2
Subtotal		***6***	***5***	***5***	***4***
Specialised Technical Support Staff					
Design Engineer	Supports ongoing design / maintenance / improvement of DGR facility as part of existing engineering group.	0.5	0.25	0.25	0.25
Safety Assessment	Update SA model, periodic updates of Final Safety Assessment Report for renewal of Operating Licence, annual reporting to validate or improve safety assessment model.	0.5	0.5	0.5	0.5
Licensing & Approvals	Renew and maintain the operating license; prepare and submit quarterly and annual reports to CNSC; renew operating licence every 5 years .	0.5	0.5	0.5	0.5
Public Affairs	Public affairs support for DGR facility.	2.5	2	2	2
Subtotal		***4***	***3.25***	***3.25***	***3.25***
Estimate of Total DGR Staff		**29**	**26**	**24**	**23**

Table 10-3 – Labour Required for DGR Facility Operations

10.3 Inspection and Maintenance

A planned maintenance system will be produced prior to commencement of operations. The plan will provide full control of maintenance activities and enable the facility to attain a net availability of 90 % during working hours excluding scheduled stoppages for statutory inspections and maintenance. Unplanned outages would be likely to reduce the utilisation to 80 % of total working time, i.e. 200 days per year (also see Section 10.1.3). Original equipment manufacturers (OEM) will also be engaged to ensure the plan meets their recommendations and requirements, and identifies major equipment maintenance or condition inspections that need to be scheduled and would, in all likelihood, be contracted to the OEM to perform.

10.3.1 Scheduled Surface Inspection and Maintenance

Daily, weekly and monthly statutory inspections as well as maintenance of surface facility installations (hoists, compressors, heating plant (in winter months), the main electrical substation and diesel generator) will be carried out by the mechanics, electricians and instrument technicians. The weekly and monthly inspections and maintenance will be scheduled to occur outside of scheduled waste package transfer and emplacement working hours. However, it has been assumed that the statutory daily work would be performed during the normal working day. These activities will be overseen by the SRE, who will also be accountable for testing equipment as required in the OMR [R48].

10.3.2 Scheduled Underground Inspection and Maintenance

Technicians will perform regular scheduled inspection and maintenance of various underground installations and equipment (e.g. ventilation system, pumps, electrical substation and dust control equipment) in addition to assisting with inspection and maintenance of the surface equipment and electrical substation. Such inspections and maintenance will take place inside of scheduled working hours and conducted so as not interfere with waste emplacement activities.

Inspection and maintenance will be required in various ancillary rooms (including the lunchroom and maintenance facility), access tunnels, empty emplacement rooms, shaft liners and other underground facilities during operations. This will initially consist of scheduled observations and use of geotechnical instrumentation to monitor the performance and condition of the rock support elements, rock pillars, roof and floors in the emplacement rooms and access tunnels. Geotechnical instrumentation would consist of rock bolt load cells, multipoint borehole extensometers and room convergence arrays that will have been specified and installed during construction. These instruments will be read frequently (typically weekly) during construction and then quarterly by a specialised contactor throughout the Initial Operation Phase of the repository (i.e. first 5 years). At that time an assessment regarding the frequency of future readings would be made.

Maintenance requirements for rock support elements and the concrete floors is expected to be minimal during the initial operating life of the repository. However, some limited repair and installation of rock bolts and shotcrete may be required periodically and this work would be performed by a specialised contractor. Over time (10 to 20 years) and depending upon traffic levels and corrosion rates in the repository, the concrete running surface in portions of the access tunnels and some rock support elements may require more extensive repair. At this time, engineering inspections and rehabilitation contracts may be necessary. Such contracts would be similar to scheduled shut-downs of industrial plants and require three to six months to complete.

There are legal requirements for daily, weekly and monthly shaft inspections (§249.1(a) & (b) of the OMR [R48]), which are primarily visual in scope. In addition, a detailed structural condition survey should be performed annually to supplement these weekly shaft observations. Initial maintenance would likely be minimal but rehabilitation work similar to that described for the access tunnels, may prove necessary but at a much reduced frequency (say no more than once during the 40-year life of the repository).

During the operating life of the repository, the integrity of the shaft lining system will be included in shaft inspections. While the rate of infiltration of ground water through the shaft lining is expected to be low and remain so over the life of the repository, any changes in inflow will be noticeable during these inspections and also from sump pump duty cycle observations. In addition, full structural condition surveys will be performed by qualified structural engineers at regular intervals. If required, appropriate repairs will be performed to restore the integrity of the shaft liner.

10.4 Equipment Requirements

The mobile equipment that will be used to handle waste packages at various locations in the DGR is described below. The estimated mobile equipment requirements for the DGR facility are given in Table 10-4. The equipment is briefly described below and in more detail in Section 10.4.1.

The majority of the waste packages will be moved within the DGR facility by a fleet of eight diesel-powered forklifts and five rail carts, consisting of:

- Four underground light-duty forklifts with a lifting capacity of 6 tonnes. Up to three of these may be operating at any one time, with the fourth acting as a stand-by for use in the event of a breakdown or maintenance. These forklifts will move the lighter packages, such as LLW bins or unshielded Resin Liners, from the Main Shaft station to emplacement rooms.
- One surface light-duty forklift with a lifting capacity of 6 tonnes. It will operate in the WPRB. It will be used to offload LLW bin-type waste packages from delivery trucks, place them in the staging area, and load them onto the low-profile and self-propelled rail carts for transfer to the shaft cage.
- Two underground heavy-duty forklifts with a lifting capacity of 40 tonnes. One will normally be operational with one stand-by unit. This machine will move the heavy and large forkliftable waste packages such as the retube waste containers or shielded Resin Liners, from the Main Shaft station to emplacement rooms.

- One surface heavy-duty forklift with a lifting capacity of 40 tonnes. It will be used on surface in the WPRB for off-loading heavy and large waste packages from delivery vehicles. This rubber-tired forklift will also be used to deliver waste packages from the WWMF.

A custom-built T-H-E Handler will be used to load the T-H-E Transfer Bell into the cage. An identical machine will be located underground to remove the T-H-E Transfer Bell from the cage and to transfer the package to the emplacement room. The HEM will be located in the emplacement room and will be used to place the T-H-E Liners in their final emplaced positions.

Location	**Mobile Equipment**	**Fleet Size**
Waste Package Receiving Building	Light-duty forklift	1
	Heavy-duty forklift	1
	Rail cart	5
	40-tonne Overhead Crane	1
	T-H-E Handler	1
Underground	Light-duty forklift	4
	Heavy-duty forklift	2
	Rail cart	Included above
	T-H-E Handler	1
	40-tonne Gantry Crane	1
	Horizontal Emplacement Machine (HEM)	1
	Personnel Carrier	3
	Mobile work staging	1
	Mobile rock bolting unit	1

Table 10-4 – Mobile Equipment Requirements

There is other mobile equipment that would be used to directly or indirectly support DGR operations, but is not included in the equipment list in Table 10-4. Specifically, the following mobile equipment is not listed:

- Equipment for waste retrieval at the WWMF (i.e. cranes, forklifts).
- Equipment for transfer of waste packages to DGR from the WWMF (i.e. flatbed trucks, forklifts[20]).
- Equipment to perform surface maintenance (i.e. snow removal or road maintenance equipment).
- Equipment for personnel transfer on surface.
- Special equipment for non-routine tasks.

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[20] Note that the heavy duty forklift at surface will be stored at WWMF and can be used to transfer heavy packages from there to the WPRB.

Where there is a risk of fire on mobile equipment such as forklifts or the T-H-E Handler, a custom fitted fire suppression system will be installed and maintained. This system would be foam or dry chemical based (i.e. non-water). See Section 7 for further descriptions of fire detection and suppression systems.

10.4.1 Forklifts

The DGR will employ a fleet of forklifts for the receiving, staging and emplacement of LLW and ILW packages. Forklifts will be used wherever practical in the waste package transfer system, as they are flexible and efficient while maintaining positive control of the package. This will help to minimise potential damage to packages while ensuring flexibility in all areas from the WPRB to the emplacement rooms. Forklifts are currently used regularly in the WWMF for movement and placement of waste packages. Some customisation of commercially available equipment is expected to ensure that operators have good visibility while transporting the large waste packages (e.g. off-set cabs, reversible operator's chair, cameras and screens).

Diesel equipment is extensively used with successful safety performance in underground mining and civil projects. Ventilation for the facility has been designed to meet the required legislation for diesel use underground. Diesel equipment allows for greater flexibility and range, and does not require extensive electrical services or battery charging stations that electrically-powered forklifts would require.

Two categories of forklift will be used on surface and underground at the DGR; light duty and heavy duty. The light duty forklifts will be used to transport lighter packages such as the bin-type LLW packages and the unshielded Resin Liners. The heavy duty forklifts will be used to transport package that are large in size and have a mass greater than 6 tonnes.

A common light-duty forklift type should be used for both surface and underground application to reduce the amount of spares required as well as to facilitate operator and service technician familiarity. The main difference between the light duty forklifts will be the mast. Underground, the forklift must be capable of stacking packages up to five high whereas on surface the stacking height at the staging areas is limited to two high. Another requirement for the surface forklift is the requirement to enter an ISO container (i.e. be capable of passing through the door aperture of a standard ISO container door) to unload waste packages. The lower lifting height requirement of the light duty forklift in the WPRB will allow this forklift to access the ISO container.

The heavy-duty forklift on surface will have pneumatic tires while all light-duty forklifts and the underground heavy-duty forklifts will have solid tires. The heavy duty forklift used on surface will be stored at the WWMF and be used to transport waste packages from the WWMF to the WPRB. This trip will be made on an asphalt road surface, therefore, pneumatic tires will be required. The light duty forklifts, both surface and underground, and heavy duty underground forklift will have solid (or cushion tires) suitable for a finished concrete floor with embedded rail, similar to the forklifts used at the WWMF. The solid tire forklifts will not be able to travel on asphalt surfaces (i.e. outside) without causing damage to the tires and asphalt surface. However, cushion-tire forklifts have a more compact wheelbase and are generally preferred for manoeuvrability and precision placement operations.

Visibility is a key design issue with all of the forklifts due to the size and shape of the packages. During package transport and emplacement, spotters will be required when manoeuvring packages that block or reduce the visibility of the operator. In addition to spotters, the forklifts can be equipped with cameras and / or sensors to help the operator navigate, noting that safety of nearby spotters will need to be considered. All forklifts will be fitted with appropriate safety equipment including seatbelts, lights, proximity sensors, backup alarms, speed limiters and guards to minimise the risk to personnel working nearby and the risk of collision with other objects. Equipment selection for the heavy duty forklifts will specify either reversible or side mounted seating to optimise operator visibility. This will allow the forklifts to operate with the load either leading or trailing the direction of travel. Such equipment is used (or planned for use) in an underground repository environment at the WIPP at Carlsbad, New Mexico and at the Konrad repository in Germany. Examples are shown in Figure 10-3 and Figure 10-4. While both of these forklifts were custom-built, conventional large capacity forklifts are available and it is anticipated that they could be relatively easily customised as needed for equipment to be used in the DGR.

Both the light and heavy duty forklifts used underground will be transported underground via the Main Shaft. Transportation of the light duty forklift fully assembled will be possible. However, the heavy duty forklift will likely require disassembly (i.e. removal of tires, counter weights, etc.) depending on the specific make and model selected.

Figure 10-3 – 41 ton Forklift at WIPP
(Courtesy: WIPP)

Figure 10-4 – Forklift for Konrad
(Courtesy: DBE)

The general specifications that apply to all forklifts and examples of currently available units are detailed in Table 10-5.

Location (S = Surface, U/G = Underground)	-	S	S	U/G	U/G
Duty Class	-	Light	Heavy	Light	Heavy
Maximum load	kg	6,000	36,150	6,000	36,150
Load centre	m	0.9	1.2	0.9	1.2
Maximum lift height	m	2.0[21]	4.0[22]	4.8	2.8
Minimum lift height during transport	m	0.3	0.5	0.3	0.3
Fork length	m	2.0	3.0	2.0	3.0
Tires (P – Pneumatic, S – Solid)	-	S	P	S	S
Side shifting forks	-	Yes	No	Yes	Yes
Load cell for package mass	-	Yes	Yes	Yes	Yes
Fuel	-	Diesel	Diesel	Diesel	Diesel
Fuel tank capacity	L	70	340	70	340
Sample Make	-	Hoist	Hoist	Hoist	Hoist
Sample Model	-	F180@36	P800	F180@36	F900@36
Sample Power Rating	kW	64	246	64	149
Maximum load for sample forklift.	Kg	8,064	36,320	8,064	40,860
Turning radius	m	3.0	6.5	3.0	4.9
Overall width	m	1.54	4.2	1.54	2.5
Length, not including forks	m	3.4	7.1	3.4	5.0
Length, including forks	m	5.4	10.1	5.4	8.0
Height (standard mast lowered)	m	2.2	4.2	2.5	4.5
Width of sample forklift	m	1.6	4.0	1.6	2.7

Table 10-5 – Preliminary Forklift Specifications

Shielding could be incorporated into the forklift design if required for worker dose rate reduction, although it is proposed that such measures would be best achieved by attachment of temporary shielding mounted on the forklift mast to provide a screen between the operator and the waste package. The nominal distance between the operator and the waste package would be 2 to 3 m for all forklift transfer operations. Future detailed analysis will determine procedures and equipment modifications required to optimise worker dose rate.

In all cases operating procedures will require the use of proper pallets and attachments to ensure that the risk of damaging equipment or waste packages is minimised at all times. Travelling speeds for larger packages will be controlled to walking speeds (2.5 km/h). The small forklifts will travel at speeds of up to 6 km/h when transferring a waste package. Roadways will be concrete and well maintained, which will allow for secure travel to all extents of the DGR facility. The maximum distance, over which the forklifts will travel carrying a waste package underground, is approximately 1,200 m.

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[21] This lift height is to stack Group A packages two (2) high in the staging area of the WPRB.
[22] Assumed value - should be confirmed with package retrieval requirements at WWMF.

10.4.2 Equipment for T-H-E Liner Transfer

The T-H-E Liner packages, which are too long to be transported horizontally down the shaft, will be handled using specialised custom-built equipment. On surface, one T-H-E Handler will secure and hydraulically erect the package inside the Main Shaft Koepe cage, so that it can be transported vertically down the shaft. Another T-H-E Handler will be located underground, which will be used to remove the package from the cage, rotate it back down to the horizontal, and transport it within the repository. The HEM will be located in the emplacement room where it will accept the package from the T-H-E Handler and place the T-H-E Liner in its final emplaced position. This equipment is further described in Sections 6.2.3 and 6.3.6.

10.4.3 Cranes

Cranes will be used in the following applications:

- Group B packages – general handling, as they have no forklift pockets.
- Group D packages - T-H-E Transfer Bell – transfer from trailer to T-H-E Handler and within emplacement room from T-H-E Handler to HEM.

To accomplish these transfer operations, a 40 tonne overhead crane is required in the WPRB and a 40 tonne gantry crane is required underground (single crane shared between rooms)

Within the WPRB there will be the 40 tonne overhead crane which will be used to unload fresh Resin Liners from their transportation packages and to place them in sacrificial concrete shields It will be possible operate this crane remotely so as to ensure worker safety during this transfer operation. This crane will also be used for transferring shield plug containers and heat exchangers onto rail carts, and for transferring the loaded T-H-E Transfer Bell from the flatbed truck onto the surface-based T-H-E Handler. The crane will have clearance below to allow operation of the T-H-E Handler. Note that the T-H-E Transfer Bell will need to be turned 90° in a horizontal plane in the WPRB because the T-H-E Handler is oriented 90° from the trailer in the offloading bay. This turning procedure would be done by the operations personnel holding guide ropes.

A gantry crane will be installed in the emplacement rooms where Group B and Group D packages are allocated (refer to drawing H333000-WP408-05-042-0006). The gantry crane will be used to off-load the shield plug containers and heat exchangers from the rail cart and move them to their final emplacement positions. This same gantry crane would be relocated to the adjacent room and used to transfer the loaded T-H-E Transfer Bell onto the HEM. Lifting the T-H-E Liner in the emplacement room is most reliably done using a gantry crane with a twin hook, single hoist design. The hooks will be rigidly connected to each other and run from a single hoist. This will ensure the T-H-E Liner is being lifted from both hooks at the same speed. The spread of the hooks will negate any tilting effect due to potential for variation in the positions of the T-H-E Liners' centres of gravity. This sling design will also be used for lifting the Shield Plug Containers and Heat Exchangers.

For the purpose of crane design and specification, the waste packages will be considered to be “critical loads”. A critical load is defined as "any lifted load whose uncontrolled movement or release could adversely affect any safety-related system when such a system is required for unit safety or could result in potential off-site exposure in excess of the limit determined by the purchaser" [R65].

Cranes handling critical loads must, as a minimum, have single failure proof design features. In some cases it may necessary to have enhanced safety features, including increased design factors and redundant components that minimise the potential for failure. These details will need to be further interpreted in future stages of design. The cranes will remain in a safe state in the event of a power failure.

Location	Purpose	Crane Type	Nominal Capacity (tonnes)
WPRB Offloading Bay	Moving Waste Packages	Overhead	40
WPRB Maintenance Area	Rail Equipment Maintenance	Monorail	10
Main Shaft station Underground	Shaft Operations	Monorail	20
Main Shaft Hoist Deflector Sheave Deck	Maintenance	Monorail	10
Ventilation Shaft Headframe	Maintenance	Monorail	10
Main Shaft Auxiliary Hoist Deflector Sheave Deck	Maintenance	Monorail	2
Main Shaft Koepe Friction Hoist Deck	Maintenance	Overhead	50
Ventilation Shaft Hoist Room	Maintenance	Overhead	40
Underground Maintenance Area	Mobile Equipment Maintenance	Overhead	40
Emplacement Room for Group B and Group D Waste	Waste Package Emplacement	Gantry	40
Surface Electrical Room	Maintenance	Monorail	5
Underground Electrical Room	Maintenance	Monorail	5

Table 10-6 – Crane Locations and Capacities

Figure 10-5 – Example of Overhead Crane and Rail-Bound Rail cart
Courtesy: Mentor Dynamics

10.4.4 Rail Carts

Rail carts will be used for shaft handling of waste packages as described in Section 6. The rail carts are 5.2 m length and 2.65 m width, and will fill the operating envelope of the cage. The deck height will be approximately 0.5 metres and has been minimised to ensure that the potential energy due to height and associated risk is maintained as low as possible during all parts of the package transfer process. An on-board electric motor will be powered and controlled using a retractable tether cord. A fail-safe braking system will also be provided to minimise the risk of uncontrolled movement. Each axle will be paired with secondary wheels to ensure stability when crossing the narrow gap at the shaft station-to-cage interface. The fixed axles will be lighter, less complex, and lower profile than pivoting wheel “trucks” as used in most surface commercial rail cars, however wide-tread wheels will be required to navigate through turns at rail switches and emplacement room entrances. Speed of the rail carts will be limited to 30 metres per minute.

10.4.5 Trillium Work Platform

If fresh Resin Liners are delivered from the nuclear generating stations directly to the DGR, then a special platform (such as the Trillium Platform used at the WWMF) would be used to access the top of Trillium transportation package for the purpose of removing the Resin Liner. This platform will be stored outside the WPRB, near the empty Resin Liner Shields. The platform will be moved by forklift in and out of the WPRB as it is needed. The overhead crane will be used to position the platform over the transportation package.

10.5 Shielding Wall and Closure Wall Designs

A shielding wall may be constructed at the entrance to individual emplacement rooms when filled with waste packages for the purpose of reducing radiation fields in the adjacent access tunnel. Permanent closure walls will be constructed within the access tunnels to fully isolate a group of waste-filled rooms within individual panels. Descriptions of the design of shielding and closure walls for the DGR are provided below.

10.5.1 Emplacement Room Shielding Walls

At the completion of room filling, and if required, a shield wall will be erected at the entrances to waste-filled rooms to reduce radiation fields in the adjacent access tunnel. Although there is no intention to re-enter the emplacement room after the shielding wall is erected, provisions to allow ventilation flow and safe re-entry will be in place. The shielding wall would also act as a barrier to prevent unplanned entry into a waste-filled room.

In order to maintain the ventilation system within the emplacement rooms while operations are ongoing within a given panel, shielding walls will be constructed to slightly above the highest waste package container within the room. This will create a window between the roof and the top of the wall, through which air can flow into the room; the exhaust ventilation duct exiting the room will pass above this wall. A concrete frame will be created along the side walls of the emplacement room in order to ensure that a true fit is provided between the concrete blocks and the emplacement room wall.

Shield wall designs will ultimately be developed to suit actual conditions at room entrances. Actual radiation fields after emplacement of waste packages may be lower than expected due to radioactive decay and the arrangement of higher and lower dose rate packages in the room. Hence the final wall design will be decided just prior to wall construction. The design analyses would also consider potential impacts of seismic events and pressure differential on wall integrity. The durability of the walls would be specified so that they could withstand potential vehicle impacts over the lifetime of the repository.

A conceptual design for an emplacement room shielding wall is shown in Figure 10-6.

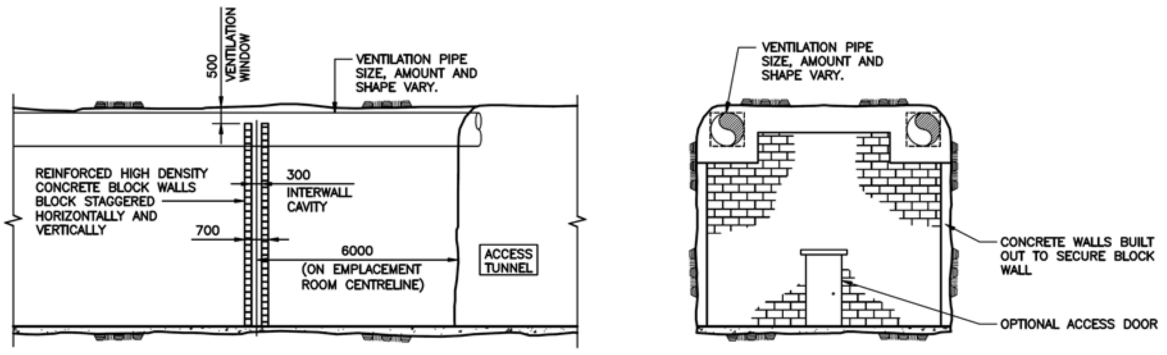

Figure 10-6 – Conceptual Design for Emplacement Room Shielding Wall

10.5.2 Closure Walls

After a group of rooms have been filled with waste packages and following the determination that there is no need to retrieve the waste for any reason, a closure wall will be constructed in the access tunnel to fully isolate this group of rooms. The underground space behind the closure wall will not be ventilated. These closure walls will be designed to limit release of tritiated air, natural and waste-generated methane, and other off-gases from waste packages (e.g. H_2 and CO_2), as well as potentially contaminated water. In the remote event that explosive gases build up behind the closure wall and an explosion occurs, the air blast from the explosion would be contained by the closure wall. The conceptual design for the closure wall is shown in Figure 10-7.

It is currently assumed that there will be up to three closure walls in place at the end of repository operations. The first wall would be erected about five years after start of operations and would isolate all rooms in Panel 2. The next wall would be erected fifteen years later and would isolate nine rooms in Panel 1, which are furthest from the shafts. A third wall may be erected at end of repository operations to isolate the last five rooms in Panel 1, which are located closest to the shafts. The planned location of these closure walls is shown on drawing H333000-WP408-20-042-0001.

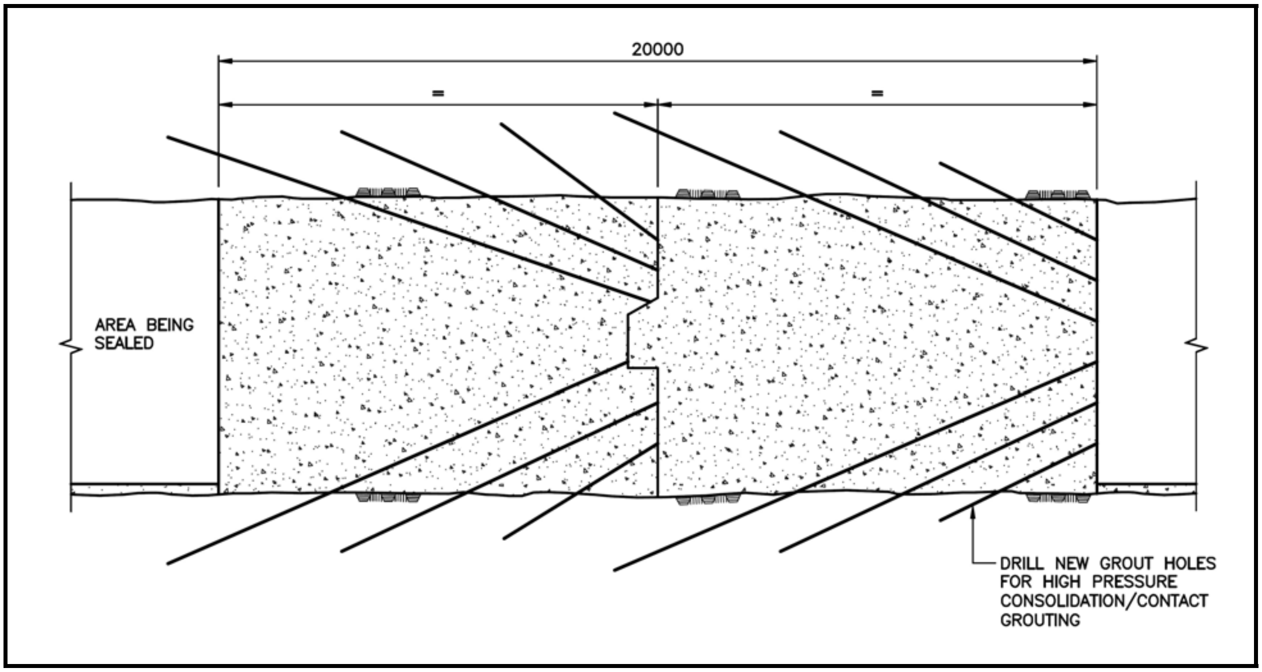

Figure 10-7 – Conceptual Design for Access Tunnel Closure Wall

The closure wall shown in Figure 10-7 would consist of two pours of mass concrete within the access tunnel. Following each pour, new grout holes would be drilled through the concrete into the surrounding host rock for provision of high pressure consolidation / contact grouting. This closure wall resists pressure through friction between the concrete plug and the rough surface of the access tunnel along the entire length of the seal.

Access tunnel closure walls will prevent accidental worker entry into closed panels and be able to withstand a 3 MPa force, which is considered to be a reasonable value to assume for an initial design basis. Future engineering should undertake a computational fluid dynamics (CFD) analysis to confirm the magnitude of the force from a potential explosion in the sealed off section of the panel, which would enable a full preliminary design of the wall to be produced.

10.6 Waste Package Retrieval

The materials that will be placed in the DGR are considered waste and there is no scenario envisaged in which retrieval would be considered necessary. However, in the unlikely event that any waste package(s) would need to be retrieved from a room following emplacement, retrieval can be achieved.

A specific plan for retrieving the package(s) would be developed in advance. First, the position of the waste package(s) to be retrieved will be identified using the IWTS system (see Section 6.1.1), and the number and type of packages, that will have to be moved to access the identified waste package, will be determined. Alternative locations, which may be temporary or permanent, for the packages will be identified. They could be relocated to another room, which is partially filled or empty. This new location could be suitable as a permanent disposal location for these packages. Alternatively, it may be necessary to temporarily store some or all of the packages in an access tunnel and then to replace them in the room from which they came after the retrieved package has been removed. In this event, it will be necessary to determine whether any special precautions need to be taken because of dose rates of the moved packages. Areas may need to be demarcated in the repository for these packages and personnel access restricted to ensure workers cannot be exposed to unacceptable levels of radiation.

Once the aforementioned planning has been completed, the retrieval procedure would be carried out by one of two methods depending on the status of the room:

1. For an open room, packages would be removed using the reverse of the initial emplacement procedure. In most instances this would involve using the same equipment (forklifts, rail carts etc.) that had been used to originally emplace the waste packages.
2. For a waste-filled room that is isolated by a shield wall, the ventilation fan system for that room would need to be re-established and run for adequate time to purge the room of any noxious or other gases and to ventilate the room. The gas monitoring instrumentation in the exhaust duct would be used to determine when the atmosphere is safe to proceed into the room. The packages would be recovered in the same manner as for an open room. If a gantry crane is required for retrieval and it is not present in the specific room, then this equipment would be reinstalled after the shield wall has been opened.

Although it would be possible to remove waste packages from a room without excessive difficulty, it is expected that the retrieval procedure would be relatively slow to complete to ensure worker safety at all times. If any waste packages were required to be moved to surface, they would be handled in the reverse way to which they were moved underground.

There is one major exception to the aforementioned retrieval process, which is the retrieval of a T-H-E Liner located in a disposal tube within the emplacement room housing the 16 Concrete Pipe Arrays (see Section 6.3.6 and Figure 6-7). Relative to the other waste packages it will be more difficult to retrieve this waste package type. To retrieve a T-H-E Liner from the first Concrete Pipe Array at the entrance of the room, the sequence of events would follow these steps:

- Re-install the gantry crane in the room, if it is not already present.
- The HEM machine would be positioned in the emplacement room and the Transfer Bell loaded into position on its frame.
- The concrete cap would then be pulled out of the end of the pipe using a grappling attachment fitted to the end of the ram of the machine. (The cap will have cast in attachment pockets to enable easy connection to the grappling attachment.)

- The attachment would then be connected to the T-H-E Liner similarly to when the T-H-E was originally removed from the in-ground storage cells at the WWMF and the T-H-E pulled into the bell.
- Once the T-H-E is fully enclosed in the Transfer Bell, its articulating end closures will be bolted up and the gantry crane will lift the bell with its T-H-E waste load onto the T-H-E Handler.
- The waste package can then be removed to another room for temporary storage in a fixed concrete shield or removed from the DGR totally to surface.

If the designated T-H-E liner is located in a Concrete Pipe Array behind the first array, then all liners would be have been removed from the first array using the above-mentioned procedure. The concrete structure would then be demolished and rubble removed to allow access to the next Concrete Pipe Array holding the T-H-E liner that is designated for retrieval. The above-mentioned procedure would be used to extract the designated T-H-E Liner from the second Concrete Pipe Array. This entire process would be repeated for multiple Concrete Pipe Arrays if the designated T-H-E Liner is located in an array that is located further back in the room.

11. Decommissioning and Final Sealing of Repository

11.1 Decommissioning of Repository

Following issue of the Decommissioning Licence by the CNSC, decommissioning of the DGR facility will commence. Decommissioning of the facility will entail the decommissioning of underground facilities, two shafts and all surface facilities. After the shafts have been sealed, the surface facilities stripped and removed and the surface landscape has been rehabilitated, the decommissioning will be complete. However, environmental monitoring of the DGR site will likely continue for a period of time following final sealing of the repository.

The structures, equipment and materials that would be present in the DGR facility at the start decommissioning are described in Sections 4 through 8 and 10.4. The waste packages, sacrificial shields and transfer structures (e.g. sacrificial forklift pallets) are described in Sections 3 and 6.

11.1.1 Decommissioning of Underground Facilities

Decommissioning of underground facilities will largely consist of preparing equipment and materials in the underground Shaft and Services Area for the final sealing of the repository. All other parts of the underground repository will have already been isolated by closure walls during the operations phase (see Section 10.5.2). The general arrangement of the underground repository and the planned locations of closure walls are shown on drawing H333000-WP408-20-042-0001.

Decommissioning of the underground Shaft and Services Area will involve assessing equipment and materials to determine what can or should be removed prior to repository sealing. Particular attention would be employed in areas where potentially hazardous materials, such as any waste fluids from mobile equipment, may exist. It is currently assumed that most permanent equipment and materials will remain within the repository and that only mobile equipment, which has been tested and does not contain any residual contamination, will be removed to the surface. However, if space is available and approval is received to do so, then these items of equipment may remain underground. It is possible that some of the equipment and materials could be decontaminated and salvaged for re-use or for its scrap metal.

All infrastructure connections (power, ventilation, water) will be disconnected before shaft sealing work begins. The Shaft and Services Area underground openings will be prepared for the construction of the concrete monoliths to be located at the base of each shaft (see Section 11.2.4). The monoliths would not be constructed until the shafts have been decommissioned and shaft steelwork and furnishings have been removed from the vicinity of the monolith.

11.1.2 Decommissioning and Sealing of Shafts

Decommissioning of the shafts will consist of the sequential removal of shaft infrastructure and installation of the shaft seal materials (see Section 11.2.4 below). The Ventilation Shaft would be decommissioned first followed by decommissioning of the Main Shaft.

At the Ventilation Shaft, a set of temporary stage winches will be installed, from which a working platform will be suspended on wire ropes to enable the process of placement of sealing materials to be conducted. The existing 2nd egress hoist within the Ventilation Shaft will be used as the primary means of travel between surface and the shaft bottom for workers, equipment and materials. However, once the steelwork has been stripped, the conveyances will use the stage ropes as guides, rather than the steel or timber guides. This may involve changes to the bale or supply of new buckets similar to those used for shaft sinking. Shaft infrastructure, such as ventilation, will be removed on a phased basis in a manner that ensures the provision of required services to the shaft during shaft sealing. Waste materials (such as shaft steelwork and concrete lining) will be transferred back into the repository down the Main Shaft. The stripping of shaft concrete liner and annulus of damaged rock and the construction of individual elements of shaft sealing system are described in Section 11.2.5 below.

On completion of sealing of the Ventilation Shaft, the same process will be performed at the Main Shaft. In this case, the first stage of shaft decommissioning will consist of removal of the operational Main and Auxiliary Koepe friction hoists and replacement by a stage hoist to suspend the working platform and a single drum hoist for worker, material and equipment access during the stripping of the shaft steelwork, fittings, concrete lining and damaged rock. Otherwise, decommissioning and shaft sealing will be proceed in a manner similar to that described for the Ventilation Shaft. However, in this case it will not be possible to dispose of any of the structures that have been stripped from the shaft, back into the repository.

11.1.3 Decommissioning of Surface Facilities

Surface facilities required for operation of the DGR are described in Section 4.2. The majority of surface facility decommissioning will occur following placement of the shaft seal materials (see Section 11.2), as these resources will be required to maintain service to the shafts during the installation of the seals.

Wherever appropriate, mechanisms and materials from demolition of surface facilities will be recycled or reused elsewhere to minimise requirements for disposal. Those materials that are not recyclable will be disposed of in an MOE-approved facility. Any materials or equipment in surface facilities that would be considered radioactive waste will be removed near start of decommissioning and placed in the underground repository prior to start of shaft sealing. Should any of that equipment be required for the decommissioning or shaft sealing activities, replacements would be procured and installed. All buildings will be decommissioned and removed from the site.

The expected order of surface facility decommissioning is as follows:

- Main Shaft Koepe hoisting system that was used during operations and installation of temporary hoist system for shaft sealing work.
- Refrigeration plant (and bulk air cooler if installed).
- Heater building.
- Exhaust fans.
- Ventilation Shaft Headframe, hoisting system (including temporary winches installed for shaft stripping and sealing) and collar house.

- Main Shaft Headframe and temporary hoist system as well as associated buildings, including the WPRB.

The Main Shaft Headframe and WPRB would be decommissioned last because they will be required during shaft sealing. These structures would be inspected, tested for contamination and, if necessary, decontaminated for use during shaft sealing operations. The WPRB would act as a warehouse for the shaft sealing materials and as a maintenance workshop for the seal construction equipment.

Following removal of all surface facilities, the site will be graded and re-vegetated using species native to Bruce County and local genetic stock where practical. The location of the shafts will be appropriately secured to ensure the possibility of inadvertent entry is minimised. Sustainable systems will be employed on this site to ensure that long-term management of storm water is provided without impact on the surrounding environment.

11.2 Shaft Sealing Design and Construction Methods

At the time of repository closure, the shafts will be sealed over the full depth from the repository level to the surface. The design of the shaft sealing system that is presented in this section is based on guidance from NWMO and plans adopted by other national waste management organisations.

Design of the shaft sealing system will satisfy the relevant sections within the Ontario Mining Act and Ontario Regulation 240/00 (Mine Development and Closure) under Part VII of this Act [R66], as well as Section 11 (Well plugging) of the Provincial Operating Standards, Oil, Gas, Salt Resources of Ontario [R67].

In view of the long time over which the shaft sealing must be effective, the approach to this preliminary design was to research and consider other proposed systems designed or proposed for other repositories around the world and test work that had been carried out. Specifically the following case studies were investigated:

- WIPP in the United States of America (USA), where a full design has been produced and approved.
- Morsleben Repository in Germany.
- Atomic Energy of Canada Limited’s (AECL) conceptual design for a spent fuel repository in Canada.
- Agence Nationale pour la gestion des Déchets Radioactifs (ANDRA)’s conceptual design for a spent fuel repository sealing system in France.

The main conclusions from the review of these designs were:

- Multiple materials serving repetitive functions should be incorporated into the design to maximise redundancy.
- Bentonite-based materials are universally recognised as a suitable primary sealing material and should be utilised in the DGR sealing system.

- Engineered and compacted native material should be used as fill in the upper reaches of the DGR shafts, where the restriction of groundwater flow or radionuclide migration is not a concern.

11.2.1 Excavation Shaft Diameter for Sealing

The finished internal diameter of the Main Shaft is 6.5 m. In order to determine the effective shaft seal diameter, the removal of shaft lining and support materials and excavation of HDZ must be considered. The effective main shaft diameter includes removal of the 600 mm thick concrete liner, 75 mm thick initial support, an assumed overbreak thickness of 150 mm from the shaft sinking operation and an assumed 500 mm thick HDZ of rock, which will be removed from Reaches 2b, 3 and the section of Reach 4 above the top of the concrete monolith. Therefore, the effective diameter for the Main Shaft for sealing would be 9.15 m. The Ventilation Shaft has an internal finished diameter of 5.0 m and a 500 mm thick liner and, using a similar method, the effective diameter for sealing was determined to be 7.45 m.

11.2.2 Design Approach

The design approach for the shaft seal design focused on the use of simple, relatively well understood, durable materials and methodologies for emplacement. Seal materials, construction methods and arrangement are outlined below. Since the shaft seal will not be implemented for several decades, there is time to incorporate new information learned during operation of the DGR as well as from long-term sealing tests at the DGR and international repository sites. Therefore, the design presented herein is intended to provide a reasonable assurance that a competent shaft seal can be constructed using currently available materials and methods, but is not necessarily the final design.

A key consideration in the design approach for the shaft sealing system is the potential formation of damage zones during shaft sinking and operations. When man-made openings are created in rock formations, disturbance and damage to the surrounding host rock is expected to occur as a result of damage due to the excavation method itself, or mechanical changes resulting from stress redistribution. It is well understood that the creation of these zones occurs, however, the extent and characteristics of these zones is uncertain and depends on local conditions in the geosphere. As a result, this damage zone can be difficult to define prior to completion of the actual excavation. For this report, these damage zones are divided into the HDZ, EDZ and the Excavation Disturbed Zone (EdZ). These zones are defined in [R68] as:

- HDZ – zone where macro-scale fracturing or spalling may occur, thereby inducing changes in flow and transport through the interconnected fracture system (i.e. permeabilities within the rock increased by at least 2 orders of magnitude).
- EDZ – zone with hydromechanical and geochemical modifications inducing changes in flow and transport properties (i.e. permeabilities within the rock increased by at least 1 order of magnitude).
- EdZ – zone with possible hydromechanical and geochemical modifications, without material changes in flow and transport properties (i.e. permeabilities within the rock materially unchanged).

As a result, the HDZ and EDZ will show increases of hydraulic permeability. This has a significant impact on shaft sealing, as the potential flow of groundwater into the DGR and the potential migration of contaminants (in water and / or gas) out of the DGR through the HDZ and EDZ must be assessed and controlled.

The properties of the HDZ and EDZ are sensitive to site-specific conditions and will ultimately need to be measured after shaft construction at the DGR site. It is expected that these zones will not be uniform due to in-situ stresses around the shafts. According to the definition of EDZ as given in [R68], the bulk hydraulic conductivity of the remaining material would then be less than 10^{-10} m/s. The HDZ removal during each lift thickness will be made until only rock exhibiting this EDZ hydraulic conductivity is reached. The actual thickness of HDZ to be removed has been assumed for the purposes of preliminary design to be 500 mm. This assumption will be evaluated in subsequent design phases using numerical modelling and continue to be re-assessed on the basis of observations and geomechanical field testing during shaft sinking. The final required HDZ removal depth can only be verified at the time of shaft seal construction.

The extent of the damage zones remaining at the end of the operational period of the DGR may be less than would be initially expected as a result of salt or mineral precipitation from the host rock into the openings. The extent of damage zone formation has been estimated without considering any potential benefits of salt or mineral precipitation in the design of the seal.

11.2.3 Seal Materials

Concrete, bentonite / sand mixture and asphalt will be the sealing materials used in Reaches 4, 3 and 2b. Native earthen materials excavated during shaft sinking or some other suitable material will be used as “fill” material in Reach 2a (this latter material is not described below). The following sections describe the proposed seal materials and their attributes. These materials are common to most proposed shaft sealing system designs for deep nuclear waste repositories (e.g. [R69], [R70], [R71], [R72]). It is anticipated that research and development will continue on these and other materials for use in shaft sealing systems. This research and development will likely lead to improvements that will be incorporated into the actual design to be presented as part of the future decommissioning licence application.

11.2.3.1 Concrete

Concrete is proposed within the design to provide a stable foundation for the overlying seal materials (in the form of a monolith at the base of the shafts) and to serve as a structural component designed to key into the shaft wall to provide support and confinement for other sealing media (in the form of concrete bulkheads). Nearly all the scientific and engineering literature regarding the sealing of deep waste repositories propose the use of mass concrete for some components of the sealing system.

The following engineering properties of concrete are considered advantageous for deep repository shaft sealing systems:

- Capable of rapidly developing structural properties.
- High strength.
- Provides a low permeability barrier until the time that concrete begins to degrade (hydraulic conductivity ranges from 10^{-11} m/s to 10^{-14} m/s).

- Broad range of performance objectives can be achieved by changing the mix – type and proportion of ingredients and the means by which it is emplaced.
- Typical ingredients are abundant and inexpensive.
- Extensive experience with concrete design, construction and testing.
- Technology established for underground uses in the petroleum and mining industries, including the sealing of closed wells, mine shafts and boreholes.

Some potential drawbacks of concrete that must be addressed in the design and construction of a repository sealing system include [R73]:

- Geochemical compatibility with the host rock and groundwater. Non-equilibrium conditions may lead to leaching of components from the host rock to groundwater / pore water.
- Interface problems at the contact between concrete and host rock (i.e. shrinkage of concrete).
- Excessive heat generated from exothermic hydration reaction in large emplacements can result in thermal cracking of the concrete.
- Longevity of concrete.

Some of the potential concerns with concrete can be avoided or minimised by optimising the concrete mix. In particular, the concrete portions of the repository that do not have long-term requirements (e.g. floors) could be made from standard concrete mixtures and reinforced with steel if necessary. But the long-term seals could be constructed (without steel reinforcement) using concrete mixtures that are low-shrinkage, low-alkalinity and sulphate-resistant.

11.2.3.2 Bentonite Clay

Compacted clays or clay / sand mixtures are the most commonly proposed sealing materials for nuclear waste repositories. The use of compacted clays has been extensively investigated and tested against a variety of seal performance requirements. Montmorillinite-rich smectite (bentonite) clays have received the most attention as they have higher swelling potential and sorptive capacity compared to other clays.

The addition of sand aggregate to the bentonite mixture increases the strength of and ability to handle the mixture. The addition of aggregate to the clay also reduces the capacity for shrinkage.

Research by AECL [R74] indicates that adding up to 50% sand does not significantly alter the hydraulic conductivity or swelling pressure as compared to pure bentonite under conditions of identical compaction effort. This is because the density of clay in these mixtures remains approximately constant and dominates the performance. Although sand is added as filler, it improves the mechanical behaviour of the mixture such that the achievable mixture density is increased, which results in the overall clay component density remaining approximately unchanged.

The following engineering properties of compacted bentonite / sand mixtures make it an advantageous material for use in a shaft sealing system:

- Low hydraulic conductivity (10^{-10} to 10^{-14} m/s).
- High sorptive capacity for radionuclides.
- High swelling potential allows bentonite to heal itself when fractured. The swelling potential also maintains tightness between the seal material and shaft wall. As bentonite sorbs water, the interstitial layer in the clay material will expand to create swelling pressure, thereby developing fluid-like properties within the bentonite. This may then squeeze into the openings in the EDZ along the shaft wall, providing a partial seal in the EDZ immediately adjacent to the shaft wall.
- Demonstrated longevity in many natural environments.
- Demonstrated success sealing waste containment structures such as landfills.

Potential issues related to the use of bentonite as a sealing material are listed as follows [R73]:

- Quality assurance of materials and emplacement techniques.
- The time required for a tight seal to develop between the compacted bentonite material and the shaft wall.
- Cation exchange between the bentonite and saline groundwater may result in the loss of swelling pressure and a corresponding increase in hydraulic conductivity of the bentonite materials.

NWMO has advised that common bentonite / sand mixtures studied in repository field experiments are 70:30 bentonite / sand (e.g. the AECL Tunnel Sealing Experiment and Enhanced Seal Project) and 50:50 bentonite / sand (e.g. the AECL Buffer-Container Experiment). The SKB Prototype Repository experiment has used 100% bentonite (i.e. no sand). Since it can be harder to compact in-situ, 100% bentonite is often considered in the form of blocks, whereas the bentonite / sand mixtures can be placed as blocks or compacted in-situ. Blocks can be fabricated to higher densities than possible with in-situ compaction.

The bentonite-sand mixture and the form of placement can be optimised as part of future design work. For the preliminary design, an in-situ compacted mixture of 70:30 bentonite / sand is considered. This provides sufficient swelling potential and low hydraulic conductivity, with practical handling properties.

11.2.3.3 Asphalt

Asphalt, (bitumen with fillers), is cited in the engineering literature as suitable sealing material for repository access shafts because of its many desirable engineering properties. The following properties of asphalt produce a suitable sealing system material:

- Readily adhesive.
- Low hydraulic conductivity (10^{-11} to 10^{-14} m/s).

- History of successful use in mine shafts.
- Ability to heal if deformed (visco-plastic).
- A range of viscosity can be achieved – viscosity can be made sufficiently low such that it penetrates and potentially seals portions of the EDZ.
- Resistant to most acids, salts and alkalis.
- Significantly stronger in compression compared to the bentonite/sand mix (about 5 times), yet not as strong as concrete.
- Longevity.

The use of asphalt would also provide an independent barrier to groundwater flow, thus providing redundancy within the design.

There are some potential issues with asphalt as a sealing system that must be considered [R73]:

- The longevity of asphalt can be reduced due to microbial degradation.
- The influence of the heat introduced during asphalt placement on host rock behaviour must be considered.

The reference asphalt mixture is based on a mix of asphalt compounds and aggregate, combined with a small porosity fraction to ensure low permeability.

11.2.4 Seal Arrangement

The arrangement of the recommended sealing system for the Ventilation and Main Shafts, including an explanation of the selected components, their relative location and role in the sealing system, is discussed in ascending order from the repository horizon to the ground surface. Drawing H333000-WP411-10-042-0001 provides a layout of the full seal design which is also shown in Figure 11-1.

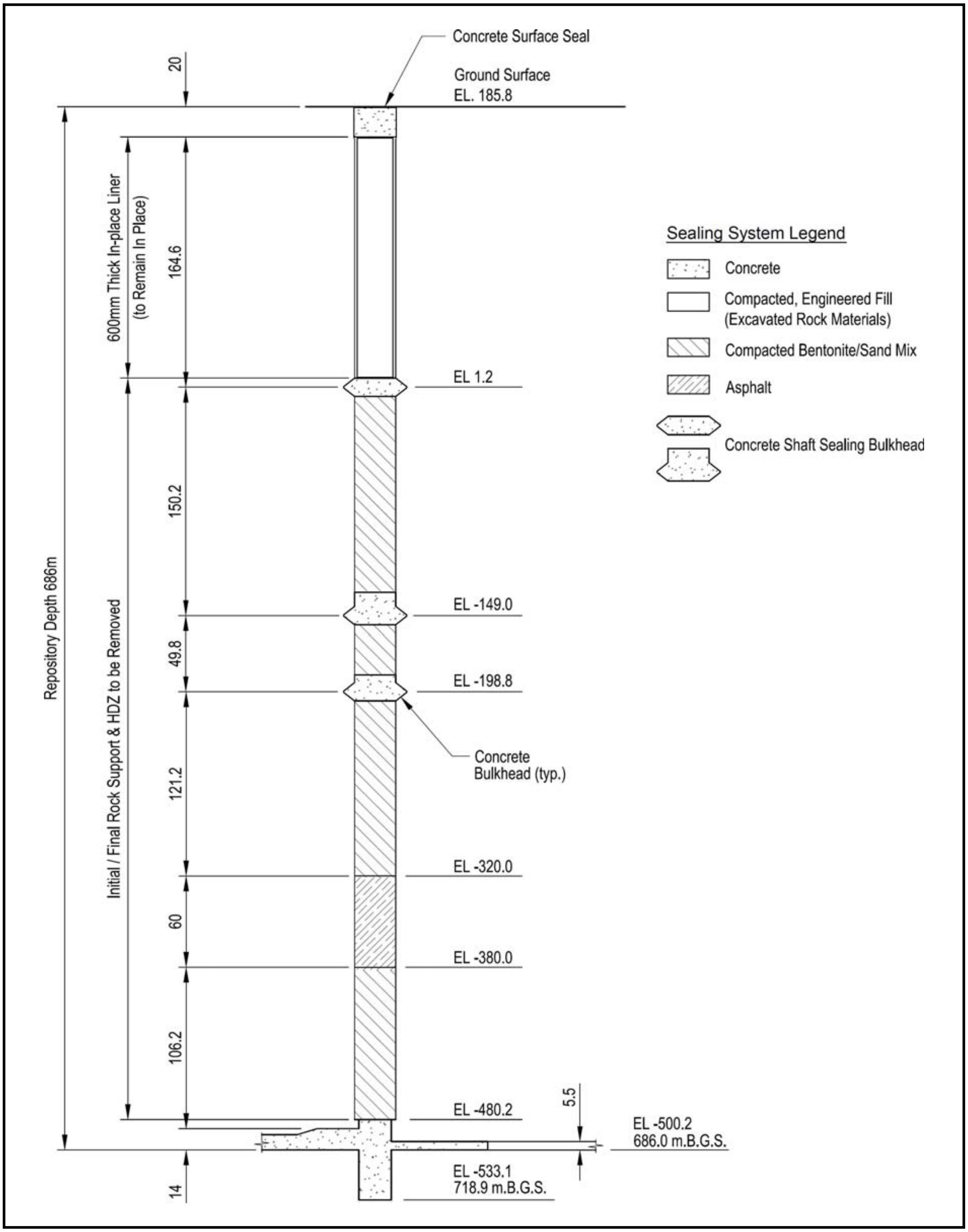

Figure 11-1 – Arrangement of Main Shaft Seal

A concrete monolith is planned for placement at the base of the seal system on each shaft. Concrete will provide a stable foundation for the overlying seal materials and a high degree of support to the repository station openings. Moreover, the concrete monolith will ensure the necessary structural strength to withstand an internal gas pressure of 14 MPa, as dictated by the System Requirements [R46]. The monolith will be extended from the vertical shaft into the transitional area of the horizontal excavations to provide a temporary protection against the possibility of gas pressure damaging the overlying seal system components. Over time gas will leak into the shaft bottom via the tunnel EDZ; however, preliminary conservative modelling of the forces at work on the seal elements has shown that the downward forces of the overlying seal materials will outweigh the uplift force provided by gas pressure.

The monolith will be created in two stages, one for the Ventilation Shaft, followed by another for the Main Shaft. However, they will form one contiguous mass concrete structure and there will be no structural reinforcement. All services and utilities will be stripped out of the excavations that will be filled by the monolith to remove potential voids. Bulkheads will be constructed at the maximum limit of the monolith in the underground Shaft and Services Area tunnels and other openings prior to placement of concrete. The concrete monoliths for the Main Shaft and Ventilation Shaft will be created by filling the sumps, ramps to the shaft bottom, shaft stations (i.e. to heights of 14 m and 7.5 m respectively) and into any surrounding tunnels or peripheral rooms (i.e. to a height of ~ 7.5 to 8.5 m) to a distance of about 60 m [R50] beyond the circumference of the excavated shaft diameter (See Figure 11-2). A typical section for the concrete monolith is provided in drawing H333000-WP 411-10-042-0002. There will be no removal of the HDZ at the repository station elevation.

Mass concrete will also be poured 40-60 m down into the base of the shaft (i.e. through the extra shaft depth excavated for the sump), into the ramps at the base of the shaft and approximately 5 m above the monolith into each shaft. Contact / seal grouting will be applied around the monolith in order to minimise the potential impacts of shrinkage at the interface with the Cobourg Lower Member.

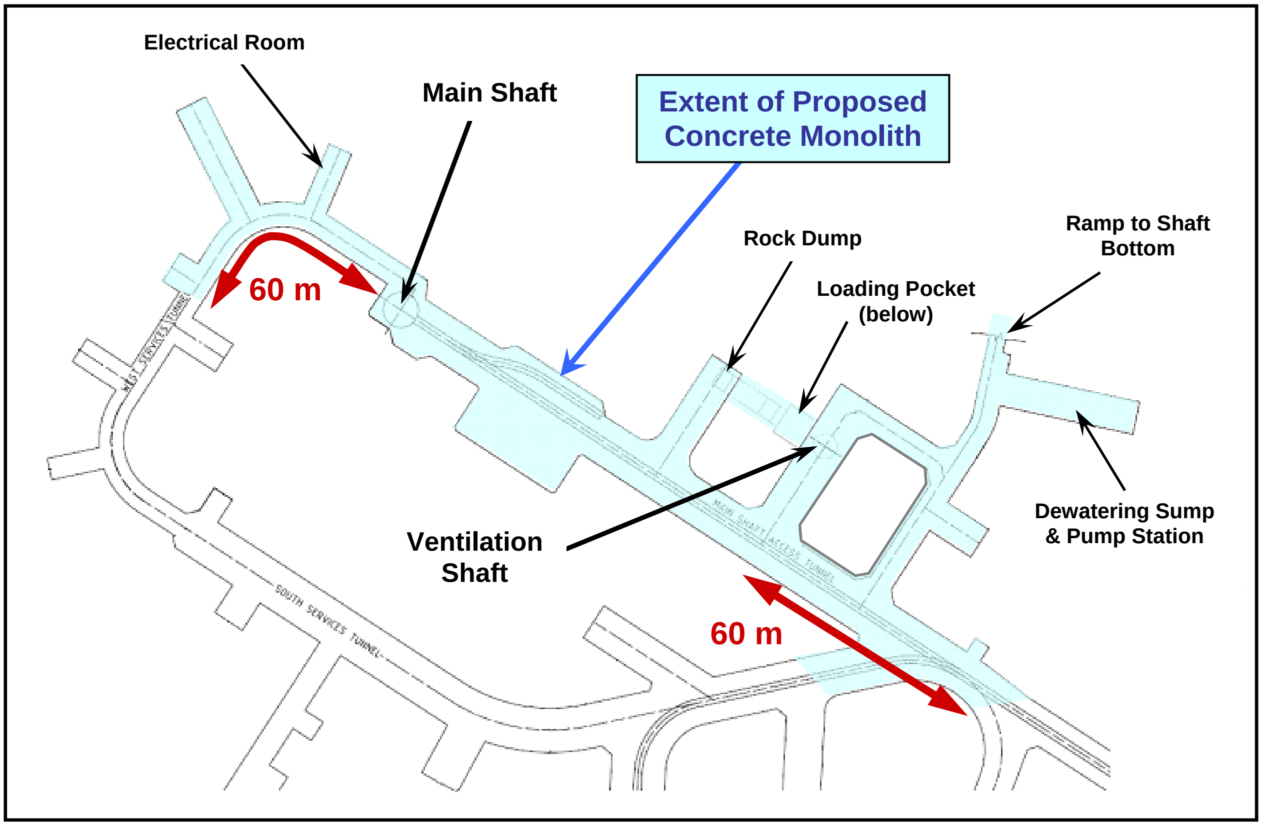

Figure 11-2 – Underground Shaft and Services Area showing Extent of Concrete Monolith
(Monolith shown in light blue - modified from [R50])

The concrete monolith is then overlain by a column of compacted bentonite / sand. While the concrete provides an immediate low permeability barrier to fluid flow, the compacted bentonite / sand materials act as a low permeability barrier in the long term to retard the movement of radionuclides out of the repository and minimise the potential for groundwater flow down into the repository. As the compacted bentonite / sand materials saturate with groundwater from the surrounding rock, they will generate swelling pressures which will aid in the development of a tight seal at the shaft wall contact. In combination with swelling potential of the Georgian Bay Formation and Cobourg Collingwood Member, the clay swelling will promote some healing of the EDZ. Hydraulic conductivity of the EDZ may also be reduced as a result of salt and mineral precipitation from the host rock into these features.

Grouting is not recommended around the bentonite / sand columns as shrinkage of the shales is not expected to occur and the clay will naturally swell to fill any gaps between bentonite/sand column and rock sidewall of the shaft. However some local grouting may be required at contact zones or major discontinuities.

Throughout this section and all seal sections up to the top of Reach 2b, shaft support structures and concrete liners will be removed to ensure a complete seal of the shaft column to the surrounding low-permeability host rock. Also, an additional 500 mm of host rock will be excavated beyond the initial shaft diameter to remove the HDZ formed during shaft sinking and the operational period of the DGR. The removal of the HDZ rock and shaft support structures will occur in small vertical lifts in a sequential manner, through mechanical means. Each section of removal will be closely followed by backfilling of the lift with densely compacted material. This process will minimise the stress changes in the rock and hence supplemental growth of the EDZ.

An asphalt column is then placed above the bentonite / sand column. The asphalt column extends over a length of the Georgian Bay Formation to just above the Queenston / Georgian Bay contact. Asphalt was selected for this location because it has the ability to flow into the contact between the Queenston Formation and the Georgian Bay Formation and seal it against potential inflows. It will also be compatible with the expected hydrocarbon bearing layers of the Georgian Bay Formation. Furthermore, the use of another low permeability sealing material provides an additional level of redundancy to the sealing system against upward or downward fluid flow. Asphalt is also stronger than bentonite / sand materials and will provide additional structural support for the seal materials. It may be necessary to install a concrete separation pad on the lower bentonite / sand column to prevent excessive seeping of liquid asphalt into the lower bentonite / sand material. A period should be allowed for the asphalt to cool and solidify before commencing placement of the next bentonite / sand column above. The thickness of the asphalt column is approximately 60 m, as shown in drawing H333000-WP411-10-042-0001.

The bentonite / sand column overlying the asphalt forms another low permeability barrier increasing the redundancy of the system. It will be constructed using the same methods and materials described for the lower bentonite / sand columns. As groundwater seeps into the clay, it is expected that the swelling potential of the bentonite / sand in combination with the swelling potential of the Queenston shale will develop a very tight contact seal and potentially heal portions of the EDZ in this section. This bentonite / sand column will transition from Reach 3 into Reach 2b where the same procedures will be followed to place the bentonite / sand mixture.

In Reach 2b there are two higher permeability units within the surrounding geosphere. The Guelph Formation has a hydraulic conductivity which is 2 to 3 orders of magnitude greater than adjacent formations. Due to the expected lateral flow along this unit, a concrete cylinder will be placed along the full extent (~ 6 m) of this unit. In order to ensure structural stability, the concrete bulkhead will be constructed to a height equivalent to the diameter of the excavated shaft (following HDZ removal) immediately below the permeable zone. Further, the concrete bulkhead will be keyed into the surrounding host rock by an additional 0.5**r* beyond the edge of the prepared shaft in order to maintain structural stability. The use of this bulkhead will provide confinement to the seal materials below in order to develop swelling pressure within the bentonite / sand columns. The concrete used to construct the bulkhead will be similar to that selected for the shaft station monolith. Concrete bulkheads will also be pressure grouted to increase the tortuosity of the concrete / rock interface and thus minimise groundwater inflow. A typical section for the concrete monolith, showing typical contact grouting, is provided in drawing H333000-WP411-10-042-0002.

From this bulkhead, another compacted bentonite / sand column is constructed to the A1 / A2 units of the Salina Formation. The upper approximately 4 m of the Salina A1 unit is similar to the Guelph Formation, having a higher permeability within the surrounding geosphere. Again due to the potential lateral flow in this area, a concrete bulkhead will be installed exactly as proposed at the Guelph Formation.

Above this section, a compacted bentonite / sand column will be installed in the B through F Units of the Salina Formation. Unit F represents a lower (at least one order of magnitude) permeability zone within the dolostones (an aquitard) between a fresh water aquifer above and more saline-water-bearing formations below. To prevent movement of the poor quality, saline groundwater from the lower Salina Formation upwards through the shaft cross-section into the upper fresh water aquifer, a further concrete bulkhead will be constructed. Though higher flow pathways may exist above the Salina F unit, placement of engineered seal materials beyond the F unit is not recommended for the following reasons:

- If the bentonite / sand column is to be extended in this area, the shaft lining would need to be stripped through portions of Reach 2a, which could cause some release of saline water volumes behind the seal during construction of the seal and thus compromise the upper section of the bentonite / sand column; and
- The rock surrounding the shaft “cylinder” would have a higher hydraulic conductivity in Reach 2a than what would be attained the shaft column, so any saline water would migrate upwards faster through the rock than in the shaft seal.

The installation of this uppermost bentonite / sand column in Reach 2b and uppermost concrete bulkhead will prevent the interaction of saline groundwater in the Salina Formation with the freshwater in upper aquifer. This is consistent with the applicable requirements within Section 11 (Well plugging) of the Provincial Operating Standards, Oil, Gas, Salt Resources of Ontario [R67].

If seal materials are supplied and placed as specified, it is considered likely that the column of seal materials would be structurally stable. As the three concrete bulkheads will be keyed into the adjacent rock in Reach 2b, these bulkheads would be designed to provide structural support for the overlying seal materials and confinement of the swelling seal materials between the bulkheads. The location and the need for additional bulkheads will be predicted by numerical modelling in subsequent design phases and on the basis of observations and geomechanical field testing during shaft sinking and at the time of shaft seal construction. These confirmatory analyses and investigations will assist in the determination of final bulkhead requirements at the time of shaft seal construction.

The shaft is then filled to the top of Reach 2a with ‘Granular A’ material, possibly from crushed rock obtained during shaft excavation. The fill material will be engineered and compacted to a hydraulic conductivity of no greater than 10^{-4} m/s. Removal of the concrete liner throughout this section is not essential. Therefore, it will be left in place to avoid safety risks to workers and the time and labour required for its removal; however the state of the liner and the possibility of removal should be examined prior to seal construction to determine the potential costs and benefits of removal prior to a final decision being made.

The fill will be topped by a surficial concrete cap through Reach 1, representing the final element of the seal system. This cap, which will comply with regulatory requirements [R66], will serve to:

- Limit surface water inflow into the shaft cross-section by creating a solid, impermeable seal at the shaft entrance.
- Further reduce the potential for subsidence, as concrete is stronger than compacted fill.
- Provide a marker for the shaft locations.
- Reduce the potential for inadvertent human entry by providing a restrictive barrier at the surface.

In Reaches 4 and 3 and the majority of Reach 2b, the hydraulic conductivity of in-situ, undisturbed rock has been demonstrated to be less than 10^{-12} m/s. Even with the use of controlled blasting techniques, excavation for shaft sinking will disturb the rock mass around the shaft excavation perimeter creating an HDZ and EDZ in the rock immediately outside the shaft lining. During future shaft sealing, shaft lining materials (including initial support shotcrete) and the HDZ thickness of the surrounding rock will need to be removed in a controlled manner and with controlled lift thicknesses in Reach 4 above the top of the repository station monolith and throughout the height of Reaches 3 and 2b until only the EDZ material remains. Each removal thickness will be closely followed by the placement and compaction of the sealing materials before proceeding to the next lift.

With proper preparation, placement and compaction of the sealing materials, bulk hydraulic conductivity of the sealing material of less than 10^{-10} m/s should be achieved. Since the greater hydraulic conductivity of the sealing material, rock / material contact interface or the EDZ rock would govern the bulk hydraulic conductivity of the seal, the overall shaft seal system within Reach 3 should have a bulk hydraulic conductivity of less than 10^{-10} m/s on the basis that both the above-mentioned assumptions and a tight contact between the rock and the sealing materials can be practically achieved.

11.2.5 Seal Construction Methods

Preliminary construction methods for the shaft sealing system are described below:

11.2.5.1 Shaft Access during Sealing and Construction Sequence

At the Ventilation Shaft, a set of temporary stage winches will be installed, from which a working platform will be suspended on wire ropes to enable the sealing process to be conducted. The existing 2nd egress hoist will be used as the primary means of travel between surface and the shaft bottom for workers, equipment and materials. Shaft infrastructure, such as ventilation, will be removed on a phased basis in a manner to ensure that required services are provided to the shaft during shaft sealing. Above Reach 2b, the concrete liner will be left in place, while all other shaft infrastructure is removed. Within this area, concrete found to be above the approved clearance levels will be removed by planning, scarifying or by drilling and spalling.

On completion of sealing of the Ventilation Shaft, the same process will be performed in the Main Shaft. In this case, the first stage of shaft decommissioning will consist of removal of the operational Koepe friction hoist and replacement by a stage hoist to suspend the working platform and a single drum hoist for worker, material and equipment access during the stripping of the shaft lining and HDZ.

11.2.5.2 Receipt and Storage of Sealing Materials

Following decontamination of the WPRB, it will be converted for use as the Sealing Materials Receipt and Storage Building. Use of this location will provide convenient loading / unloading for haulage trucks and a storage location in close proximity to the shaft entrances.

Some bulk materials may require storage outside of the WPRB. Following decommissioning of the surface facilities associated with the DGR, there will be ample land available in close proximity to the WPRB for storage of these materials.

11.2.5.3 Removal of Shaft Infrastructure

Shaft infrastructure, including the concrete liner, is to be removed from the bottom of the shaft through Reach 2b (~183 m from the top of the shaft). All shaft infrastructures (up to the top of Reach 2b) will be mechanically cut from the shaft in a series of controlled lifts. Additional analyses will be performed to determine the lift thickness such that sufficient support is provided to the newly-exposed rock face by the overlying shaft infrastructure. It is anticipated that mechanical cutting of the shaft liner will be required in order to minimise impacts on the surrounding host rock. Water jetting may be a potential alternative to mechanical cutting that will be considered.

Waste materials resulting from the removal of shaft infrastructure will be brought to the surface and reused / recycled wherever possible. Materials that cannot be reused or recycled will be disposed of at an approved location in accordance with existing waste management regulations.

Following removal of the shaft infrastructure, HDZ removal will commence. HDZ will be removed through mechanical means, such as with a roadheader or jackhammer mounted to the hoist, or operated manually, in order to minimise the extent of new formation of EDZ. It has been identified that HDZ may be removed through the use of a water jet, or a similar non-mechanical methodology; this prospect will be examined in further detail at a later phase of design.

Waste rock resulting from excavation associated with the HDZ removal will be reused on site wherever possible, or disposed of in the WRMA established during construction of the DGR.

11.2.5.4 Construction of Keys for Concrete Bulkheads

Similar to the removal of the HDZ described, construction of keys for concrete bulkheads will be completed using mechanical means in order to minimise the potential for formation of new EDZ. The entire concrete bulkhead key will be constructed in a one pass sequence. For the Main Shaft, this will be equivalent to a 9 m pass, while a 7.5 m pass will be required in the Ventilation Shaft. The key cavity will consist of excavation to a maximum depth, at the mid point, of approximately 2 m in both the Main and Ventilation Shafts.

Waste rock resulting from excavation associated with the keying of concrete bulkheads will be reused on site wherever possible or disposed of in the WRMA established during construction of the DGR.

11.2.5.5 Concrete Mix and Placement

Concrete will be mixed on the surface in a temporary batch plant to be located within the SSFA. Concrete will be placed in the shafts through the use of a slickline and header. A slickline is essentially a steel pipe secured to the shaft wall to transport fluid concrete from the surface to the required depth. At the base of the slickline, a slightly larger steel pipe called a header diverts the downward flow of material 45 degrees, dissipating the impact energy of the falling material. A flexible hose is then connected to the header enabling exact placement of the material. This methodology was also proposed for WIPP.

The DGR requires the placement of concrete at depths of up to 720 metres below the ground surface; experience with concrete placement to depths of this magnitude is common in mining applications.

11.2.5.5.1 Placement as Concrete Monolith

Concrete for the monolith will be placed in mass (i.e. without structural reinforcement). Construction of bulkheads at the maximum limit of the monolith in the underground Shaft and Services Area tunnel and other openings will be required prior to placement of concrete. The concrete monolith will be created by filling the shaft station (i.e. to heights of 14 m and 7.5 m respectively) and into any surrounding tunnels or peripheral rooms (i.e. to a height of ~ 7.5 to 8.5 m) to a length of approximately 60 m beyond the circumference of the excavated shaft diameter (see Figure 11.2). Bulkheads will be installed at the outer extent of the proposed monolith location in order to contain the concrete while it cures.

A typical section for the concrete monolith is provided in drawing H333000-411-10-042-0002. There will be no removal of the HDZ at the repository station elevation. Mass concrete will be poured to fill all openings at the base of two shafts and the monolith will extend 30-40 m down into the base of the shafts (i.e. through the extra shaft depth excavated for the sump), into the adjoining ramp and approximately 5 m above the monolith into the shaft. The installation of this monolith could potentially generate large amounts of heat during the curing process. To control such heat build-up, proper mass concrete construction procedures will be followed. Contact / seal grouting will be applied around the monolith in order to minimise the potential impacts of shrinkage at the interface with the Cobourg Lower Member.

The concrete monolith for the Ventilation Shaft will be constructed first, with that for the Main Shaft constructed after Ventilation Shaft sealing is complete. These monoliths will be merged into a single monolith in the main access tunnel between the shafts.

11.2.5.5.2 Placement as Concrete Bulkheads

As with monoliths, concrete for the bulkheads will be placed in mass, with similar measures employed to control heat build-up. Contact / seal grouting will also be applied around the bulkheads in order to minimise the potential impacts of shrinkage at the interface with the Cobourg formation limestone. Concrete will be poured directly onto the upper layer of the bentonite / sand columns located below each bulkhead.

11.2.5.5.3 Placement as Surficial Cap

The surficial cap will be constructed using general use concrete. At this location, a higher percentage of air entrainment within the concrete is required to account for freeze / thaw considerations. The surficial cap will be constructed through staged pours, in approximately

3 m lifts. The use of structural elements within the concrete of the surficial cap is not recommended at this time, however this can be considered in a future phase of design.

11.2.5.6 Bentonite / Sand Mix and Placement

Bentonite will be mixed with sand to a 70:30 mix on the surface in order to ensure stability of the column while maintaining the desired low permeability barrier provided by the bentonite. The mixing of sand with the bentonite will increase the strength of the column, providing additional support for the seal materials above, while also reducing the capacity for shrinkage. This will also reduce the potential for significant dust generation during emplacement which may impact the safety of the working environment within the shaft.

Mixing of the bentonite with the sand could be undertaken in a manner similar to that used by AECL for their 40:60 bentonite / sand component of the Underground Research Laboratory (URL) shaft seal. This is proposed to be accomplished through the use of a temporary batch plant, similar to that which is proposed for concrete production on site (see Section 11.2.3.1). This would consist of a typical concrete dry batching truck that has two hoppers, one holding the sand component and the other holding the bentonite, along with a tank that holds water. The sand and bentonite are fed onto a conveyor belt that feeds a screw-auger which mixes the materials as they approach the discharge spout. Water is applied to the mixture as required as it enters the screw-auger. This system would require calibration in order to ensure an adequate moisture content is reached within the combined materials [R75]. The materials can then be transported directly into the shaft, or stored temporarily within plastic bags to retain moisture levels, and then transported to the shaft.

The combined bentonite / sand materials can then be placed within the shaft either loose, or in pre-compacted blocks. The current reference design assumes that materials will be placed loose via a slickline and header, as is proposed for concrete, and then compacted in-situ to a dry density of approximately 1.6 Mg/m^3. According to [R76], this will lead to an Effective Montmorillonite Dry Density (EMDD) equal to 1.2 Mg/m^3.

Compaction of these materials can be performed using vibratory plate compactors, sheepsfoot rollers or by dropping a large weight onto the materials. Vibratory plate and sheepsfoot compactors require the placed lift of seal materials to be roughly 150 mm to 300 mm to ensure compaction of the full depth. Weight dropping can compact much thicker lifts depending on the size of the weight and the height it is dropped from. At this time, it is assumed that vibratory plate compactors will be used as was proposed for the URL given the potential issues with the use of internal combustion engine devices within the relatively poor ventilation environment of the shaft during sealing. Experience working with compaction equipment during tests at the URL has shown that smaller compaction equipment is required in proximity to the shaft walls in order to ensure adequate compaction; as such the use of a small compactor will be required in combination with the compaction equipment for the majority of the lift to be covered.

Experience with the AECL shaft seal project shows that it is practical in a shaft environment using the above approach and appropriate quality controls to achieve the target density and good mixing of the bentonite/sand components [R77].

11.2.5.7 Asphalt Mix and Placement

An asphalt mastic mix will be prepared on the surface with the use of a temporary pug mill, heated to a sufficient temperature that will be located within the SSFA.

Following mixing, liquid asphalt is pumped to the shaft and placed through the use of a slickline and header, in much the same manner as concrete. The slickline will require heating in order to maintain the asphalt's liquid state. A similar system was proposed for emplacing the asphalt components of the WIPP sealing system. Asphalt will be placed in lifts (lift thickness to be determined).

Following placement of the asphalt, sealing operations will be ceased to allow for cooling of the asphalt in order to ensure a safe working environment. In order to promote cooling, ventilation into the shaft will be maintained during this period, as is proposed for WIPP. Air temperature within the shaft, at a location 1-3 m above the asphalt column will be monitored remotely in order to establish the point at which shaft sealing can resume.

11.2.5.8 Placement of Compacted Engineered Fill

Native earthen / rock materials will be crushed and screened prior to placement. This material will then be graded on the surface and hydrated in order to obtain an optimal moisture content for compaction. Fill materials will then be transported into the shaft, via the slickline and header, as is proposed for concrete.

Following placement, compaction of engineered fill will be completed in the same manner as bentonite / sand, with the exception that compaction can be accomplished in larger lifts (i.e. 0.3 m vs. 0.15 m).

12. Project Execution

12.1 Licensing and Environmental Approval

Under the NSCA [R52], the DGR will require licences from the CNSC for site preparation, construction, operation, decommissioning and abandonment.

OPG applied for a site preparation and construction licence in August 2007. However, before a decision to issue a site preparation and construction licence can be made, an Environmental Impact Statement (EIS) prepared by OPG will need to be approved by a Joint Review Panel under the Canadian Environmental Assessment Act (CEAA). The entire licensing process after submission of the EIS and the licensing documentation to the Joint Review Panel (scheduled for Q1 2011) may take up to two years.

12.2 Safety and Environment

12.2.1 Health and Safety

For the DGR project, health and safety of workers will fall under the provincial jurisdiction. OHSA, Regulations for Construction Projects and Ontario Mining Regulations will apply.

The project safety program will have two components:

- Design safety program.
- Construction safety program.

Training requirements for local contractors and their employees will be a principal focus of the construction safety program. This training program will be developed and implemented prior to the start of construction and will focus initially on the training required to support early activities at site, such as heavy equipment operation and shaft sinking activities.

The principal elements of the design safety program to meet the plant functionality criteria consist of:

- HAZOP (Hazard and Operability Study) of Piping and Instrumentation Diagrams (P&IDs).
- Layout reviews for safety.
- Operability and maintainability reviews.
- Fire safety reviews.
- Insurance risk reviews.
- Legislative compliance reviews.
- Ergonomic reviews.

12.2.2 Environmental Compliance

The Environmental Permit Registry (EPR) is a component of a larger permit registry that covers other project aspects such as engineering and safety. The EPR is comprised of two parts:

Part 1 outlines the various permits that have been both obtained or that will be obtained in the future, referencing the appropriate legislation and regulations, government contact person, timelines and Project team responsibilities. Part 2 outlines the specific requirements and conditions of existing permits and serves as a key compliance tool.

There will also be an active site component of the Environmental program in the form of monitoring. The purposes of the follow-up / monitoring programs for the Project are to:

- Continue collection of baseline environmental data to assess environmental impacts of day to-day activities during construction and operation and at closure.
- Detect unanticipated environmental impacts (if any).
- Verify the accuracy of the environmental assessment and determine the effectiveness of proposed mitigative measures and the need for modification to these measures or the requirement for additional measures.
- Ensure compliance with applicable regulations and requirements of environmental permits.

In all cases, the results of the monitoring and follow-up programs will not be kept in isolation but will be summarised on at least an annual basis and will be used to modify existing procedures / designs / mitigation measures as appropriate to minimise environmental impacts. Reporting will meet all regulatory requirements.

The monitoring / follow-up programs will be implemented by site personnel and will be supported by external laboratories and consultants as appropriate.

12.2.3 Engineering and Procurement

Engineering is currently split into a phased approach. The next phase of engineering will progress the design to approximately 25 percent complete or an equivalent of basic engineering. It is proposed to move into detailed engineering thereafter, such that the majority of engineering will be complete prior to receiving the construction licence and commencing construction activities.

Engineering will be done using an intelligent 3D design model or 2D CADD (Computer-Aided Drafting and Design) for the surface and underground facilities.

Tenders will be called for all equipment whether specialised or bulk items.

To avoid disputes over shortages, surpluses or damaged materials, contractors will be required to procure their own materials. The exceptions to this supply approach are the following, which will be purchased by the project procurement group: certain high value / high volume construction materials, large bulk orders and electrical cable (contractor mark-ups for these items would be significant and the supply / install interface is relatively simple).

12.2.4 Contracting Strategy

The construction contract strategy is based on a conventional construction management approach whereby the work is packaged into contracts and awarded on a unit price or lump sum basis. The construction contract strategy will be further optimised, taking into account the following factors:

- The cost of contractor mobilisation and demobilisation.

- The complexity of interfaces between concrete, building structural steel, internal structural steel, equipment installation, mechanical / piping work, electrical and instrumentation work, etc. and likelihood of problems of interference and congestion.
- The desire to maintain a managed open site labour relations strategy.
- Availability of skilled labour.
- Availability of qualified contractors.
- Potential labour relations conflicts.
- Extent of design and construction overlap and state of completion of engineering at time of tender for construction contracts.
- Higher cost of materials purchased by contractors versus potential for contractor claims where materials are supplied to them.
- Advantages of pain share / gain share.
- Contractor mobilisation time required.

All contracts and purchase orders will be in the name of OPG with the EPCM (Engineering, Procurement, Construction Management) provider as its representative. The project will use the standard contract documents agreed upon for use by OPG and NWMO.

Construction alliance strategies will also be explored.

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Appendix B – Definitions and Abbreviations

OPG's DGR Project Glossary [R68] provides the primary source for definitions and abbreviations. The following listing includes the more commonly used acronyms within this Preliminary Design Report, some of which may be specific to certain of the specialised topics presented herein, or may be otherwise misinterpreted.

Ø	Diameter
Φ	Friction Angle (degrees)
σ_H	Major Principal Horizontal In-situ Stress
σ_h	Minor Principal Horizontal In-situ Stress
σ_v	Vertical Stress
AECL	Atomic Energy of Canada Limited
ALARA	As Low As Reasonably Achievable
ALW	Active Liquid Waste
ANDRA	French National Agency for Radioactive Waste Management
BC	Below Collar
Bruce Power ERT	Bruce Power Emergency Response Team
BTEX	Benzene, Toluene, Ethylene and Xylene
BTS	Brazilian Tensile Strength
c	Cohesion
CADD	Computer-Aided Drafting and Design
CDR	Conceptual Design Report
CEAA	Canadian Environmental Assessment Act
CFD	Computational Fluid Dynamics
cm	Centimetre
CMTS	Cable Modem Terminal Services
CNSC	Canadian Nuclear Safety Commission
CO	Carbon Monoxide
CPU	Central Processing Unit
CSA	Canadian Standards Association
°C	Degrees Celsius
D&B	Drill & Blast
DBC	Depth Below Collar

DCS	Distributed Control System
DGR	Deep Geologic Repository
DPG	Douglas Point Grid
EC	Environment Canada
EDZ	Excavation Damage Zone
EdZ	Excavation Disturbed Zone
E_i	Modulus of Elasticity (Intact)
EIS	Environmental Impact Statement
EMDD	Effective Montmorillonite Dry Density
EPCM	Engineering, Procurement, Construction Management
EPR	Environmental Permit Registry
E_{rm}	Modulus of Elasticity (Rock Mass)
FTE	Full-Time Equivalent
GBR	Geotechnical Baseline Report
GPa	Gigapascal
g/L	Grams per Litre
GPa/m	Gigapascal per Metre
GSCP	Geoscientific Site Characterization Program
GSI	Geological Strength Index
ha	Hectare
HAZOP	Hazard and Operability Study
HDPE	High Density Polyethylene
HDZ	Highly Damaged Zone
HEM	Horizontal Emplacement Machine
HERE	Horizontal Emplacement and Retrieval Equipment
HMI	Human Machine Interface
HP	Health Physics
HVAC	Heating Ventilation and Air Conditioning
ICEA	Insulated Cable Engineers Association
ICRP	International Commission on Radiological Protection
ILW	Intermediate Level Waste
I/O	Input / Output

ISO	International Organization for Standardization
IWTS	Integrated Waste Tracking System
JRP	Joint Review Panel
kg	Kilogram
K_H	Horizontal Hydraulic Conductivity
kN	Kilonewton
K_n	Normal Stiffness
K_{0H}	Ratio of Major Principal Horizontal In-situ Stress to Vertical Stress
K_{0h}	Ratio of Minor Principal Horizontal In-situ Stress to Vertical Stress
K_s	Shear Stiffness
km/h	Kilometres per Hour
kPa	Kilopascal
kV	Kilovolt
kVA	Kilovolt-Ampere
kW	Kilowatt
LIDAR	Light Detection and Ranging
L/s	Litre per Second
L&ILW	Low and Intermediate Level Waste
LHD	Load Haul Dumper
LLSB	Low Level Storage Building
LLW	Low Level Waste
m	Metres
MASHA	Mines and Aggregates Safety and Health Association
mASL	Metres Above (Mean) Sea Level
mBGS	Metres Below Ground Surface
MCC	Motor Control Centre
MCR	Main Control Room
mg	Milligram
m_i	Hoek-Brown Material Parameter
mm	Millimetres
m_N	Magnitude (local scale used in Bruce monitoring network)
MN	Meganewton

MNR	Ministry of Natural Resources
MOE	Ministry of Environment
MOL	Ministry of Labour (Ontario)
MPa	Megapascal
MPC	Mine Power Centre
m/s	Metres per Second
mSv/h	Millisieverts per Hour (Dose Rate)
MVA	Megavolt-Ampere
N	Newton
NBC	National Building Code of Canada (2005)
NFC	National Fire Code
NGS	Nuclear Generating Station
NO_2	Nitrogen Dioxide
NSCA	Nuclear Safety and Control Act
NWMO	Nuclear Waste Management Organization
OEM	Original Equipment Manufacturer
OHSA	Occupational Health and Safety Act (Ontario)
OMR	Ontario Regulation 854 Mines and Mining Plants
OPC	Ordinary Portland Cement
OPG	Ontario Power Generation
P&ID	Process and Instrumentation Diagram
Pa	Pascal
PHC	Petroleum Hydrocarbons
PLC	Programmable Logic Controller
PLT	Point Load Test
PPE	Personal Protective Equipment
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride
r	Radius
RH	Relative Humidity
RMR	Rock Mass Rating System
RPR	Radiation Protection Requirement

RQD	Rock Quality Designation
SAM	Small Articles Monitor
SCR	Secondary Control Room
SPGP	Sleeve Port Grout Pipe
SPT	Standard Penetration Test
SRE	System Responsible Engineer
SSFA	Shaft Service Facilities Area
t *or* tonne	Metric Tonne (=1,000 kilograms)
t/m^3	Metric Tonne per Cubic Metre
T_{adj}	Adjusted Tensile Strength
TBD	To Be Determined
TDD	Time-Dependant Deformation
TDS	Total Dissolved Solids
T-H-E	Tile Hole Equivalent
TM	Technical Memorandum
TSS	Total Suspended Solids
UCS	Unconfined Compressive Strength
U/G	Underground
URL	Underground Research Laboratory
USA	United States of America
UTM	Universal Transverse Mercator
V	Volt
v	Poisson's Ratio
V AC	Volt - Alternating Current
VoIP	Voice over Internet Protocol
VFD	Variable Frequency Drive
WAC	Waste Acceptance Criteria
WBGT	Wet Bulb Globe Temperature
WBM	Whole Body Monitor
WIPP	Waste Isolation Pilot Plant
WMO	World Meteorological Organisation
WPRB	Waste Package Receiving Building (at the DGR Main Shaft)

WRMA	Waste Rock Management Area
WVRB	Waste Volume Reduction Building
WWMF	Western Waste Management Facility
XLPE	Cross Linked Polyethylene
yd	Yard

Appendix C – Compliance with System Requirements

Key System Requirements for the DGR facility and systems have been specified in [R46].

The table in this appendix provides a cross reference to demonstrate where the System Requirements have been incorporated into this Design Criteria [R47]. Section 1.0 of the System Requirements document is introductory and general in nature and has therefore not been included in this table.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
2.0 Functional Requirements			
	2.1	6.0, 6.1.1	Waste Package Handling, Transfer & Emplacement.
	2.2	4.3.6.4, 4.1	DGR Level and Geoscience Stations.
	2.3	9.10	Potential for Future Expansion.
	2.4	10.3.2, 10.3	See Geotechnical Design Criteria also.
	2.5	11.1.1, 11.1.1, 11.1.3, 11.2	Decommissioning and Final Sealing of Repository.
3.0 Performance Requirements			
	3.1	6.1	General Description of Facility and Waste Package, Transfer & Emplacement.
	3.2	3.0, 6.0, 9.1	Waste requirements specified in Appendix D and outline in Waste Package Handling.
	3.3	6.0, 10.1.3, D.2	Waste Package Handling, Transfer & Emplacement.
	3.4	6.0, 10.1.3	Waste Package Handling, Transfer & Emplacement.
	3.5	4.1, 4.5.6, 7.2.3, 7.4, 7.5	Radiological Contamination Release and control and Waste Rock Management Area.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
	3.6	2.5.2, 4.5.4, 11.2.3	The change from ENE to E orientation is primarily by changing the access tunnel to Emplacement Room angle to a minimum of 45° and then rotating the panel access tunnel to complete the amount of turn required to achieve the proper orientation. In order to maintain the borehole stand-off distance of 100m, one emplacement room was shifted from Panel 2 to Panel 1 and the lengths adjusted to fit. It was confirmed that this layout concept provides a very flexible arrangement to make the adjustment after the field in situ stress orientation measurements are complete.
4.0 Interfacing Requirements			
	4.1 (a, b, c)	6.1.1	Most of Section 6.
	4.2	6.0	
	4.3	4.1, 4.2, 4.2.1, 4.2.3, 4.2.4	Description of Surface Facility, Main Shaft Area and connection to WWMF.
	4.4	4.2.3, 4.2.4.4	
	4.5	5.1, 5.3, 5.5, 8.9.4	Intake Fans, Air Heating and Conditioning Plant.
	4.6	6.1.1, 10.6	
5.0 Design Limits			
	5.1	1.2.1, 9.3.1	See Executive Summary.
	5.2	3.6.2, 4.3.1, 10.1.2.1	Hoisting Duties / Systems.
	5.3	4.5, 9.10	Emplacement room – Expansion case / Potential for Future Expansion.
	5.4	1.2.2, 4.5.1.1.2	In particular sections 9.3.1 and 9.3.2. See Figures 4-19 and 4-20 for details of calculating UCS values and Pillar Failure Study.
	5.5	4.2.4	Waste Rock Management Area.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
6.0 Seismic and Anthropogenic Vibration Requirements			
	6.1	2.5.7	Structural design to applicable national and provincial codes. In particular the Headframes including crash beams shall comply with CAN/CSA S16.1-10.
	6.2	2.5, 4.2.4.9, 9.3.2.1.2.1	Geotechnical Conditions.
	6.3	2.5, 4.5.1.5.4	Geotechnical Conditions.
7.0 Design Constraints			
	7.1	4.2	Also found in Executive Summary.
	7.2	1.2.1, 4.5.4, 4.1	
	7.3	4.2.4.10.2, 4.3.6.4, 9.1.2.4	Surface Water / Long Term Monitoring. Full scale site characterization program.
	7.4	2.5.6, 4.5.1, 4.5.4	Rooms to be aligned to principle stress direction.
	7.5	4.5.1 / 4.5.4.2 / 2.5.6	
	7.6	4.1	Also included in the Executive Summary.
	7.7	4.5.2, 5.1, 5.6	Ventilation System and Operation and Exhaust Fans.
	7.8	4.2	Surface Facilities and Infrastructure.
	7.9	See comments column	The requirement to segregate LLW and ILW packages into different rooms was changed by NWMO. The System Requirements Document will be updated to reflect this change.
	7.10	4.5.4.1	All of the Base Case rooms and facilities are located within the OPG Retained Land Boundary and respect a 100m radius clearance from any of the DGR boreholes.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
8.0 Room Closure and Package Retrievability			
	8.1	1.5, 11.1.1, 4.5.4.1, 5.2, 5.4.3, 5.7, 10.1.2.1, 10.5	Following the above mentioned 10 to 15 year period of continuous flushing, a group of rooms will be permanently sealed by the construction of a closure wall in the panel access tunnel.
	8.2 (a, b, c, d, e)	4.5.4.1, 10.5.2	All addressed in Section 10.5.2.
	8.3	4.5.4	In particular Section 10.6.
	8.4	4.5.4.1, 10.6	
9.0 Shaft Seal Systems			
	9.1	1.2.2.1	The following engineering properties of concrete are considered advantageous for deep repository shaft sealing systems: • Provides a low permeability barrier in the short-term (10^{-11} m/s and 10^{-14} m/s). • Broad range of performance objectives can be achieved by changing the mix – type and proportion of ingredients and the means by which it is emplaced.
	9.2	11.2.2.1	Some potential drawbacks of concrete that must be addressed in the design and construction of a repository sealing system include: • Geochemical compatibility with the host rock and groundwater. The mix design can be altered, such as by the incorporation of brine, to ensure compatibility with host rock.
	9.3	11.2.2.1	• Longevity of concrete. Concrete materials will remain stable in the long-term, however this will not be in perpetuity. As the cement leaches from the concrete, it will degrade into a mixture of granular materials (i.e. gravel and sand). This could have potential impacts on structural stability of the seal. Granular materials remaining following concrete degradation can be designed to ensure a high degree of grain to grain contact and interlock is maintained (i.e. a large aggregate content) for provision of structural support for surrounding seal materials in perpetuity.
	9.4	11.2.2.1	

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
	9.5	11.2.1	Design Approach
	9.6	11.2.1	
	9.7	11.2.3	Concrete monoliths are planned for placement at the base of the seal system on each shaft. Concrete will provide a stable foundation for the overlying seal materials and a high degree of support to the repository station openings. Moreover, the concrete monolith will ensure the necessary structural strength to withstand an internal gas pressure of 14 MPa.
10.0 Environmental Requirements			
	10.1		
	(a)	4.3.2.1, 4.3, 4.4.1, 4.4.2, 4.4.4	Safe modern hoist; quick access in clean air to underground infrastructure with offices, Lunch Room etc being close to Main Shaft and remote from waste emplacement rooms; air conditioned ventilation system.
	(b)	4.0	Proper due-diligence was executed in ensuring that there is adequate roof and floor support at this level of study is incorporated into the design of the emplacement rooms, access tunnels and shaft. Detail Geomechanical and Geotechnical analysis were conducted to support sealing and rock support arrangement.
	(c)	5.0	Ventilation of rooms until closure walls are installed to limit risks of corrosion. The temperature of the repository is maintained by means of humidity control to prevent condensation leading to corrosion of packages.
	(d)	2.2.2, 4.2.4, 7.2, 7.4.3, 7.5, 8.1, 8.2, 8.9, 11.1 11.2, 12..1, 12.2	There are steps taken into the design at this level of study to control flow in and out of the repository.
	10.2	5.5, 7.5, 8.1, 8.6	Humidity control will be maintained within the repository.
	10.3	4.5	In particular section 4.5.4 speaks about the general gradient that will be maintained in the emplacement rooms and access tunnels to ensure water run off.
	10.4	2.3, 2.4, 2.5	

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
11.0 Operability Requirements			
	11.1	10.1.3	
	11.2	8.9	
	11.3	6.0	
	11.4	4.0	
	11.5	2.5, 4	
	11.6	6.0	
	11.7	6.0	
	11.8	5.0	Air supply will be used to maintain safe working conditions through all stages of the DGR life. The total volume of air supplied to the DGR will vary based on the nature of work being performed and number of active and non-active rooms and will be periodically adjusted throughout the life cycle of the facility.
	11.9	8.1	In particular 8.1.3.
	11.10	8.1	
12.0 Reliability Requirements			
	12.1	10.3	
	12.2	8.5	
	12.3	8.5	
	12.4	4.2, 4.5.7	In particular 4.2.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
13.0 Maintainability Requirements			
	13.1	10.0	A planned maintenance system will be produced prior to commencement of operations. The plan will provide full control of maintenance activities and enable the facility to attain an overall availability[23] of 90 % during working hours excluding scheduled stoppages for the inspections and maintenance.
	13.2	4.5.1	
	13.3	6.0, 10	
	13.4	4.0, 6.0, 10	
	13.5	6.0, 7.0	
14.0 Periodic Inspection and Monitoring Requirements			
	14.1	2.5.4.5, 4.2, 11.1	
	14.2	7.0	
	14.3	7.0, 5.0, 11.1.1, 11.1.2	
	14.4	3.1, 3.5, 6.1.1	
	14.5	7.5, 11.1	
	14.6	11.1	Following decommissioning and closure of the repository in addition to the monitoring program that would have occurred during the preclosure period, further environmental assessment will continue and the acquisition of a decommissioning licence.
15.0 Safety Requirements			
	15.1.1		All aspects of the report.
	15.1.2	7, 11	
	15.1.3	6.1.1, 7.5	
	15.1.4	6.1.1, 11.1	

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[23] Available means that the DGR facility is operational and ready to handle waste packages.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
	15.1.5	1.0	Most sections that speaks to a robust design for the repository.
	15.2.1		Most sections in the PDR. In particular sections 2, 4.2 and 11.1.
	15.2.2		Most sections, in particular sections 1, 6.1.1, 6.3.1 and 11.1.
	15.2.3	6.1, 6.3.1, 7.5	
	15.2.4	6.1.1	
	15.2.5	5.0	
	15.2.6	5.4.3, 10.5.1	
	15.3.1	7.1, 7.3, 7.4, 8.4, 8.6, 8.7	
	15.3.2	7.1, 7.3, 7.4.1	
	15.3.3	6.0	
16.0 Security Requirements			
	16.1	8.11	Security chain link fencing will surround the site in accordance with Bruce Site requirements and similar to the WWMF perimeter fencing. Gates will be placed at all access points including emergency access to the west and east of the facility.
	16.2	8.11	
	16.3	4.5.2	The operations storage – explosives tunnel is short and needs to be sized for the different purposes. During the development stage this tunnel and storage area will be accessed with equipment carrying day use quantities of explosives.
17.0 Safeguard Requirements			
	17.1	-	No requirements.
18.0 Constructability Requirements			
	18.1	4.0, 9.0	Most of section 9.
	18.2	2.5, 4.0, 9.0	

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
	18.3	4.0	Once the facilities are commissioned for sinking the shafts will be sunk in parallel to the DGR horizon at about 686m depth below collar (DBC). The Main Shaft will excavate the geoscience sub-drift in the Reach 3 shales as the shaft passes this level. Once at the DGR level, both shafts will shift to lateral excavation of the shaft stations and facilities that are required to be constructed to enable lateral development after the shaft sinking. The shafts will then continue to the bottom and the shaft bottom ramp will be driven.
	18.4	9.5	
	18.5	2.5.2, 4.5, 9.5	
	18.6	9.3.2, 11.2.2	A key consideration in the design approach for the shaft sealing system is the potential formation of damage zones during shaft sinking and operations.
19.0 Regulations, Standards and Codes			
	All sub-sections	See example in comments column	Design of the shaft sealing system will satisfy the relevant sections within the Ontario Mining Act and Ontario Regulation 240/00 (Mine Development and Closure) under Part VII of this Act (Ontario Regulation 240, 2000), as well as Section 11 (Well plugging) of the Provincial Operating Standards, Oil, Gas, Salt Resources of Ontario (Ontario Ministry of Natural Resources, 2002).
20.0 Other Requirements			
	20.1	6.1.1	A controller based at the DGR WPRB will coordinate the process and ensure that all packages received are in accordance with planning roster and undergo an incoming inspection process to confirm that the packages conform to Waste Acceptance Criteria.
	20.2		Not in scope of the Project.
	20.3		Not apart of the scope of the PDR.

System Requirements		***PDR Reference Section***	***Comments***
Section	***Sub-Section***		
21.0 Comparison with Similar Systems			
	All sub-sections		
22.0 Records			
	None.		No requirements.
23.0 Technical References			
	None.		No requirements.

Appendix D – Waste Package Category Information Sheets

The purpose of this document is to organise the DGR inventory into groups, according to the size, mass and handling features. These groupings can then be used to simplify the design process, specifically in the areas of the waste package handling system and simulation programming. Hence, much of the information provided in this document are intended to direct assumptions regarding simulation model inputs. Also, assumptions regarding waste package properties and handling are summarised. Pictures and drawings of the packages can be found in [R4].

D.1 Assumptions

The following assumptions apply to data presented in this document:

1. Internal grouting to stabilise T-H-E Liners, IC-2 Liners and Steam Generator Segments is included in the mass figures given in Table 3-4. For the Heat Exchanger packages, any that require sectioning will also require grout stabilisation and the mass of this grout is included in the assumed maximum mass figures (i.e. No segment in "DGR-ready state" will have a mass above 30,000 kg).
2. Fresh Resin Liners from nuclear stations will arrive at the WPRB in a transport shield at a rate no higher than one liner per day.
3. It should be noted that the dose rate data given in the tables of each Group sub-section are those taken at the time that the packages were placed into storage at the WWMF, with the exception of pre- in-service Resin Liners in Group C and Group F (where dose rates are based on updated measurements in Table 4.4 of [R4]) and T-H-E and IC-2 Liners in Group D (where dose rates are based on predicted decay calculations). Decay will reduce those rates by the time the packages are retrieved at the WWMF and transferred into the DGR. Waste retrieval efforts at the WWMF will re-measure package dose rates during the retrieval process when checking for DGR WAC compliance.
4. No reducing factor is included for any shielding effects of grouting or overpacking in the dose rates given for any packages.
5. Where "Average Mass" or "Maximum Mass" is stated in the tables below, the container, contents, overpacking and shield, where applicable, are included unless stated otherwise.
6. The In-Service Date, or the date when the DGR begins to accept waste packages, is currently assumed to be the year 2018.

D.2 Group A – Bin-Type Waste

Waste Category: LLW

Container Specifications:

Container Type		***Stack***[24]	***Dimensions***[24]			***Average Mass***	***Maximum Mass***	***Number***
			L	W	H	kg	kg	
A1	LLW Container Overpack	3	2.54	1.78	1.88		5,865	3,141
Overpacked in BINOPK:								
Ash Bin (Old) - bottom ash						4,541	5,108	269
Ash Bin (New) - bottom ash						3,195	3,501	816
Drum Rack - baghouse ash						3,081	3,416	47
Ash Bin (new) - baghouse ash						3,195	3,501	134
Drum Rack - non-processible drums						3,081	3,416	296
Low Level Resin Box (90")						5,246	5,865	45
ALW Sludge Box						3,411	3,771	1,534
No Overpacking Requirement:								
A2	Compactor Box	5	1.84	1.12	1.30	2,722	3,281	5,298
A3	Bale Racks	5	2.29	1.22	1.20	1,600	1,963	1,491
A4	Drum Rack - non-pro drums	5	2.29	1.22	1.20	1,490	1,825	2,663
A5	Drum Bin	5	1.96	1.32	1.03	1,450	1,740	3,317
A6	Non-Pro Bin (47" high NPB47)	5	1.96	1.32	1.19	1,460	1,735	15,349
A7	Non-Pro Bin (NPB4)	4	2.29	1.22	1.47	1,066	1,248	4,978
A8	Low Level Resin Pallet Tank[25]	3	1.24	1.24	1.68	2,000	2,420	2,126
Total								**38,363**

Note - Rows shaded in grey represent packages that are overpacked and thus count towards package quantity in A1.

Typical Package Characteristics:

- Small package size (maximum 2.54 m x 1.78 m x 1.88 m high).
- Light weight (< 5.9 tonnes).
- Comparatively large in number.

Stacking:

- Stackable metal bins.

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[24] Stack height refers to the number of bins of similar type that may be stacked together in one column. This number is based on package structural limitations; note that emplacement room height and underground handling conditions may reduce the stack height in the emplacement room.

[25] Overpacking will be required, but no details are currently available. However, dimensions stated in the table were assumed for layout purposes.

Handling:

- See drawing H333000-WP401-05-030-0001 in Appendix E for handling methodology.
- Specifically designed to be handled using a light duty forklift.
- Package staging will be utilised at WPRB and Main Shaft station underground.

Overpack:

- Overpacked containers shown in grey area of table above.

Cage Capacity:

- Multiple packages, per rail cart capacity given in Table 6-2 of Section 6.2.

Retrieval Period:

- All seasons, 25 packages per shift estimated rate of delivery to the DGR.

Arrangement Pattern and Stacking Method:

- Packages will be placed in standard LLW rooms. Any particular row of packages can contain only one footprint style for all containers. However, within any one room, different containers within this type of waste can be emplaced (i.e. consecutive rows can contain different footprint types). A gap of 50 mm is allowed between each column of packages in a row as well as adjacent rows. Stacking height is limited by the Emplacement Room height and “Stack” numbers in table above.
- Room and stacking optimisation are discussed in Section 6.3.

Container Dose Rates:

Based upon current data, the following is a summary of the contact dose rates from the various Group A packages:

Description / Name	**Contact Dose Rates (mSv/h)**				
	<0.1	0.1 to 1	1 to 2	2 to 10	> 10
Ash Bin (Old) - bottom ash	29.8%	68.5%	1.3%	0.4%	0.0%
Ash Bin (New) - bottom ash	29.8%	68.5%	1.3%	0.4%	0.0%
Drum Rack - baghouse ash	29.8%	68.5%	1.3%	0.4%	0.0%
Ash Bin (new) - baghouse ash	29.8%	68.5%	1.3%	0.4%	0.0%
Compactor Box	93.5%	5.9%	0.5%	0.1%	0.0%
Bale Rack	62.7%	28.8%	4.9%	3.1%	0.5%
Drum Rack - non-pro drums (overpacked)	89.4%	6.2%	1.0%	2.9%	0.5%
Drum Rack - non-processible drums	89.4%	6.2%	1.0%	2.9%	0.5%
Drum Bin	89.4%	6.2%	1.0%	2.9%	0.5%
Non-Pro Bin (47" high NPB47)	86.5%	10.2%	1.2%	1.9%	0.2%
Non-Pro Bin (NPB4)	86.5%	10.2%	1.2%	1.9%	0.2%
Low Level Resin Box (90")	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Low Level Resin Pallet Tank	<2 mS/h Contact, 0.1 mS/h at 1 m.				
ALW Sludge Box	75.0%	25.0%	0.0%	0.0%	0.0%

D.3 Group B – Heavy Non-Forklift

Waste Category: LLW

Container Specifications:

Container Type		*Dimensions*			*Average Mass*	*Maximum Mass*	*Number*
		L	W (or dia)	H	kg	kg	
B1	Shield Plug Container	3.00	1.80	1.80	25,583*	28,100	9
B2	Heat Exchanger	4.57	2.00		N/A	30,000	82
Total							91

* Mass of loaded container complete with shielding.

Typical Package Characteristics:

- Large package size and relatively high mass.
- Heat Exchangers lie on their round side.
- Not designed for handling with a forklift.
- Note that only a generic size / dimensions for heat exchangers have been provided. An assumed 25% of the Heat Exchangers will need to be segmented in half at WWMF in order to fit inside the cage. Note that sectioning of Heat Exchangers would require the use of stabilising grout; the mass of the grouted segments is assumed to not exceed 30,000kg.
- Shield Plug Containers are stored at WWMF with the shielding for the package sides removed. Shielding will be replaced to ensure acceptable dose rates before transfer to the DGR.

Handling:

- See drawing H333000-WP401-05-030-0002 in Appendix E for handling methodology.
- Will be lifted using cranes.
- No staging on surface or underground.
- They will arrive on a flatbed truck and will be loaded onto a rail cart in the WPRB using an overhead crane.
- Underground handling will be via rail cart. Once inside the Emplacement Room, the gantry crane will be used for emplacement.
- Shield Plug Containers must be lifted using special equipment available at the WWMF. It is assumed that each Shield Plug Container will arrive at the DGR with crane lifting devices attached.

Cage Capacity:

- One per trip on transfer cart.

Gantry Crane:

- Required at Emplacement Room to offload rail cart.

Arrangement Pattern and Stacking Method:

- Shield Plug Containers are not stackable and lid shape does not allow stacking on top.
- Heat Exchangers stacked in a pyramid shape three on bottom row and two on top.

Container Dose Rates:

Description / Name	Contact Dose Rates (mSv/h)				
	<0.1	0.1 to 1	1 to 2	2 to 10	> 10
Shield Plug Container	0%	6.6%	6.7%	26.7%	60%
Heat Exchanger	56.1%	36.6%	7.3%	0.0%	0.0%

D.4 Group C – Light ILW

Waste Category: ILW

Container Specifications:

Container Type		***Dimensions***			***Average Mass***	***Maximum Mass***	***Number***
		L	W (or dia)	H	kg	kg	
C1	Resin Liners (Unshielded, no overpack) Pre In-Service Date	1.915	1.915	2.15		5,215	288
C2	Portion of 400 (Unshielded, overpacked) Pre In-Service Date	1.915	1.915	2.22		6,670	92
C3	Tile Hole Liners in Rack	3.453	1.520	0.80	4,565	4,965	101[26]
C4	ILW Shield	1.700	1.000		2,290	2,519	7,383
Total							**8,176**

Typical Package Characteristics:

- No fresh Resin Liners (i.e. deliveries from nuclear stations post-2018) are included in this group (See Group E below).
- All Resin Liners and Tile Hole Liners will be delivered from WWMF to the DGR in stackable and forkliftable racks or pallets.
- Mass of Tile Hole Liners is assumed to include grout.
- Two Tile Hole Liners are allocated to each rack.

Handling:

- See drawing H333000-WP401-05-030-0003 in Appendix E for handling methodology.
- Handled using the light duty forklift.
- Staging may be allowed on surface and underground, as required.

Cage Capacity:

- Two Resin Liners in pallets.
- One Tile Hole Liner rack.

Retrieval Period:

- Per WWMF procedure, retrieval of Resin Liners from IC's will be done on days with low wind and a low probability of precipitation.

Arrangement Pattern and Stacking Method:

- Resin Liners in Group C can be stacked two high.

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[26] Number refers to the number of racks.

- Tile Hole Liner racks will be stacked five high.
- Resin Liner waste packages may require special allocation / distribution considerations within the emplacement rooms so that the dose rates in the Emplacement Room can be optimised.

Container Dose Rates:

Based upon current data, the following is a summary of the contact dose rates from the various Group C packages:

Description / Name	**Contact Dose Rates (mSv/h)**				
	<0.1	**0.1 to 1**	**1 to 2**	**2 to 10**	**> 10**
Tile Hole Liner[27]	3.6%	4.4%	4.1%	57.2%	30.7%
Resin Liners Unshielded	<2 mS/h Contact, 0.1 mS/h at 1 m.				
ILW Shield	<2 mS/h Contact, 0.1 mS/h at 1 m.				

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[27] Tile Hole Liners are not shielded under the assumption that these older packages will have decay rates sufficient to make them WAC compliant before receipt at DGR (i.e. <2 mS/h Contact, 0.1 mS/h at 1 m).

D.5 Group D – T-H-E

Waste Category: ILW

Container Specifications:

Waste Type		***Dimensions***		***Grout Mass***	***Average Mass***	***Maximum Mass***	***Number***
		H	W (or dia)	kg	kg	kg	
D1	IC-2 Liner	7.6	0.61	706	32,352	32,702	20
D2	IC-18 T-H-E Liner	10.7	0.55	907	31,653	31,873	444
-	T-H-E Transfer Bell	11.8	0.89	-	-	27,146	-
Total							464

Typical Package Characteristics:

- Long, slender pipes with grout-stabilised contents.
- Contents have some of the higher dose rates of the DGR inventory.
- The mass of the liners includes for the use of a low density grout and 27,146 kg for the Transfer Bell.

Handling:

- To be transferred in the re-useable Transfer Bell.
- See drawing H333000-WP401-50-042-0001 in Appendix E for handling methodology.

Cage Capacity:

- One per trip using special securing features inside the Main Shaft cage.

Retrieval Period:

- T-H-E's are stored in-ground; therefore, assume retrieval period is limited to 5 months from mid-April to mid-October. Assume 26 per year starting in 2026.
- It is assumed that 142 of these packages would need to have transfer to the DGR delayed in order to ensure acceptable dose rates.

Gantry Crane:

- Gantry crane required in emplacement rooms to offload the Transfer Bell from the T-H-E Handler and place in the HEM.

Hoist Speed:

- Assume that hoist will move at half speed.

Arrangement Pattern and Stacking Method

- Pushed out of re-usable Transfer Bell by HEM into a Concrete Pipe Array in the Emplacement Room.

Container Dose Rates:

The following is a summary of the contact dose rates from the various Group D packages:

Description / Name	**Maximum Contact Dose Rates (mSv/h)**			**Average Contact Dose Rates (mSv/h)**		
	<30	30 to 200	>200	<30	30 to 200	> 200
IC-2 T-H-E Liner – Projected to 2025	50.0%	20.0%	30.0%	70.0%	15.0%	15.0%
IC-18 T-H-E Liner – Projected to 2025	79.7%	12.8%	7.6%	90.1%	3.5%	6.4%

This dose rate data can be used to estimate the number of packages that are predicted to be DGR WAC-compliant (i.e. <2 mSv/h contact, 0.1 mSv/h at 1 m) at the time of transfer.

D.6 Group E – Fresh Resin Liners

Waste Category: ILW

Container Specifications:

Container Type		*Dimensions*			*Maximum Mass*	*Number*
		L	W (or dia)	H	kg	
E1	Resin Liners, No shield required, Post In-Service Date	1.915	1.915	2.15	5,215	212
E2	Resin Liners Shield 1, Post In-Service Date		2.20	4.25	26,850 – 28,650	86 Liners 43 Shields
E3	Resin Liners Shield 2, Post In-Service Date		2.40	4.45	36,150	227 Liners 114 Shields
E4	Resin Liners Shield 3, Post In-Service Date		2.53	2.74	28,965	476
E5	Resin Liners, Delay Transfer for Decay, Post In-Service Date		2.53	2.74	28,965	62
Total						**1063**

Typical Package Characteristics:

- This waste group only includes post in-service Resin Liners.
- Note that Shield 1 and Shield 2 have two Resin Liners stored inside.
- These Resin Liners arrive directly at the DGR from the nuclear stations.

Handling:

- See drawing H333000-WP401-05-030-0004 Appendix E for handling methodology.
- Overhead crane in WPRB will be used to remove the fresh Resin Liner from the transport shield. If the liner requires shielding, it will be placed directly into an awaiting shield.
- For Resin Liners that do not require shielding, a sacrificial pallet will be installed upon receipt so that they can handled with a light duty forklift and stacked during emplacement. The dimensions and mass of these pallets is included in these figures.
- A staging area for one partially-filled Shield 1 and one partially-filled Shield 2 package will be provided in the WPRB. Storage for empty shields and sacrificial pallets will be provided near the WPRB.
- When a sacrificial pallet or shield is full, it will be made DGR-ready and transported / emplaced on a priority basis.

Cage Capacity and Stacking:

- Refer to Group C (unshielded) or Group F (shielded).

Retrieval Period:

- Packages will arrive from nuclear stations throughout the year and will be handled on a priority basis. The DGR will not receive more than one Group E package on any given day.

Container Dose Rates:

Dose rates for fresh Resin Liners are given before shielding.

The use of shielding will be used to ensure that all each Resin Liner package will achieve WAC compliance. With the highest dose rate Resin Liners, the transfer may need to be delayed to allow sufficient decay and reduction of dose rate.

Description / Name	**Contact Dose Rate (mSv/h)**				
	<0.1	0.1 to 1	1 to 2	2 to 10	> 10
ILW Resin Liners	11.3%	13.2%	3.6%	21.4%	50.5%

D.7 Group F – Heavy Forkliftable

Waste Category: LLW (SGSGMT, ETH) and ILW (RWC, Shielded Resin Liners)

Container Specifications:

Container Type		***Dimensions***			***Mass***	***Maximum Mass***	***Number***
		L	W (or dia)	H	kg	kg	
F1	Steam Generator Segments Bruce A	2.37 - 4.12	2.40 - 2. 60		35,044	35,000	128
F2	Steam Generator Segments Bruce B[28]	2.27 - 2.99	2.50 - 3.60		34,966	35,000	192
F3	Steam Generator Segments Pickering	3.17 - 4.46	1.80 - 2.50		27,435	35,000	192
F4	Encapsulated Tile Hole	4.6	1.5		25,000	27,500	66
F5	Resin Liner Shell from Quadricells in Pallet	2.62	2.62	5.01	28,650[29, 30]	35,000	120 Liners 60 Shells
F6	Resin Liner Shield 1, Pre In-Service Date	4.25	2.2			29,760	198 Liners 99 Shields
F7	Resin Liner Shield 2, Pre In-Service Date	4.45	2.4			36,150	700 Liners 350 Shields
F8	Resin Liner Shield 3, Pre In-Service Date	2.74	2.53			30,420	252 Liners 252 Shields
F9	Retube Waste (Pressure Tubes)	1.85	1.85	2.25	29,100	35,000	458
F10	Retube Waste (End Fittings)	1.7	3.35	1.92	33,500	35,000	918
Total							4,075

Typical Package Characteristics:

- All large and heavy packages that can be handled using heavy duty forklift.

Steam Generator Segments:

- The mass for each Steam Generator Segment includes light weight grout filling in addition to forklift pockets and the 65mm steel seal plates welded to the each cut surface.
- See Section 6 for more details on Steam Generator Segments. Note that, unlike the other Steam Generator Segments, the Bruce B Steam Drum Segments (64) are too large in diameter to lay down (i.e. 'disc' face down) in the cage and will need to be transported as a vertical disk supported on a lifting frame. This lifting frame will be integral to the package and will be installed at WWMF.

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[28] Note that Bruce B Steam Drum will require an additional steel lifting frame, mass estimated at 970 kg.

[29] Shells are assumed to have a height of 4.6 m and a mass the same as a Shield 1. Because the Shell is taller than a Shield 1, it is recommended that a better estimate of Shell mass be attained in the future.

[30] Includes the 1,800 kg mass of the sacrificial pallet.

Resin Liner Shields:

- Only pre in-service Resin Liners are included.
- Note that Shield 1 and Shield 2 have two liners stored inside.
- 60 of the Shield 1 packages are from Quadricells and will require a sacrificial pallet.

Encapsulated Tile Hole (ETH):

- It is assumed that all ETH packages will be similar to those retrieved during the RWOS 1 Grouted Tile Hole Retrieval Project (i.e. all package will have integral forklift pockets).

Retube Waste Containers

- Heavy concrete / steel composite shields resulting from reactor refurbishment.
- Note: “calandria tubes” and “calandria tube inserts” packages for all purposes are grouped as “pressure tube” packages.

Stacking:

- Steam Generator Segments – stacked two high where possible.
- Shielded Resin Liners and ETH’s – one high.
- Pressure tube containers stacked maximum two high.
- End fittings containers stacked maximum three high.
- Stacking in of Retube Waste Containers will be two high.

Handling:

- See drawing H333000-WP401-05-030-0005 in Appendix E for handling methodology.
- No staging on surface or underground.
- Shaft transport using rail cart.
- All segments will be handled by heavy duty forklifts. With the exception of the Bruce B Steam Drum Segments, all segments will be handled with the flat end down. The Bruce B Steam Drum Segments will be handled “standing up” with the round edge down. To allow forklift handling, a lifting frame will be welded to each of these segments before they are sent to the DGR.

Cage Capacity:

- One per trip.

Container Dose Rates:

The following is a summary of the contact dose rates from the various packages:

Description / Name	**Contact Dose Rates (mSv/h)**				
	<0.1	0.1 to 1	1 to 2	2 to 10	> 10
Steam Generators - Bruce A	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Steam Generators - Bruce B	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Steam Generators - Pickering B	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Encapsulated Tile Hole (ETH)	82.6%	17.4%	0.0%	0.0%	0.0%
Resin Liners Shield 1	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Resin Liners Shield 2	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Resin Liners Shield 3	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Resin Liner Shells from Quadricells	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Retube Waste (Pressure Tubes)	<2 mS/h Contact, 0.1 mS/h at 1 m.				
Retube Waste (End Fittings)	<2 mS/h Contact, 0.1 mS/h at 1 m.				