Deep Geological Repository Conceptual Design Report

Crystalline / Sedimentary Rock Environment

APM-REP-00440-0015 R001 May 2016

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ABSTRACT

Title: **Deep Geological Repository Conceptual Design Report Crystalline / Sedimentary Rock Environment**
Report No.: **APM-REP-00440-0015 R001**
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Abstract
The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management (APM), Canada's plan for the long-term management of used nuclear fuel. The APM approach encompasses centralized containment and isolation of the used fuel in a Deep Geological Repository (DGR) in a suitable rock formation, such as crystalline rock or sedimentary rock, in an informed and willing host community.

This report describes concepts for a DGR facility in either a crystalline or sedimentary rock environment receiving the Used Fuel Container (UFC). For costing purposes, it is assumed that the facility will receive 3.6 million used CANDU fuel bundles over a 30-year period. The report describes the required facilities and infrastructure needed to safely receive and package the used nuclear fuel, and place UFCs in the underground repository. At the end of placement activities and following a period of extended monitoring the DGR facility will be decommissioned and closed. All underground rooms, tunnels and the three shafts will be permanently sealed.

EXECUTIVE SUMMARY

The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management (APM), Canada's plan for the long-term management of used nuclear fuel. The APM approach encompasses centralized containment and isolation of the used fuel in a Deep Geological Repository (DGR) in a suitable rock formation, such as crystalline rock or sedimentary rock within an informed and willing host community.

As of June 2015, Canada has produced over 2.6 million used fuel bundles. An inventory of 3.6 million used fuel bundles is used for consistency in life cycle cost reporting. If Canada's existing reactors operate to the end of their planned lives, including planned refurbishments, the inventory that will need to be managed in the DGR facility could be 5 million bundles or more, depending on future operating conditions. The used fuel bundles inventory is periodically reviewed by the NWMO. Some illustrations provided in this report are based on a 4.6 million used fuel bundle repository to match the inventory projection in 2015.

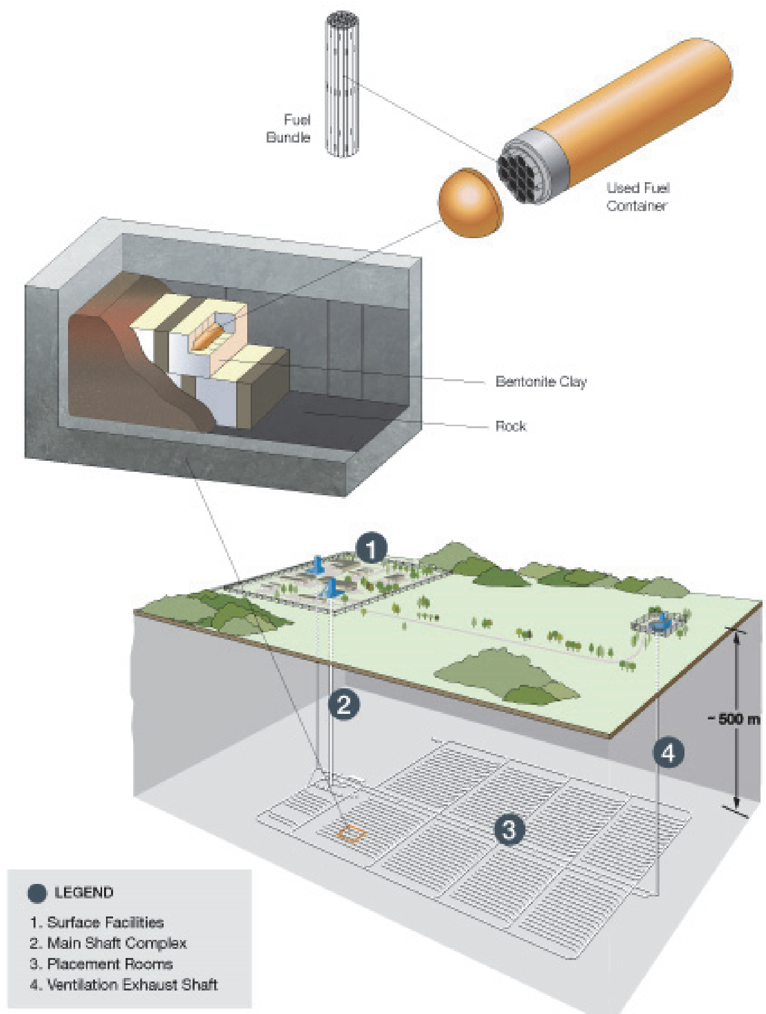


Illustration of a Deep Geological Repository

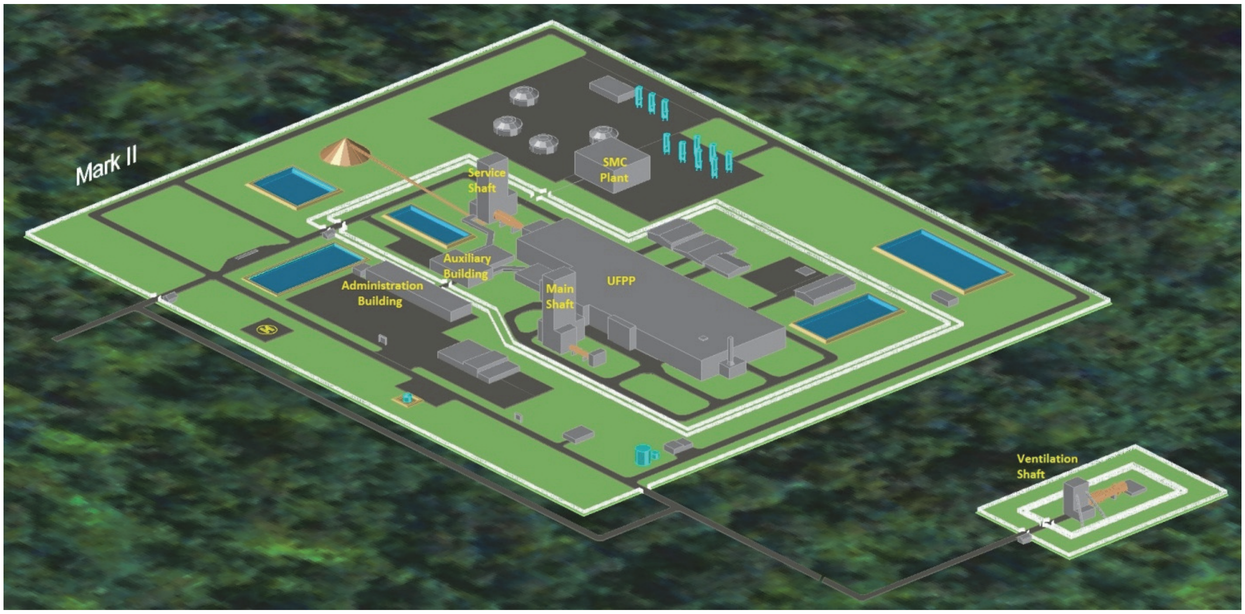
This report describes concepts for a DGR facility in either a crystalline or sedimentary rock environment receiving the Used Fuel Container (UFC). It describes the required facilities and infrastructure needed to safely receive and package the used nuclear fuel, and place a UFC in the DGR.

Surface Facilities

The DGR facility will be self-contained and will have facilities for operation, maintenance and long-term monitoring.

For security purposes, certain areas of the surface facilities will have restricted access. These restricted areas include the Used Fuel Packing Plant, Main Shaft complex, Service Shaft complex and Ventilation Shaft complex. Security and double perimeter fencing will be required to prevent unauthorized access into these areas.

Other surface areas outside the restricted area (also called the Protected Area) would include the Administration Building, Sealing Materials Compaction Plant and a concrete batch plant. A management area for excavated rock from the underground repository would also be required. Its location (on-site or off-site) and footprint would be determined in collaboration with the community.



Key DGR Surface Facilities

External facilities, located outside the DGR's perimeter fences, will be required to support the DGR facility. Such facilities include a Centre of Expertise and accommodation for construction personnel.

Used Fuel Packing Plant (UFPP)

The used nuclear fuel will be received at the UFPP from the interim storage sites located at the source reactor storage sites. The used fuel will be transported in certified road transportation packages (Used Fuel Transport Package or UFTP). The UFTPs will be received at the UFPP where the contained used fuel bundles will be transferred to the UFCs. The filled UFCs will then be sealed, inspected and inserted into buffer boxes. The buffer boxes will contain blocks of highly compacted bentonite (HCB) with a cavity machined in the blocks to hold the UFC. The combined UFCs / buffer boxes would then be dispatched for placement in the underground repository. There will also be provisions for recovering any UFCs that do not fulfill the requirements for long-term disposal.

The UFPP will incorporate multiple processing lines for receiving and unloading used fuel from the UFTPs and for safely processing and handling the UFCs.

Sealing Materials Production Plants

Concrete batch and Sealing Materials Compaction (SMC) operations are required to produce repository sealing materials for encapsulation of the placed UFCs.

Imported aggregate will be stockpiled and then used to support the material needs of a concrete batch plant and the SMC plant. At the concrete plant, the aggregate would be blended with binders and a water reducing admixture to produce low heat, high performance (LHHP) concrete for the bulkheads at entrances of the UFC-filled placement rooms. At the SMC plant, highly compacted bentonite (HCB) blocks for the buffer boxes will be manufactured and directed to the UFPP. In addition, the SMC plant will manufacture dense backfill (DBF) blocks comprised of aggregate, clay and bentonite. The SMC plant will also produce 100%-bentonite gap fill that will be placed around the stack of buffer boxes inside each placement room. The plant will employ custom designed presses and moulds for manufacturing the blocks with specialized lifting devices in place to handle the formed materials.

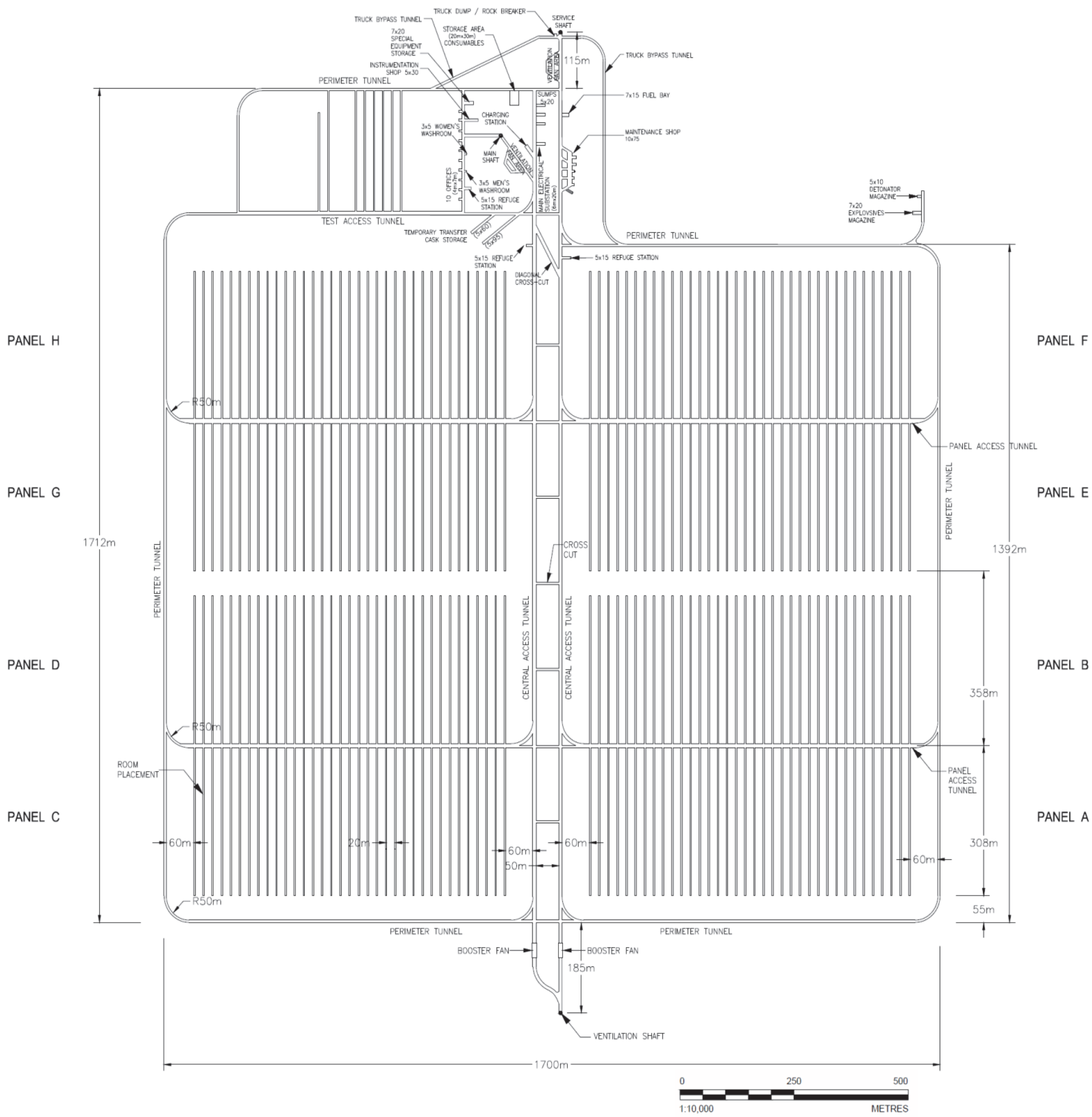
Shafts and Hoists

Three shaft complexes (head frames, hoisting plants and shafts) will support the underground repository. The Main Shaft complex serves as the exclusive conveyance structure for the surface-to-underground transfer of the buffer boxes (with UFCs). The Service Shaft complex is a multi-purpose hoisting facility for the repository, and incorporates equipment for delivering excavated rock to ground surface, and personal and materials to the underground repository. This combined usage system is set up with five compartments to accommodate two counterbalanced skips, a main service cage and counterweight, and an auxiliary cage for off-shift or secondary egress hoisting. The Ventilation Shaft complex handles the majority of the repository exhaust and also serves as a secondary means of egress from the underground repository.

Underground Facilities

The underground facilities are comprised of the following two main areas: a) Underground Services Area located at the base of the Main Shaft and Service Shaft; and b) placement area comprised of eight panels of rooms.

The following figure illustrates the layout of the underground repository (for the crystalline rock design concept).



Underground Repository Layout (Crystalline Rock)

The Underground Services Area would provide a range of facilities to support DGR operations. Such facilities include:

- Underground Demonstration Facility
- Refuge stations, offices, washrooms;
- Maintenance shop and warehouse;
- Battery charging station (for battery-powered forklifts for placing buffer boxes);
- Underground diesel fuelling station and equipment / material storage areas;
- Explosives and detonators magazines;
- Main electrical substation; and
- Truck dump equipped with grizzly and rockbreaker.

The Underground Demonstration Facility (UDF) is situated near the Shafts, which is established soon after the repository level is reached. The UDF would support geoscientific verification, validation of construction methods, demonstration of excavation and placement techniques and long-term demonstration of the sealing systems. There is also a potential of using the UDF as a training area for future DGR employees.

The in-room placement of the buffer boxes containing the UFCs will involve a two-high stacking arrangement of the boxes. The rows of boxes will be separated by spacer blocks. The buffer boxes will be placed in a retreating arrangement within the placement room with any remaining voids backfilled with loose bentonite pellets.

The basic arrangement of the underground repository involves a series of parallel, dead-end placement rooms, organized into panels. All underground openings will be excavated by controlled drill and blast methods. The placement rooms will have a rectangular shape of nominal dimensions 3.2 m wide by 2.2 m high.

Heat will be generated by the UFCs. Such heat and the resulting elevated thermal regime must be evaluated with respect to potentially induced thermal stresses, as well as, the requirement that temperature on UFC surfaces must be at or below 100°C at all times. To meet this thermal requirement, the center-to-center spacing of the buffer boxes was set at 1.5 m for crystalline rock or 1.7 m for sedimentary rock. In addition the center-to-center spacing of placement rooms was set at 20 m for crystalline rock and 25 m for sedimentary rock.

During the initial construction of the underground repository, the Underground Services Area, including the UDF, the perimeter tunnels, the central access tunnels and two panels of placement rooms would be developed. Following the start of operations, excavation of placement rooms would proceed concurrently with placement activities. Sequencing of development (excavation) and UFC placement activities will provide separation of these two activities from a manpower, ventilation and equipment perspective.

For the crystalline geosphere, the underground repository covers an area approximately 2,000 m in length (Service Shaft to Ventilation Shaft centerlines) and 1,400 m in width. Each panel of placement rooms requires an area of about 350 m by 700 m in size.

For the sedimentary geosphere, the repository covers an area approximately 2,200 m in length (Service Shaft to Ventilation Shaft) and 2000 m in width. Each panel of placement rooms requires an area of about 390 m by 880 m in size. The repository in sedimentary rock has a slighter larger footprint area because the sedimentary rock has a lower thermal conductivity. Thus in order to meet maximum thermal design criteria, the spacing between rooms and UFCs within each room is slightly larger which leads to a larger underground repository footprint in a sedimentary setting.

Underground Ventilation

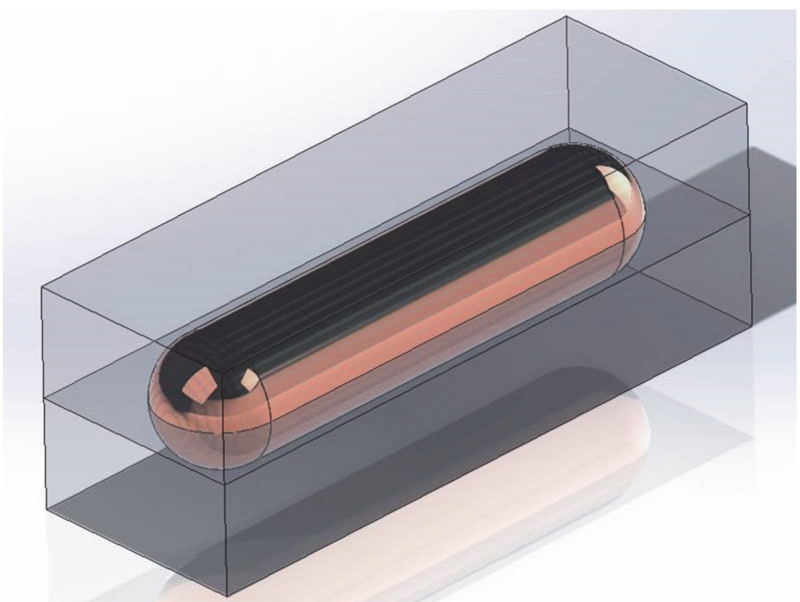
Three primary airways will be used to ventilate the repository. The Main Shaft will constitute a dedicated fresh air passage. The primary exhaust air passage will be via the Ventilation Shaft and relatively small amounts of air will exhaust via the Service Shaft. A series of surface fans and underground booster fans will be required to achieve the design air flow distribution in the underground repository. A surface-based fresh air heating plant will be used to heat air in winter months. Auxiliary fans and ducting that are located in the underground tunnels and rooms will direct airflow into active placement rooms.

Container Placement and Retrieval

The UFC incorporates a steel core or inner vessel for structural strength and has a 3-mm-thick layer of fully-bonded copper coating on the exterior of steel core. The function of the copper coating is to provide a corrosion-resistant barrier in the repository environment. The inner vessel is designed to withstand any mechanical and/or hydraulic loading that may be imposed on the UFC during the postclosure period.

The UFC holds 48 used-fuel bundles distributed in four layers of 12 bundles per layer. To provide structural support, all components are welded together into one integrated basket assembly.

Prior to underground transfer, the UFC would be pre-packaged into a rectangular shaped buffer box. The Buffer Box is comprised of highly compacted bentonite formed into blocks with a machined cavity to house the UFC. The dimensions of the Buffer Box are 1 m x 1 m x 2.8 m.



UFC with Buffer Box

Concepts for the safe transfer and placement of the UFCs have been developed based on a review of proven nuclear industry material handling concepts, as well as related work by other national radioactive waste management organizations. The identified concepts for transfer and placement will employ radiation shielding to allow unrestricted movement of personnel.

The transfer and placement technology will be refined and demonstrated at a mock-up of the placement room in a surfaced-based proof test facility and ultimately at the UDF. This demonstration work will also encompass the potential retrieval of the UFCs from the repository placement rooms for subsequent return to the DGR's surface facilities. The intended retrieval approach assumes re-use of some of the container placement and mining equipment.

Operational Safety and Radiation Shielding

Both during the operational phase and the period of extended monitoring following placement of the last UFC, there will be a requirement for monitoring to demonstrate facility integrity and safety. Key monitoring programs will address:

- Worker occupational health and safety;
- Environmental monitoring at the surface and underground;
- Nuclear material safeguards and radiation protection;
- Site security and emergency response plans; and
- Support systems including fire detection and suppression.

Radiological calculations have been carried out on selected aspects of the DGR's design elements to confirm that the potential whole-body dose for facility employees during normal operations at the DGR are well below the limits established by the Canadian Nuclear Safety Commission (CNSC). The design includes sufficient shielding and use of remote operations to keep doses As Low As Reasonably Achievable (ALARA) in accordance with CNSC guidance and the most recent recommendations of the International Commission on Radiological Protection (ICRP).

Extended Monitoring, Decommissioning and Closure

Subsequent to the cessation of used-fuel placement activities, there will be a period of extended monitoring. Following the receipt of regulatory approval, the DGR facility will be decommissioned and the underground repository sealed. When sealing or closure of the repository is complete, the site will be available for surface use. These post-placement activities will take place in the following order, with assumed durations as shown:

- 70-year or more extended monitoring period;
- 10-year decommissioning period;
- 15-year closure period; and
- Postclosure period.

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AECL	Atomic Energy of Canada Limited.
ALARA	As Low As Reasonably Achievable
ANFO	High impact explosive made of a mixture of ammonium nitrate and fuel oil
APM	Adaptive Phased Management
Backfill	An engineered mixture (solid or loose) designed to infill a void
Bentonite	A swelling clay material used as a sealing material
Bulkhead	A concrete stopping / plug
Cage	Shaft conveyance used to move personnel and material underground
CANDU	CANada Deuterium Uranium
Cask	Mobile container for used-fuel storage or transfer (also ‘Flask’)
CCTV	Closed circuit television
CNSC	Canadian Nuclear Safety Commission
Collar	The shaft opening at surface and the structure that supports the headframe
D&C	Decommissioning and closure
DBF	Dense backfill
DGR	Deep Geological Repository
Drill and Blast	Rock excavation by loading and detonating drill holes with explosive
EDZ	Excavation damage zone
ERT	Emergency Response Team
Geosphere	The rock environment the DGR will be located within
GF	Gap Fill
Grizzly	Heavy duty grate to stop oversize rock from falling into a muck pass
HCB	Highly compacted bentonite
Headframe	Tower structure that supports a hoisting operation, situated above the shaft
Heading	A tunnel that is being developed
HEPA	High efficiency particulate air (filter)
Hoek-Brown	Rock mass strength criteria
Hot Cell	An isolated and shielded room for contaminated (radioactive) material and equipment
HTP	Horizontal tunnel placement
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
IFB	In-floor borehole
ILW	Intermediate-level waste
Isotropic	Same in all directions
Jumbo	A mechanized drilling machine

kg	Kilogram
kV	Kilovolts
L & ILW	Low and intermediate level waste
LAN	Local area network
LHD	Load / haul / dump unit (low-profile version of a surface front end loader)
LHHP	Low heat high performance (concrete)
LLW	Low-level waste
Loading Pocket	An underground assembly next to shaft to transfer excavated rock into skips
m / mm	Metre(s) / millimetre(s)
m^2 / m^3	Square metre(s) / cubic metre(s)
MAVRIC	Monaco with Automated Variance Reduction using Importance Calculations
Mbgs	Metres below ground surface
MCNP	Monte Carlo N-Particle evaluation technique for radiation assessments
Module	Rack system holding used fuel bundles within a rectangular framework
MPa	Megapascal (unit of pressure)
MSM	Master slave manipulator for remote handling in radiation shielded areas
Muck	Broken rock
NDT	Non-destructive testing
NEW	Nuclear Energy Worker
NFC	National Fire Code
NFPA	National Fire Protection Association
NFWA	Nuclear Fuel Waste Act
NWMO	Nuclear Waste Management Organization
OHSA	Occupational, Health and Safety Act
OPG	Ontario Power Generation
Permeability	The ability of a rock or soil mass to transmit water
Pillar	Rock left in place to support and separate open areas
PLC	Programmable logic controller
PPE	Personal protective equipment
QA/QC	Quality Assurance / Quality Control
Raise	Vertical excavation used for ventilation, or to move personnel via ladders
Rock Bolt	A long anchor bolt installed in a drilled hole for local ground support of excavated face.
Safety Bays	Cut-out in tunnel for personnel to stand when equipment is passing
SCALE	Standardized Computer Analyses for Licensing Evaluation
Scissor lift	Working platform that can be raised and lowered
Shaft	Vertical excavation for the hoisting of personnel, materials and rock
Shotcrete	Concrete sprayed on tunnel surfaces for ground support
SKB	Svensk Kärnbränslehantering AB

Skip	Shaft conveyance mainly used for hoisting excavated rock to surface
SMC	Sealing materials compaction
Swellex	Steel tube pressurized to expand in a drill hole to hold rock in place
TBD	To be determined
TC	Transfer cask (intra-site)
UDF	Underground Demonstration Facility
UFC	Used-Fuel Container (holds the used-fuel bundles in repository)
UFPP	Used Fuel Packing Plant
UFTP	Used Fuel Transportation Package
Wi-Fi	Trademark for wireless wide local area network
Working Face	The front end of a tunnel that is being developed
Xactex	Low impact explosive

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1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management (APM), Canada's plan for the long-term management of its used nuclear fuel. The APM approach encompasses centralized containment and isolation of the used fuel in a Deep Geological Repository (DGR) in a suitable crystalline or sedimentary rock formation, in an informed and willing host community.

The NWMO has adopted a UFC design that provides containment for 48 CANDU used fuel bundles. Prior to transfer to the underground repository, the UFCs are pre-packaged into rectangular shaped buffer boxes to facilitate placement inside the underground placement rooms. The repository is assumed to be located in a crystalline or sedimentary rock geosphere at a nominal depth of 500 m.

This report describes the concept for the facilities and infrastructure needed to safely receive, repackage and place (in an underground repository) the used nuclear fuel as transported from source reactor storage sites. Section 2 lists the main design criteria and battery limits that formed the basis for the conceptual design. Section 3 of this report addresses the proposed surface facilities including the Used Fuel Packing Plant (UFPP), which will receive and process the incoming used fuel, and then pack the used fuel inside the UFCs and Buffer Boxes. Section 4 describes the shafts and hoists that will service the underground repository. Section 5 provides an overview of the underground repository, as well as the supporting ventilation system. Section 6 deals with the intended procedures to transfer buffer boxes (with UFCs) to the underground repository and then place the buffer boxes inside a placement room. This section also describes the procedures that will be followed to seal the placement room. Section 7 addresses the potential retrieval of UFCs from the repository. Sections 8 describes site security and safeguard features. Section 9 addresses operational safety and monitoring systems. Section 10 addresses the issue of decommissioning and closure. Key technical references are listed in the References section.

Two supporting appendices are included with this report. Appendix A provides information on the UFC and Buffer Box. Appendix B provides a series of radiation shielding calculations to support the design concepts presented in this report.

2. DESIGN CRITERIA

The following sections identify regulations, the main assumptions and other design criteria that form the basis for the conceptual design work presented in this document. Battery limits (the scope of design work) are also discussed.

2.1 ACTS, REGULATIONS AND CODES

The following are the key acts, regulations and codes that are applicable to the design of the DGR facility:

- Nuclear Safety and Control Act, Canada Gazette Part III, Vol 139, 1997 and associated regulations;
- CNSC Radiation Protection Regulations. These regulations prescribe a maximum effective (whole body) dose of 1 mSv/a to a member of the general public and 100 mSv per 5 year dosimetry period (with not more than 50 mSv in any single year) to a Nuclear Energy Worker;
- Ontario Regulation 854, Mines and Mining Plants;
- National Fire Code (2010); and
- National Building Code of Canada (2010).

2.2 ASSUMPTIONS

The primary assumptions that formed the basis for the conceptual design are the following:

Used-fuel Characteristics

- The used fuel inventory to be accommodated comprises 3.6 million CANDU fuel bundles;
- All used fuel bundles are 10 years to 30 years out-of-reactor prior to shipment;
- The used fuel is present in a used fuel bundle. Used fuel bundles are transported in storage modules. In a storage module, 96 fuel bundles are arranged as linear pairs in tubes held in a rectangular framework;
- The used fuel modules are transported by road within a Used Fuel Transport Package (UFTP) to the DGR; and
- Each UFTP will hold two used-fuel storage modules, one stacked on top of the other.

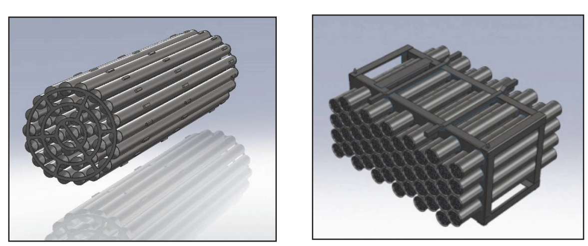

Figure 1: Fuel Bundle and 96 Bundle Module

Used-fuel Handling, Packaging and Placement

- The used fuel will be repackaged at the UFPP into UFCs;
- The UFC will be a copper-coated steel vessel and one UFC basket (see Appendix A);
- Prior to transfer underground, the UFC is pre-packaged into a two-piece rectangular shaped buffer box made from highly-compacted bentonite with a machined cavity to house the UFC. The Buffer Box dimensions are 1 m x 1 m x 2.8 m and each box has a loaded mass of about 7,125 kg[1];
- All fuel received at the UFPP will be sufficiently cool for dry storage. The interim dry storage area will have the capacity to hold a six-week supply of fuel bundles for processing in the UFPP;
- Empty storage modules (used in the delivery of used fuel bundles) will be decontaminated in a dedicated area within the UFPP and then sent for recycling or reuse;
- In the event that filled UFCs are returned from the underground repository (for example as part of a retrieval program), it shall be possible to modify the UFPP so that packaging process can be reversed in order to cut open and unload the UFCs;
- The UFPP will be designed with the principle that any anticipated abnormal operational occurrences shall not lead to serious consequences for the environment, personnel or the plant itself;
- A rate of placement equivalent to 120,000 used-fuel bundles per year will be accommodated. This is equivalent to 2,500 UFCs (in buffer boxes) placed per year (48 used-fuel bundles per UFC);
- A maximum of 10 UFCs will be placed in the repository per day based on the assumption there are 250 working days each year;
- Each UFC/buffer box will be transferred inside a shielded transfer cask in a horizontal position on a trolley from the UFPP to the entrance of the placement room; and
- Auxiliary Building incorporates remote handling / monitoring facilities for the remote control of underground buffer box placement equipment to be used inside placement rooms.

Underground Repository Setting

- For the purposes of this conceptual design work, it is assumed that the repository will be located either within a high-quality sparsely fractured crystalline or within a sedimentary rock geosphere which has a thick homogenous and competent host rock formation;
- The underground repository will be constructed at a nominal depth of 500 m below ground surface (shaft bottom allowances for sumps, etc. will be below this elevation);
- The repository's placement rooms and access tunnels will have a pre-defined minimum stand-off distance from a major fracture and/or investigation borehole;
- To the extent practical and necessary, placement rooms will be oriented with respect to the in-situ stress fields so as to minimize stress concentration around openings to promote long-term stability and minimize rock support requirements;

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[1] As designs for Used Fuel Container and the associated Buffer Box change, it is likely that dimensions and mass of buffer box will change. For example during later stages of this design study the Buffer Box dimensions were changed to 1m x 1m x 2.9m. This change will lead to small adjustments in the design of other aspects of the DGR facility and these changes will be made at a later stage of design.

- Placement room geometries will be designed to minimize stress levels and excavation damage at the rock surface; and
- Flexibility will be provided in the repository layout so that changes can be implemented if necessary (e.g., due to adverse rock conditions).

Used-fuel Placement and Retrieval

- An in-room horizontal placement method will be utilized in the underground repository;
- Buffer boxes containing the UFCs are stacked between spacer blocks and surrounded by bentonite pellets;
- The placement room cross-section will be sized to provide the required clearances for excavation, insertion of sealing materials and UFC placement. It will also contribute to excavation stability;
- Design includes a space allowance equal to about 10% of each room to account for possible groundwater seepage or unsuitable rock conditions (this assumption increases the total number of placement positions to be established);
- UFC placement configurations will ensure temperature on the UFC container surfaces does not exceed 100°C;
- Upon completion of each placement room, a seal will be constructed at the room entrance to allow bentonite to develop swelling pressure and limit migration of radioactivity out of the room including migration via the excavation damage zone (EDZ); and
- The deep geological repository shall be designed to allow retrieval of used-fuel containers prior to closure of the repository. Design of the deep geological repository shall consider measures to assist postclosure retrieval insofar as these measures do not compromise safe repository performance and nuclear material safeguard measures.

Radiation Shielding

- Using Canadian Nuclear Safety Commission's guidance document, "Keeping Radiation Exposures and Doses As Low as Reasonably Achievable (ALARA)", CNSC G-129 Revision 1, permanent and temporary radiation shielding systems will be designed to ensure that doses are maintained ALARA during both normal operations and anticipated abnormal operational occurrences;
- Shielding will be integrated into the design of structures, equipment and containers as required and the use of remote handling techniques will be maximized;
- In order to simplify construction, maintenance and operations, shielding will be comprised of ordinary materials (e.g., steel, lead, concrete) wherever possible and be designed for easy decontamination of exposed surfaces; and
- Shielding design is based on an assumption that 10-year-old used fuel is being handled inside the transfer cask. To achieve shielding for neutron and gamma radiation from 10-year-old fuel, it is necessary to add a layer of polyethylene to the carbon steel transfer cask.

Supporting Operations

- A hoisting speed of not more than 2.5 m/s will be used for movement of transfer casks with buffer boxes down to underground repository;

- The shaft complexes must function during the construction phase and the operations phase including the period of extended monitoring;
- Service Shaft and Ventilation Shaft employ Blair multi-rope hoists to eliminate the need for timber guides (required for single-rope drum hoisting systems) and thus reducing fire hazard inside shafts;
- Redundant services (i.e. duplicating services in the Service Shaft) are located in the Main Shaft;
- Waste processing facilities will be capable of safely and efficiently handling, treating and packaging any generated low and intermediate level (non-fuel) waste prior to disposal in a suitable long-term waste management facility;
- Ventilation for the underground repository will provide effective dilution of equipment emissions (e.g., diesel-powered vehicle exhaust) and dissipation of heat to provide a comfortable working environment, and be kept under positive pressure;
- Raw material inventories will be adequate to compensate for any delivery delays due to adverse weather conditions; and
- Surface ponds have been sized to accommodate a 1-in-500 year storm event. This assumption is conservative and may be revised in a later stage of design.

Decommissioning and Closure

- After placement is complete there will be a 70-year extended monitoring period during which underground access will be maintained and the placement rooms will be monitored;
- During this extended monitoring period, the capability to retrieve UFCs from placement rooms will be maintained; and
- To degree that it is practical to do so, final decommissioning and closure of the DGR facility will return the site to natural conditions and there will be no provision for re-entry to underground repository after closure.

2.3 BATTERY LIMITS

The battery limits for the design work are essentially represented by the DGR’s perimeter fence systems, which encompass practically all of the design elements outlined in this report with a few exceptions. These exceptions relate to the external site facilities discussed in Section 3.15.

3. SURFACE FACILITIES AND INFRASTRUCTURE

The DGR surface facility includes buildings, systems and equipment for operation, maintenance, and long-term monitoring. Surface facilities are identified as either being in a Protected Area (i.e., a restricted area) or associated with the Balance of Site. The differentiation being that all buildings or activities pertaining to the handling and storage of used nuclear fuel are located in the Protected Area. The Protected Area is located in the center of surface facilities site and is surrounded by Balance of Site area. The two areas are separated for safety and security reasons (see Figure 2).

External facilities, located outside the DGR's perimeter fence, are also required for support of repository construction and operation. Such facilities include a Centre of Expertise and accommodation for construction personnel (if required), as well as an area for excavated rock management.

The following section describes the primary surface facility components with the exception of the underground shafts, and the site security and safeguard features. The three shaft complexes (Main Shaft, Service Shaft and Ventilation Shaft) are discussed in Section 4. Site security measures (fencing, security checkpoints, guardhouses and monitoring rooms) and safeguard measures are described in Section 8.

3.1 SITE LAYOUT

The DGR surface facility layout is shown in Figure 2 with component facilities identified in Table 1. The facility is laid out such that all buildings which handle or store used nuclear fuel are located in the Protected Area. This area is separated from other surface facilities by a security fence, equipped with lighting and intruder detection systems. Personnel and vehicular access to the Protected Area will be strictly controlled by way of checkpoints and security gates provided with radiation monitors.

The layout of the buildings provides for the safe and efficient operation of the facility in terms of radiological zoning, material movement, traffic patterns and interaction between the services provided by the different buildings. The Service Shaft, Ventilation Shaft and the Main Shaft complexes are the anchor points for the DGR's layout. The distance between the UFPP and the Main Shaft complex, for example, has been kept to a minimum to accommodate the delivery of buffer boxes (with UFCs). The Auxiliary Building and Sealing Materials Compaction Plant are positioned either inside of, or near to the Protected Area to facilitate the transfer of personnel and materials, primarily to the Service Shaft.

The land required to accommodate the DGR surface facilities covers an area of approximately 550 m x 650 m. An additional fenced area needed for the Ventilation Shaft complex is located about 1.6 or 1.7 km (crystalline or sedimentary geosphere, respectively) from the outer perimeter fence of area occupied by the main surface facilities (see Figure 2). A three dimensional perspective of the surface facilities is provided as Figure 3.

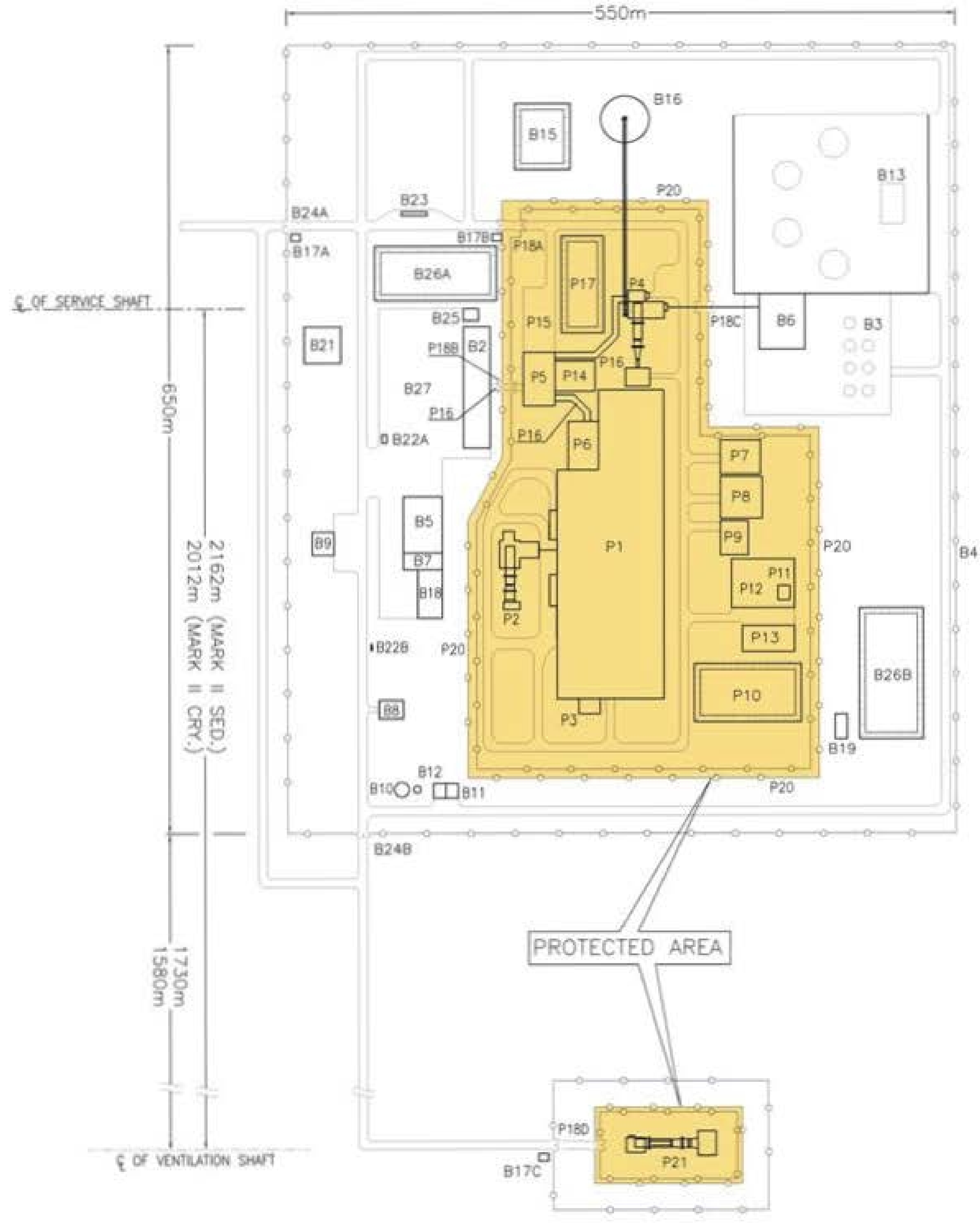


Figure 2: Surface Facilities Layout

Table 1: Area Number and Description

Area	Protected Area	Area	Balance of Site
P1	Used Fuel Packing Plant	B1	Waste Rock Management Area (WRMA)*
P2	Main Shaft Complex	B2	Administration Building including Firehall and Cafeteria
P3	Stack	B3	Sealing Material Storage Bins
P4	Service Shaft Complex	B4	Perimeter Fence
P5	Auxiliary Building	B5	Garage
P6	Active Solid Waste Handling Facility	B6	Sealing Materials Compaction Plant
P7	Waste Management Area	B7	Warehouse and Hazardous Materials Storage Building
P8	Active Liquid Waste Treatment Building	B8	Air Compressor Building
P9	Low-Level Liquid Waste Storage Area	B9	Fuel Storage Tanks
P10	Storm Water Management Pond	B10	Water Storage Tanks
P11	Switchyard	B11	Water Treatment Plant
P12	Transformer Area	B12	Pump House
P13	Emergency Generators	B13	Concrete Batch Plant
P14	Quality Control Offices and Laboratory	B14	Not Used
P15	Parking Area	B15	Process Water Settling Pond
P16	Covered Corridor / Pedestrian Routes	B16	Excavated Rock Stockpile
P17	Mine Dewatering Settling Pond	B17	Guardhouses (B17A, B17B & B17C)
P18	Security Checkpoints (P18A, P18B, P18C & P18D)	B18	Storage Yard
P19	Not Used	B19	Sewage Treatment Plant
P20	Double Security Fence	B20	WRMA Storm Water Management Pond*
P21	Ventilation Shaft Complex	B21	Helicopter Pad
		B22	Bus Shelters (B22A & B22B)
		B23	Weigh Scale
		B24	Security Checkpoints (B24A & B24B)
		B25	Security Monitoring Room
		B26	Storm Water Management Ponds (B26A & B26B)
		B27	Parking Area

* Refers to off-site facilities

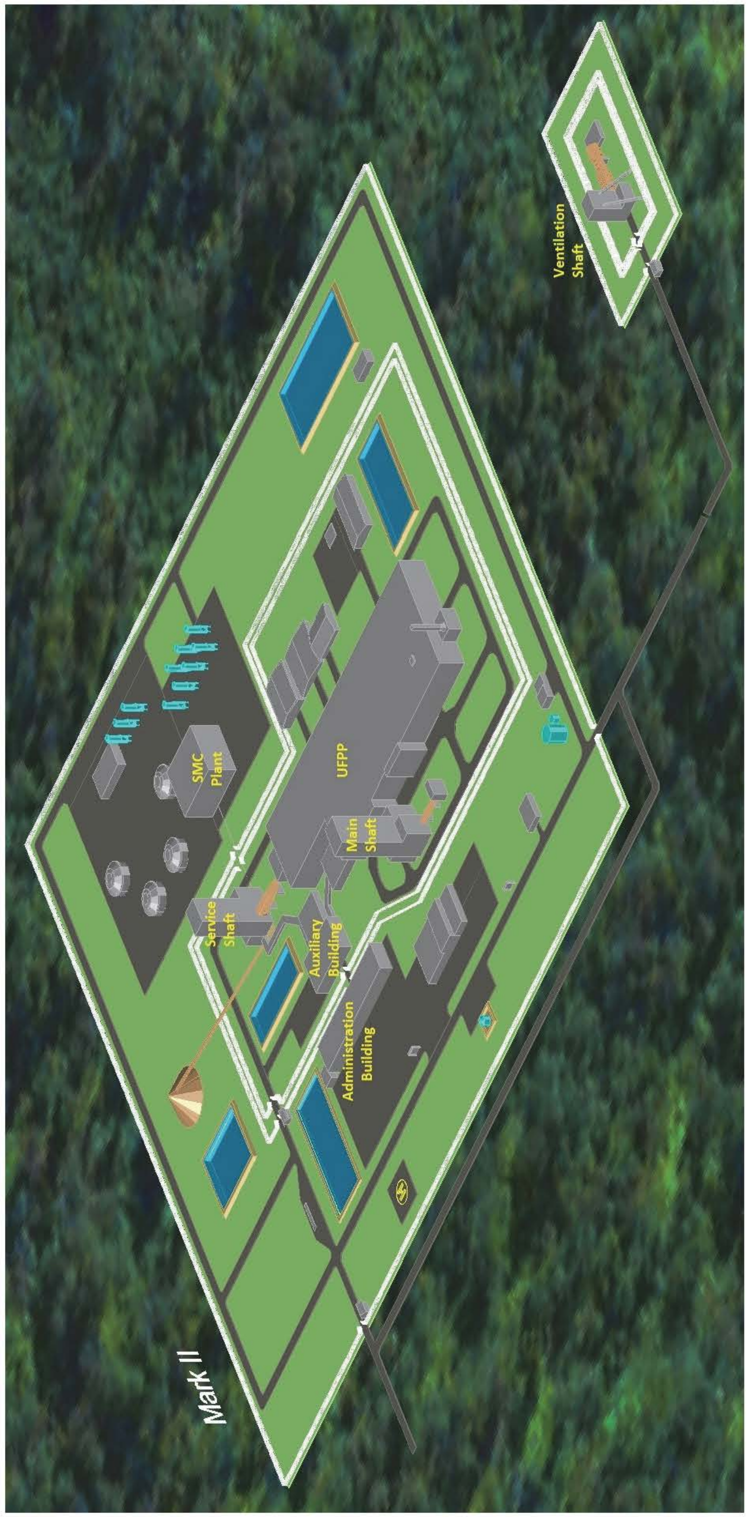


Figure 3: Three Dimensional Perspective of Surface Facilities

3.2 USED FUEL PACKING PLANT (UFPP)

Area P1

The Used Fuel Packing Plant (UFPP) is identified as Area P1 on Figure 2. This single storey building is a reinforced concrete structure and has a basement. It will include all necessary provisions for receiving used-fuel bundles in UFTPs and transferring used-fuel bundles from the UFTPs to the UFCs. The UFPP has equipment for sealing, inspecting and assembly of UFCs into buffer boxes, and for dispatching of the buffer boxes for placement in the underground repository. Any defective used-fuel containers would require repacking into a new container.

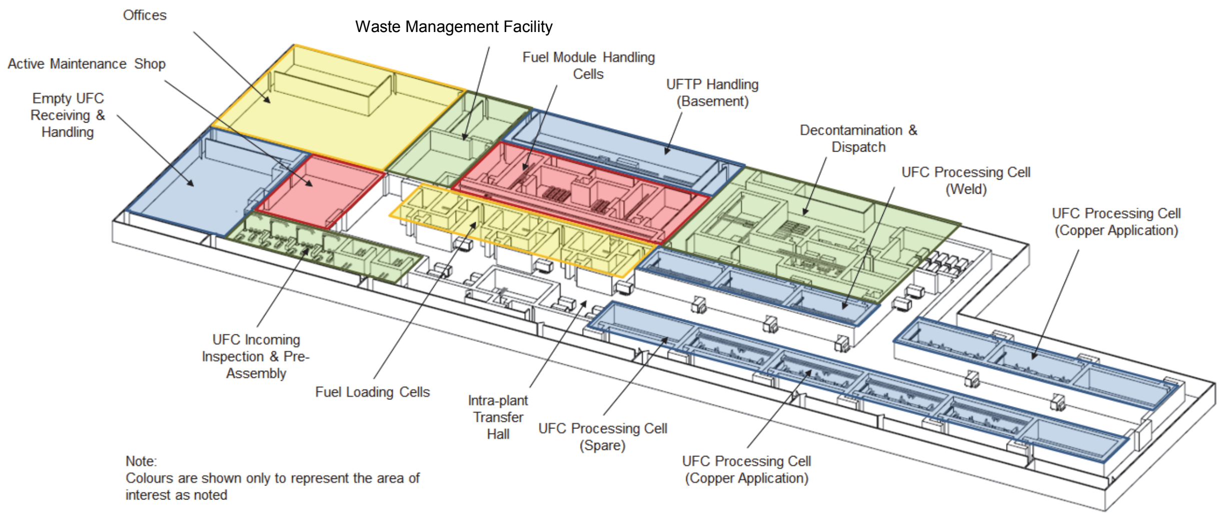


Figure 4: Overview of the UFPP Layout

Empty containers will be produced off-site at a dedicated UFC factory, with used-fuel loading and final processing to complete an integrated filled container conducted in the UFPP.

Fuel is received, unloaded and transferred into used-fuel containers in a hot cell process. Once the fuel is loaded into the used-fuel container, the hemi-head is temporarily installed and the assembly is transferred to the used-fuel container processing cell. Here the UFC is welded, examined, copper-cold-sprayed and annealed prior to being placed inside a buffer box. The buffer box is placed inside a shielded cask for transfer underground.

There are multiple processing lines for receiving and unloading UFTPs and handling the UFCs. The processing line for UFCs is designed so that several containers can be in process simultaneously. Key data for the UFPP throughput is provided in Table 2. The UFPP also includes required auxiliary systems, such as ventilation, electrical power systems, a central control room, waste management facility, and facilities for personnel and visitors.

Table 2: Key Data for Average UFPP Throughput

	Bundles per Unit	Throughput		
		Base Case Total	Annual	Daily *
Bundles	1	4,600,000	120,000	480
Modules	96	47,917	1,250	5.0
UFTP	192	23,958	625	2.5
UFC	48	95,833	2500	10

* Based on assumption of 250 working days per year

Most steps in the packaging process are remotely operated. However, after removal of the radiation source and decontamination by remote-controlled processes, all areas can be accessed by maintenance personnel. Areas and equipment for handling used-fuel bundles and filled UFCs are radiation shielded. The fuel receiving and transfer area will be kept at a negative pressure to prevent the spread of airborne contamination.

3.2.1 Used Fuel Transport Package (UFTP) Receipt And Unloading

To achieve the specified daily throughput, an average of 2.5 UFTPs will need to be processed each day. To achieve this throughput, the system will incorporate two (2) parallel and independent processing lines. Each line will process between 1 and 2 UFTPs per day. Fuel-filled modules will be placed into temporary dry storage, as required, until modules can be accepted for processing inside the UFPP.

Used fuel inside a UFTP arrives at the UFPP from the nuclear stations via the ground transportation system and is transferred to one of two (2) parallel UFTP handling cells which are located on the basement level of the plant (see Figure 4 and area with label “UFTP Handling (Basement)”). After the impact limiter is removed, the UFTP loaded with modules is raised and connected to an opening in the ground-level floor. The UFTP lid is removed and modules are lifted out of package and then transferred to the respective module handling cell on the ground level of the plant. It is assumed that wet storage is not required because all fuel received at the UFPP will be sufficiently cool for dry storage. There will be a process in place to clearly distinguish and track the empty and filled transportation packages, and to keep these packages in separate locations.

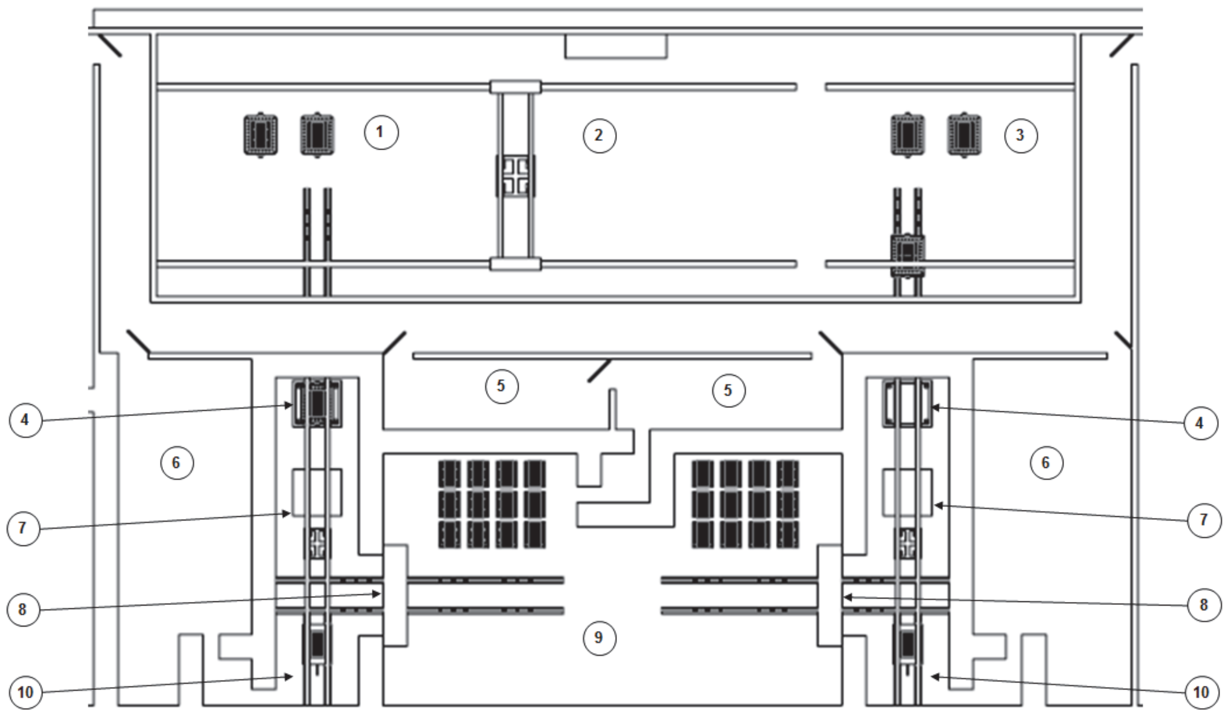


Figure 5: Fuel Module Handling Cells and UFTP Handling (Ground Level)

The UFTP Handling Cells illustrated in Figure 5 consists of the following areas or components (numbers refer to locations in the figure):

1. UFTP Storage area
2. UFTP Shipping and Receiving Hall
3. Impact Limiter Removal area
4. UFTP Vent and Transfer Cell
5. Control Room
6. Operator Room
7. Module Drying Cell
8. Module Transfer to Dry Storage
9. Dry Storage area
10. Module Transfer to Distribution Hall

3.2.2 Used-Fuel Container (UFC) Loading and Sealing

To ensure the specified daily throughput listed in Table 2 is achieved, a total of 12 UFCs are planned to be loaded per day, which corresponds to 6 fuel modules. To accomplish this, the system will utilize three parallel and independent processing lines, each processing an average of 2 modules and 4 UFCs per day (Figure 4).

A series of three fuel handling systems will be constructed, and each will be isolated from one another with airlocks and shielding walls. The ‘hot cell’ areas within will be shielded by concrete shielding walls with lead glass windows and CCTV cameras for remote viewing.

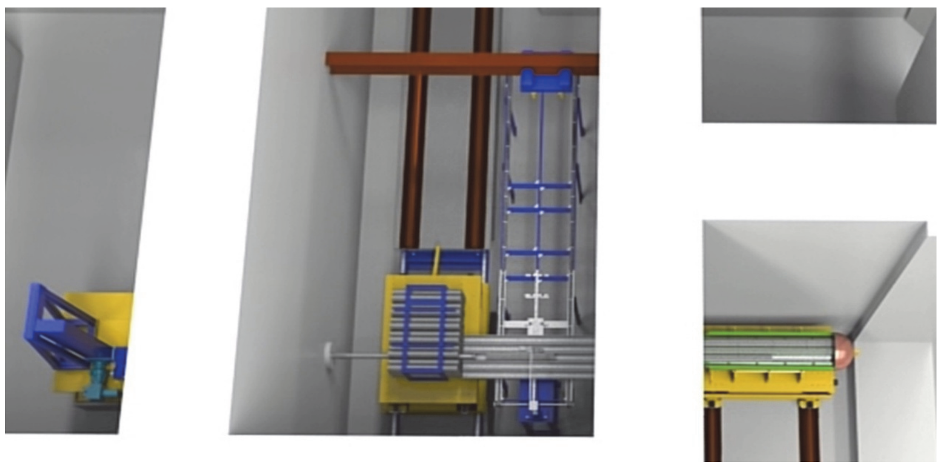


Figure 6: Fuel Transfer into Used-fuel Container

Notes for Figure 6:

1. Room at left of figure houses the equipment to operate the push rod that penetrates the hot cell shield wall.
2. Module loaded with fuel bundles is located in the hot cell at center of the figure.
3. Bundles are pushed by the rod into the UFC located in hot cell at right of figure. The UFC is shown in a cut-way view with top half of the UFC removed for the purpose of this illustration.

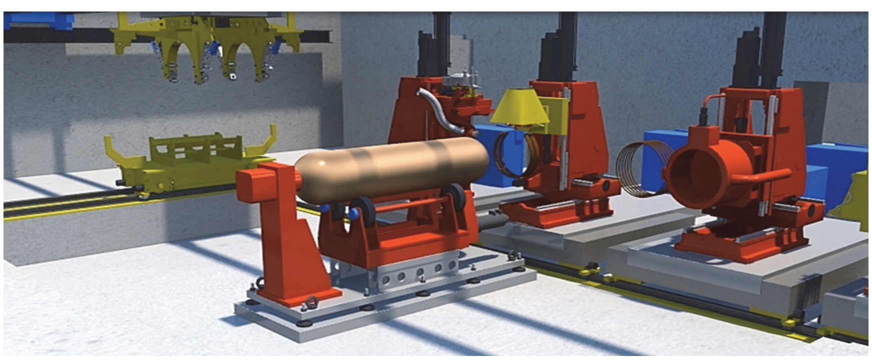


Figure 7: Automated Work Tables inside Processing Cell

Inside the processing cell, four automated work tables are responsible for:

1. Welding the hemi-head to the shell (Figure 8)
2. Clean-up machining of the weld (if required)
3. Non-destructive examination of the weld (Figure 8)
4. Copper cold spray over weld area (Figure 9)
5. Clean-up machining of the copper cold spray (if required)
6. Annealing of the copper cold spray (Figure 9)
7. Non-destructive examination of the copper cold spray

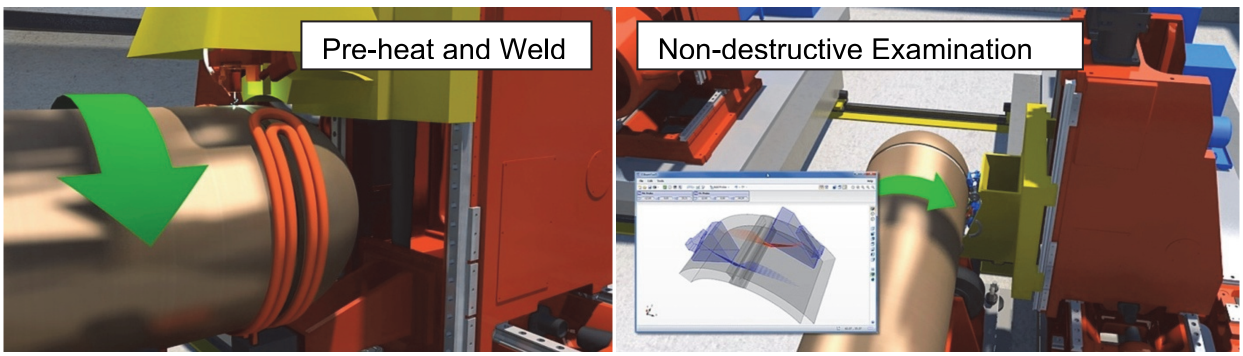


Figure 8: Weld Worktable and Non-Destructive Examination Worktable

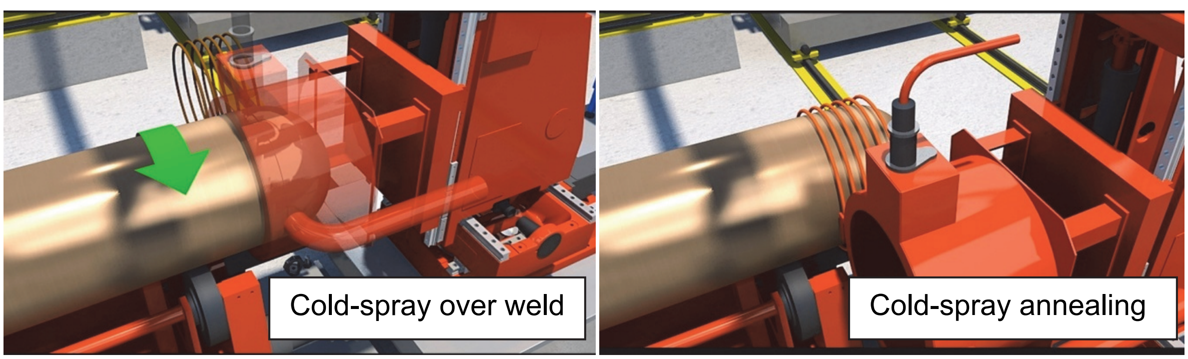


Figure 9: Copper Cold Spray and Copper Annealing Worktable

3.2.3 UFC Intra-Plant Transfer System

The UFC intra-plant transfer system is comprised primarily of an Automated Guided Vehicle (AGV) system and the UFC transfer hall where four AGVs will operate. The transfer hall contains three Work in Progress (WIP) storage areas:

- WIP Storage Area #1 for loaded UFCs – UFCs loaded with used-fuel;
- WIP Storage Area #2 for post-weld UFCs – UFCs that have just completed the welding operation; and

- WIP Storage Area #3 for completed UFCs – UFCs that have successfully been coated with copper and are ready for dispatch to buffer box assembly area.

The hall allows AGVs to access the active maintenance shop, waste management facility, fuel loading cells, process contingency manual work cell, UFC weld cell, UFC copper application cell and the UFC final decontamination cells.

All areas of the transfer hall will be shielded from radiation fields given off by the UFC using concrete shielding walls between processing areas, or by the use of a shielded UFC transfer flask. The main transfer hall is expected to be classed as Zone 2. However because there is risk that contamination could spread from the unsealed UFCs to inside and outside of the UFC flask, the area may have to be designated Zone 3. Hot cells in this facility can be considered as Zone 4 for control purposes.

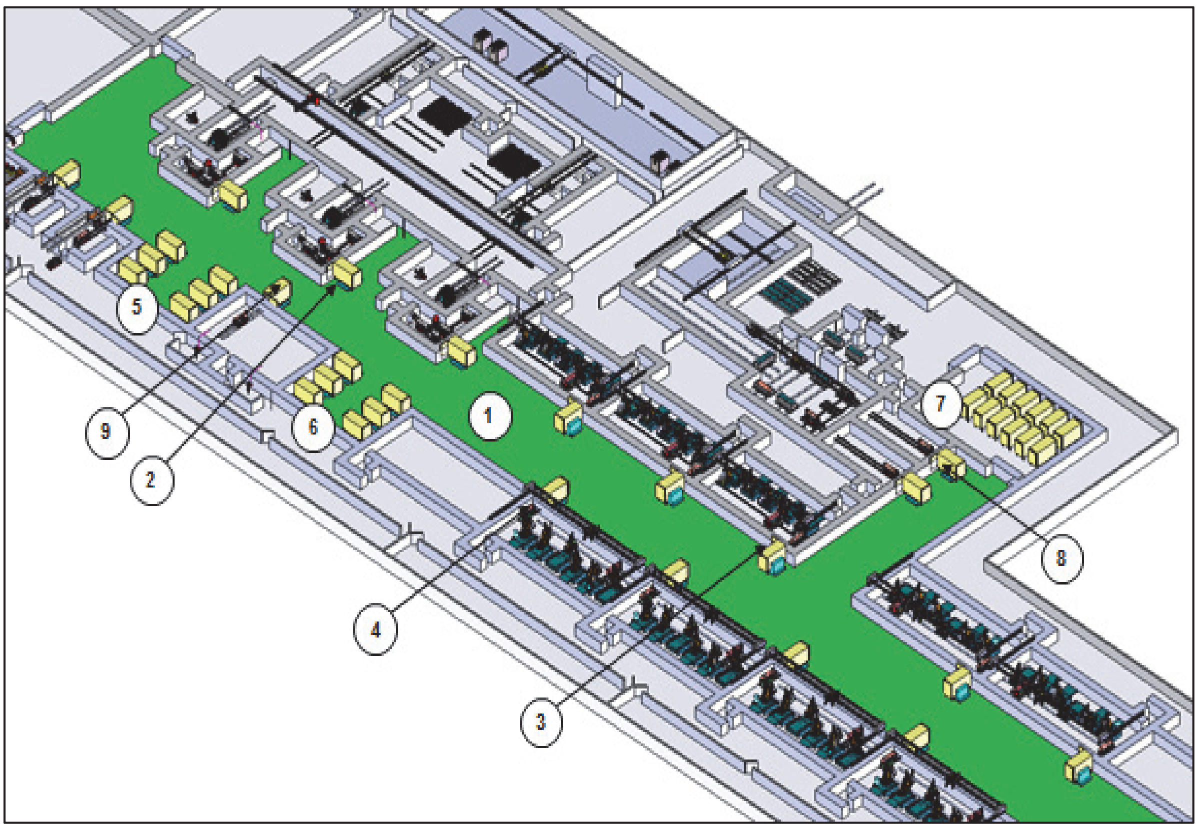


Figure 10: Used-fuel Container Transfer Hall

The UFC Transfer Hall illustrated in Figure 10 consists of the following areas or components (numbers refer to locations in the figure):

1. UFC Transfer Hall (called Intra-Plant Transfer Hall in Figure 4)
2. Fuel Handling Cell Docking
3. UFC Weld Cell Docking

4. UFC Copper Application Cell Docking
5. WIP Storage Area #1 – Loaded UFCs
6. WIP Storage Area #2 – Post-Weld UFCs
7. WIP Storage Area #3 – Completed UFCs
8. UFC Decontamination Cell Docking
9. Process Contingency Manual Work Cell Docking

3.2.4 Waste Management Facility and Active Mechanical Workshop

The UFPP includes a waste management facility, which is located below the fuel handling cell and is accessed from the cell via a dedicated port with a gamma gate. Equipment in the waste facility includes provisions for the decontamination of empty modules for recycling or reuse.

Adjacent to the waste management facility is an active mechanical workshop. The workshop can be used for maintenance, as well as for the handling, decontamination and monitoring of container components after the opening and unloading of defective UFCs.

3.2.5 Connection to Main Shaft

In the UFPP, the Buffer Box will be inspected for loose contamination prior to its insertion into a transfer cask. The transfer cask will also be inspected for loose contamination prior to leaving the UFPP and at the shaft exit point at repository level (underground). If contamination is found, the equipment or Buffer Box will be quarantined and decontaminated. The transfer cask with UFC will travel through an enclosed dedicated travel route to the Main Shaft.

3.3 AUXILIARY BUILDING
Area P5

The Auxiliary Building is situated adjacent to the border of the Protected Area and provides facilities for surface operations staff who work primarily in the Protected Area. The building is connected by covered walkways (Section 3.13) to the UFPP, the Service Shaft complex, and the Administration Building.

The Auxiliary Building is located as central as possible to the UFPP and Service Shaft to reduce the distance for personnel to walk, and also to minimize the extent of needed covered walkways. About 50 to 60 staff will be accommodated in the building.

The Auxiliary Building will be a two-storey structure and will be equipped with full fire protection and radiation monitoring systems. The building will include the following facilities:

- Operational management areas consisting of offices and meeting rooms equipped with voice, video and data connections;
- An Operations Communications Facility from which staff will control and monitor the remote underground movements of the UFCs;
- First Aid station;

- Change rooms, lockers, washrooms and shower facilities for staff and visitors accessing the Protected Area. Lockers will be in place to accommodate safety hats, boots, overalls and protective suits;
- Laundry facilities for all laundry needs exclusive to the Protected Area; and
- Protected Area cafeteria will be provided to minimize the movement of personnel into or out of the Protected Area during shifts. This cafeteria will be supported by the main cafeteria in the Administration Building, with foods being prepared and delivered on an as-required basis.

3.4 WASTE HANDLING FACILITIES

Areas P6, P7, P8 & P9

This section addresses low and intermediate level waste (L&ILW) management facilities as well as those designed for management of non-radiological hazardous wastes. The principal subject waste streams, generated in both solid and liquid form, are as follows:

- Low Level Waste (LLW): radioactive waste in which the concentration or quantity of radionuclides is above the clearance levels established by the regulatory body (CNSC), and which contains primarily short-lived radionuclides (half-lives shorter than or equal to 30 years);
- Intermediate Level Waste (ILW): radioactive non-fuel waste, containing significant quantities of long-lived radionuclides (generally refers to half-lives greater than 30 years) and
- Free Release Waste: comprises waste that in which radionuclides are below CNSC clearance levels. This would include non-radioactive hazardous and non-hazardous materials.

3.4.1 Active Solid Wastes

Figure 11 illustrates the expected primary solid L&ILW streams. As noted thereon, the main sources of active solid wastes are anticipated to be from the UFPP, the Auxiliary Building, and from the active liquid waste treatment processes.

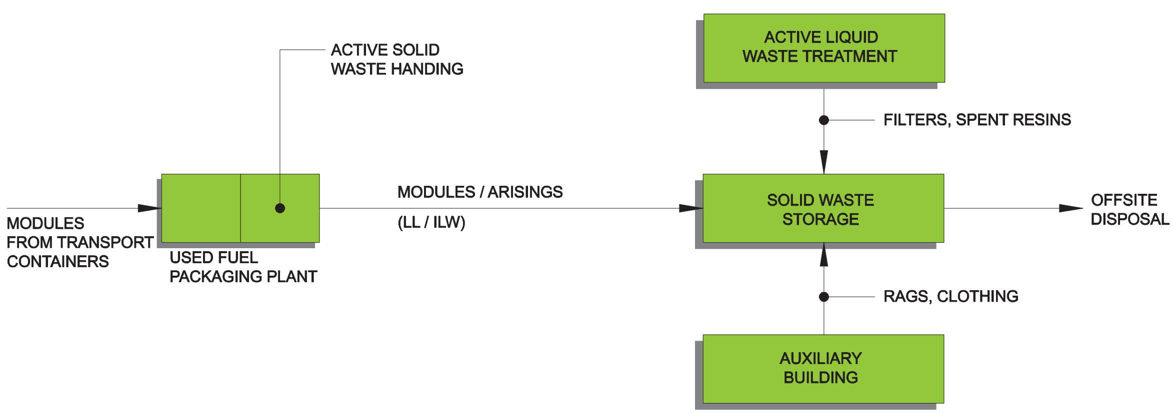


Figure 11: Active Solid Waste Flow Diagram

The modules from the incoming UFTPs will represent the most significant source of active solid waste. When a module has been emptied of used-fuel bundles, it will be decontaminated to free-release limits to allow shipment to either an off-site metals recycling facility or a storage location for future reuse. Active waste streams will also include used HEPA filters from the ventilation exhaust air units as well as spent filters and/or ion exchange media from the treatment of active liquid wastes.

Table 3: Inventory of Active Solid Wastes

Source	Description	Level	Annual Quantity
UFPP	Modules from UFTPs	L or ILW	330 m^3
UFPP	Arisings from operations and maintenance	ILW	3 m^3
		LLW	100 m^3
UFPP	Bead IX resins		500 L
UFPP	Powder resins		120 kg
UFPP	HEPA & cartridge filters		285 filters
UFPP	Hot Cell vacuum filters		0.5 m^3
Ventilation Exhausts	Used HEPA filters	LLW	TBD
Aux. Building & other Facilities	Dry swabs, swipes and clothes, etc.	LLW	TBD
	PPE (clothing, gloves, etc.)	LLW	10,000 kg
Active Liquid Treatment	Spent filters and IX media	L or ILW	20 m^3
Various	Miscellaneous	L or ILW	10,000 kg

Other active solid waste streams will include arisings (spent equipment/tools or components) from the maintenance of hot cell equipment. LLW streams will include that from general decontamination activities and/or resulting from incidental contact with loose radioactive material such as cleaning materials and used personal protective equipment (PPE).

Table 3 identifies the quantities of solid L&ILW expected to be generated. After waste reduction, approximately 2,000 m^3 of such wastes are anticipated each year. These processed wastes will be sent to an on-site interim storage building.

3.4.2 Active Liquid Wastes

Figure 12 identifies the liquid L&ILW streams. Similar to the active solid waste flows, the primary sources are anticipated to be from the UFPP and Auxiliary Building.

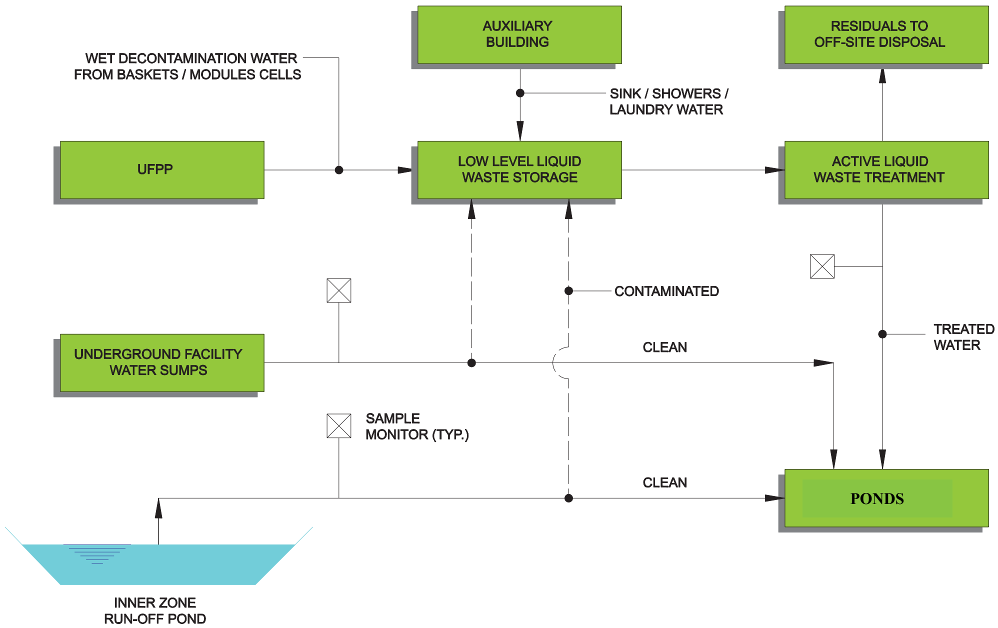


Figure 12: Active Liquid Waste Flow Diagram

Active liquid waste flows from the UFPP will originate from the decontamination of used-fuel modules, cell washdowns, and from the decontamination of UFTPs and containers. The other primary source of liquid waste flows will include some laundry wash and rinse waters (normally directed to sewage treatment system, only rerouted if indicated by monitoring).

Table 4 identifies all sources and the associated quantities of liquid L&ILW that will be generated. In total, approximately 200 m^3 of containerized active liquids and 9,000 m^3 of piped active liquid wastes will be produced each year.

The discharge water from the mine dewatering settling pond ("Underground Facility Water Sumps" in Figure 12 which is Area P17 in Figure 2) and the storm water management pond ("Inner Zone Run-off Pond" in Figure 12 which is Area P10 in Figure 2) are normally expected to have radioactivity concentrations well below limits that are acceptable for release to an off-site water body. However, in the remote event that the monitoring of pond discharge water finds radioactivity levels to be above acceptable limits, then the pond water would be routed to active liquid waste treatment building for treatment. The water could be taken to the treatment building by tanker truck or a pumping system.

Table 4: Inventory of Active Liquid Wastes

Source	Description	Level	Annual Quantity
UFPP	Module decontamination	ILW	1,250 m^3 (piped)
UFPP	Active cell wash down	ILW	10 m^3
UFPP	Cask decontamination	ILW	1,600 m^3 (piped)
Lab. & Test Areas	Cleaning and samples	LLW	100 m^3
Auxiliary Building	Laundry, change rooms	LLW	max. 6,000 m^3 (piped)
Waste Management Area	Cleaning of package exteriors	LLW	25 m^3
Underground or Surface	Mine Dewatering Settling Pond (P17) & Storm Water Management Pond (P10)	LLW	normally clean and nil (piped)
Active Liquid Waste Treatment	Spent regenerates	LLW	30 m^3 - 60 m^3

3.4.3 Non-Radiological Hazardous Waste

Various non-radiological, hazardous solid and liquid wastes will also be generated from the on-going operation and construction activities. These will include:

- Solvents used in decontamination and cleaning in non-radiological areas;
- Lubricants and greases;
- Petroleum based fuels; and
- Explosive residues.

To minimize the total amount of these waste materials, steps will be taken to limit activities that generate these wastes, find less-hazardous replacement materials, and ensure separation of incompatible materials such as organic solvents and inorganic acids. All conventional waste materials will be collected and sent to a disposal facility that is licensed to accept these types of waste materials. Spill containment and monitoring will be provided wherever hazardous liquid wastes are handled and stored.

3.4.4 Non-Radiological Non-hazardous Waste

There will be a number of conventional waste streams generated at the DGR (e.g., office and lunchroom waste, etc.). To the extent possible, the quantity of these wastes will be minimized and segregated by type for recycling.

3.4.5 Waste Management Approaches

With respect to the waste facilities, four separate operations will be incorporated into the design and operation of the DGR. As discussed in the following sections, these include:

- Active Solid Waste Handling Facility – meant to receive active solid wastes from the UFPP;
- Waste Management Area – which will manage active solid waste materials;
- Low-Level Liquid Waste Storage Area – which will receive low-level liquid waste materials prior to transfer to the treatment area; and
- Active Liquid Waste Treatment Area – a processing plant for active liquid waste materials.

Generally, non-hazardous and non-radiological refuse will be handled as in any other type of industrial setting. Such garbage will be directed to a local municipal landfill or other waste management facility. The approach to handling non-radiological hazardous waste is expected to be similar, with wastes being transported off-site to an appropriate hazardous waste management facility. The quantity of such materials will be reduced to the maximum extent possible and any collected wastes will be shipped off-site for recycling or long-term management.

Active Solid Waste Management Systems (Areas P6 & P7)

L&ILW management activities will center on two on-site operations, the active solid waste handling facility and the waste management area (Areas P6 and P7 on Figure 2, respectively).

The active solid waste handling facility is associated with and attached to the UFPP, and serves as a staging area for solid wastes from that building. It will comprise an area for decontamination of modules for reuse or recycling and for processing of other solid wastes materials. Once processed and packaged, the containerized wastes will be directed to the waste management area.

The waste management area incorporates a stand-alone storage building. Racks will be in place to accommodate about 1,000 m^3 of LLW and 300 m^3 of ILW. Additional storage space will also be available outdoors, under cover. The wastes will be stored in suitable containers to prevent damage and loss of containment. A compactor to consolidate collected material will be provided.

It is currently assumed that active solid wastes which are not, or cannot be, decontaminated to free-release limits will be placed into suitable transportation containers and shipped off-site to a licensed long-term management facility. As the quantity of waste which is combustible is expected to be limited, on-site incineration for volume reduction will not be pursued. However, further treatment at off-site facilities may be considered where appropriate.

Active Liquid Waste Management Systems (Areas P8 & P9)

Active liquid waste treatment will be managed through two facilities, a storage building located in the low-level liquid waste storage area (Area P9 on Figure 2), and the active liquid waste treatment building (Area P8), where the latter is a processing plant for the liquid wastes.

The storage building, incorporating secondary containment for spills or leaks, will provide for the interim assembly of collected liquids prior to treatment. The building will house storage tanks to receive piped and containerized active liquids as well as an area where containerized liquids would be stored. One tank will be kept empty to provide space for unplanned receipts. Over normal operations, active liquids will be transferred into one of the storage tanks for blending or moved directly to the treatment building.

The active liquid waste treatment building will house the following equipment:

- Two feed / equalization tanks with feed pumps;
- Two treated water collection and monitoring tanks with transfer pumps;
- Treatment systems comprising filtration to remove particulate contaminants, ion exchange or membrane separation to extract dissolved contaminants and possibly post-treatment filters to allow for recycling of the treated water;
- Three tanks to supply regeneration / cleaning liquids and receive spent regenerant / washwater and concentrate from the membrane separation modules; and
- Pumps to serve the three tanks above.

The treatment of active liquid wastes using particulate filters and ion exchange columns is commonly used in many locations including nuclear power plants. The system will be comprised of three 50% capacity modules, two of which would be operating at any given time with the third unit on stand-by.

Alternatives to this treatment approach include the use of membrane separation technologies such as ultra-filtration and reverse osmosis.

3.5 SWITCHYARD, TRANSFORMER AREA AND EMERGENCY GENERATOR BUILDING Areas P11, P12 & P13

Electrical services will be managed and back-up emergency power supplied by the switchyard, transformer area and emergency generator building. For security, these facilities are all located in the Protected Area.

3.5.1 Switchyard

The switchyard (Area P11 on Figure 2) is designated to host all high voltage equipment for circuit-breaking interruption, circuit-making, isolating disconnects, switching, and for the protection of transformers, lines, cables and capacitor banks. All designated equipment mechanisms will be fully enclosed and protected. Positively sequenced operations will be assured regardless of weather conditions. Protection from high winds, rain, sleet and snow will be in place. The switchyard area will be surrounded by a dyke (or perimeter ditch and sump) to collect any PCB-free spilled oil. It will be lined, as required, and have a surface comprising a compacted granular sub-base.

3.5.2 Transformer Area

Two step-down transformers each capable of handling a load of 20 MW will be located at the sub-station (transformer area) with all controls and switchgear housed in an adjacent building. These facilities are identified as Area P12 in Figure 2.

Table 5: Site Power Requirements

Equipment Description	Net M.V. Run Demand		Net L.V. Run Demand	
	(kW)	(kVA)	(kW)	(kVA)
Used Fuel Packing Plant			1,553	1,726
Sealing Materials Operations			5,016	5,573
Hoist Motors for 3 Shafts	1,375	1,526	135	150
Ventilation Systems	3,455	3,839	1,251	1,413
Waste Management Operations			374	416
Underground Demonstration Facility			785	872
Underground Operations			510	567
Other Operations and Surface Facilities			3,585	3,983
Total	4,830	5,395	13,209	14,662
Total demand, MV + LV (values rounded)			18,000 kW	
			20,000 kVA	
Calculated Power Factor (at each voltage)			1.11	
Electrical System Losses, kW (assume ~3% of demand)			541	
Total Peak Running Demand Load, with losses (rounded)			20,600 kVA	
Total Running Demand Load, with losses and 95% Overall Diversity Factor (values rounded)			17,700 kW	
			19,600 kVA	

Note: M.V. and L.V. means medium and low voltage, respectively

The total electrical power demand for the facility is indicated in Table 5. The site's power supply will be received from a high voltage overhead line branching off from the regional power grid. This line is expected to be tower mounted, with towers generally spaced at 200 m intervals for stability.

After being received at the two transformers, the electrical power will be conveyed via overhead medium voltage (13.8 kV) power lines to the plant distribution level. The power lines will run alongside access roads within the surface facilities to all buildings and terminate at step-down units. Step-down transformer units will provide the needed power for motors, buildings, compressors and other electric driven installation as per requirements. Use of underground lines with armoured cable will be considered where required depending on site conditions.

The transformer area will be situated within the previously described switchyard. Reinforced concrete platforms will be provided for the transformer units with mounted switches in steel box enclosures designed with suitable fire wall separation and fire protection measures.

3.5.3 Emergency Generators

The emergency generator building (Area P13 in Figure 2) will house the emergency power generators and related equipment. Three 2.5 MW diesel generators (one for standby) will be able to provide the emergency power needed at the DGR facility. In this respect, the primary loads that would be served by the emergency generators are for the underground ventilation system as well as for the Ventilation Shaft hoist and the Service Shaft auxiliary hoist. As illustrated in Table 6, allowances have also been made to sustain critical services in the UFPP, and the various other surface and underground operations.

Table 6: Emergency Power Requirements

Applicable Emergency Services	Needed Power (kW)
UFPP Area (allowance)	500
Exhaust and Booster Fans for Underground Ventilation	3,105
Hoists in Main Shaft, Ventilation Shaft and Service Shaft	150
Security Control Systems (allowance)	200
Miscellaneous Underground Requirements including Pumps	200
Miscellaneous Surface Requirements	300
Total:	4,455

The diesel generators will be connected to the same switchgear for the step-down transformers as connected to the medium voltage (13.8 kV) power lines from the grid. That is, the switchgear will be compatible for either grid power or diesel generated power. All other controls and switches will be housed in the emergency generator building and be capable of switch-over from the main grid to the diesel generators. A separate storage room for diesel tanks (2 weeks supply) and oil will be provided in the building.

Most buildings at the DGR will have connections for emergency power to the key areas, corridors, washrooms and external security lighting, key offices, laboratories and essential services. In an emergency, all security lighting and facilities for monitoring and detection of intrusions will receive full power.

In addition to the forgoing, uninterrupted power supplies will be in place in various facilities to ensure the continued functioning of vital computer, instrumentation and security equipment.

3.6 QUALITY CONTROL OFFICES AND LABORATORY Area P14

The quality control office and laboratory facility, illustrated as Area P14 on Figure 2, will provide space for resident quality control specialists and scientists. The staff will provide quality control, monitoring and testing for such items as groundwater, stormwater, air quality, and radiation-related issues (see Section 9).

The building, envisaged as a single storey structure, will be located in the Protected Area. It will house the quality control offices, laboratories and work stations for the facility's technicians, researchers, quality inspectors, scientists and managers. Work benches, experimental areas and refrigerators (for any chemicals or reagents requiring cool storage conditions) powered by emergency power will be in place. Meeting rooms will be provided.

In addition to the normal sprinkler system in the ceilings, firefighting equipment will be installed near most work areas and outside the laboratories.

3.7 ADMINISTRATION BUILDING INCLUDING FIREHALL AND CAFETERIA Area B2

The Administration Building (Area B2 on Figure 2) will be the first building that visitors and most staff encounter when coming to the DGR facility. Equipped with full fire protection and monitoring systems, the building will be divided into three main areas: the administrative offices, a cafeteria and the firehall. It is estimated that about 700 full-time will be working at the DGR facility and approximately 200 staff will have office space in this two-storey structure.

Employees will enter through the parking area adjacent to the building and proceed to their respective locker spaces or to the Auxiliary Building (Section 3.3). Protective clothing (for those working inside the Protected Area) and civilian clothing will be stored in separate lockers. The lockers will be of sufficient size to accommodate safety hats, boots and overalls. Provision will be made for locker space for site visitors including inspectors and government officials. Showers will also be in place.

The cafeteria will provide sit-down areas with a serviced hot kitchen for continuous full meal services.

The firehall (supported by the security monitoring room - see Section 8.1.1) will be equipped with detection and monitoring equipment for any fire hazards or smoke from any of the DGR facility operations. Firefighters will be on duty each shift, with other fire team members on standby in the event of an emergency. Two large municipal fire trucks will be available with telescopic ladders, hoses, pumps and all other typical fire-fighting tools.

The main administrative area will have offices for senior management and key staff, board-rooms for meetings and training sessions, and cubicles for other supervisory or technical personnel. Offices will have full internal and external communications facilities, as required, including internet, telephone, two-way radio systems and wired networks. Additional facilities at the Administration Building will include:

- Transportation and logistics coordination centre equipped with display monitors for the real time tracking of used-fuel transport trucks;
- Procurement area to serve as the central procurement department for all on-site equipment and consumables;
- IT and communication facilities, connected to a rooftop-mounted satellite dish;
- Health and safety training room and offices to be used for the training of employees and the orientation of visitors to the DGR; and
- Nursing station and first aid area with consultation rooms and a doctor's office. A full-time nurse practitioner will be on duty for all shifts.

3.8 SEALING MATERIALS PRODUCTION FACILITIES

Areas B3, B6 & B13

The sealing material receipt, storage and preparation facilities will be used to produce various concrete and clay-based sealing materials for the encapsulation of the UFCs / buffer boxes in the underground repository. The facilities comprise a concrete batch plant (Area B13) and a Sealing Material Compaction (SMC) plant with associated material storage bins (Areas B6 and B3, respectively). Materials, quantities or processes related to the backfilling and closure of access tunnels, shafts or other openings would be addressed at the time of final facility decommissioning and closure (see Section 10).

From the concrete batch plant, a Low Heat, High Performance (LHHP) concrete mix is produced for constructing bulkheads at the entrance to each placement room. Further, it is expected that concrete will be required for the central and panel access tunnel floors. During the operations phase, the SMC plant will produce four different clay-based sealing material products:

- Highly compacted bentonite (HCB) blocks for use in the buffer boxes;
- HCB blocks for the room seals;
- Dense backfill (DBF) blocks; and
- Gap fill for filling the space between the stack of buffer boxes and spacer blocks and the surrounding rock.

Aggregate products will be stockpiled and stored within the concrete batch plant area. Overhead field conveyors will be used to bring finished aggregate product to the concrete batch plant. In all, the aggregate, concrete batch and SMC operations are seen as an interconnected network.

The sealing materials production facilities will be situated adjacent to the Protected Area, so as to be located as close as possible to the Service Shaft and UFPP. This location will minimize the distance materials will need to be conveyed, help to reduce the footprint of the site, and lessen the need for workers in the SMC plant to enter the Protected Area. The products are brought to either the UFPP for the buffer box assemblies or to the Service Shaft for delivery underground.

For day-to-day operations, the concrete batch plant will run on an as-needed basis. Conversely, the high demand for clay-based sealing materials necessitates a three shift, daily operation for the SMC plant. All required materials (modified granular A, different binders such as cement T50, silica fume and silica flour, as well as bentonite and other clays) will be sourced from external suppliers.

The main difference between the crystalline and sedimentary repository options is the spacing between adjacent buffer boxes. This means that there will be a difference in the spacer block size, which will result in variances in the quantities of the fill materials that will be required.

The following sections initially describe the material requirements for the concrete batch plant and the SMC plant. Detailed descriptions of each plant is provided thereafter.

3.8.1 Material Requirements for Concrete Batch and SMC Plants

Table 7 summarizes the different materials required at the concrete batch plant and SMC plant on an annual basis. Where there is a difference, separate values are provided for the crystalline and sedimentary design cases.

Table 7: Materials Requirements for Concrete Batch and SMC Plants

Material	Concrete Batch Plant (tonnes/yr)	SMC Plant (tonnes/yr)
Concrete Stone	484	
Concrete Sand	416	
Modified Granular A		5,613 / 7,858*
Cement T50	45	
Silica Fume	45	
Silica Flour	90	
Superplasticizer	5	
Bentonite		21,546 / 22,653*
Clay		2,005 / 2,806*
Water	60	
Total	**1,145**	**29,164 / 33,317***

*Note: crystalline / sedimentary

3.8.2 Concrete Material Requirements

Low Heat High Performance (LHHP) concrete will be used for the construction of the placement room bulkheads immediately adjacent to room seals (see Figure 35). As a result, the demand for LHHP concrete is relatively low on a week-to-week basis. However, the plant does need to operate year-round. The other mixes, such as shotcrete, grout or other concrete uses would also place a demand on plant operations. These demands are currently undefined. The LHHP concrete materials produced will be highly specialized, and the binders require extensive on-site testing prior to use. Thus it is unlikely that externally produced LHHP concrete would be acceptable for use at the DGR.

3.8.3 Clay-Based Sealing Material Requirements

Clay-based sealing material will be required for the buffer boxes as well as for preparing and filling the placement rooms. The material composition of each of these clay-based sealing materials is as follows:

- Highly Compacted Bentonite (HCB) – 100% bentonite
- Gap Fill – 100% bentonite
- Dense Backfill (DBF) blocks – 70% aggregate, 25% clay, 5% bentonite

On a weekly basis (and allowing for a 10% rejection rate), the following materials are expected to be produced:

- Buffer boxes: 140 HCB buffer blocks;
- Placement room: 212 spacer blocks; and
- Placement room: gap fill for smoothing the floor and infilling voids.

Figure 13 illustrates a cross-section view of the placement room for the crystalline DGR design concept and the arrangement of UFCs / buffer boxes, spacer blocks and gap fill. The spacer blocks in the placement room will be 1 m in height and 2.8 m in length. The spacer block thicknesses are 0.5 m and 0.7 m for the crystalline and sedimentary DGR design concepts, respectively.

Storage silos will inventory approximately two weeks of product.

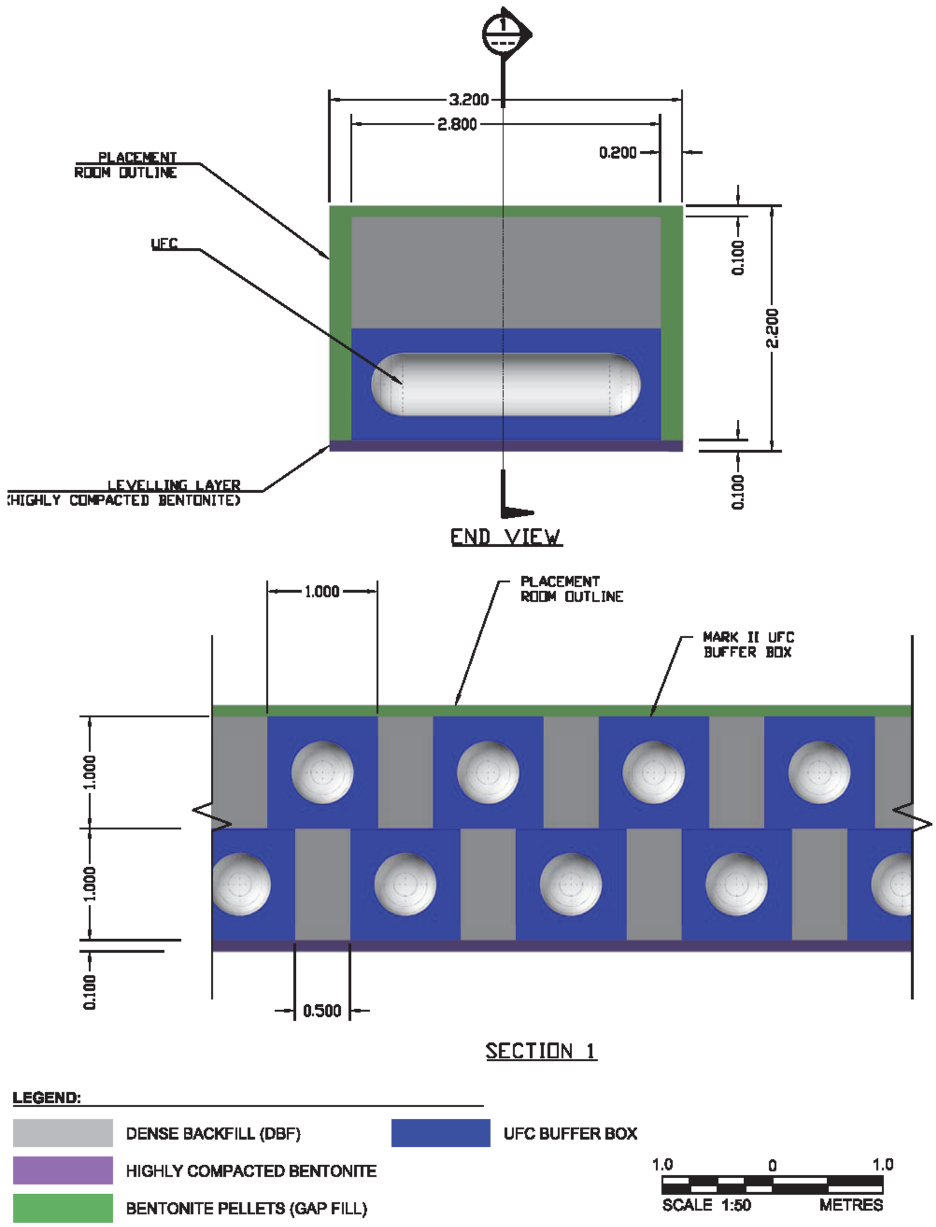


Figure 13: Sealing Material in Placement Room (Crystalline Geosphere)

3.8.4 Aggregate Supply

The minimal requirement for aggregate does not support the establishment of an on-site aggregate plant. Instead, it is assumed that this material (associated with the production of LHHP concrete and DBF products), will be purchased and delivered from an external source.

3.8.5 Concrete Batch Plant Description

The concrete batch plant (designed to primarily produce LHHP concrete) will be fed by a loader bringing aggregate from storage to a twin (coarse / fine) feed bin. The aggregate will be delivered to a batcher where it will be weighed and dispensed into a ready-mix truck. The cement T50, silica fume and silica flour will be delivered from an external resource via tanker trucks directly to the plant (Area B13 on Figure 2).

As illustrated on Figure 14 (see binder silos), cement T50 and silica fume will be stored in 75-tonne silos, with silica flour kept in a 150-tonne silo. These storage capacities are sufficient to supply LHHP concrete for two successive bulkhead pouring campaigns. The binders will be subsequently dispensed into a cement batcher, where they are weighed and discharged into a ready-mix truck (along with water and admixture). At the ready-mix truck, a homogeneous product is formed which is then delivered to the Service Shaft where it would be delivered underground via a slickline and then by underground ready-mix trucks to the pour location. The concrete plant will be enclosed where necessary to allow for year-round operation (to minimize winter weather impacts).

The plant will produce material constantly during the LHHP concrete bulkhead pours with a required capacity of between 9 m^3/hr and 18 m^3/hr. A small, commercially available plant will be employed for this application.

A crew that is dedicated to the concrete batch plant on a full-time basis would not be necessary because the plant would only be used periodically to produce concrete for the room bulkheads and panel access tunnel floors. Operations to produce concrete material will consist of a trained team (likely a supervisor, loader operator, ready mix truck drivers and batch plant operator) gathered from other parts of the DGR facility operations team.

Each year, six bulkhead pouring campaigns are anticipated. Each bulkhead pour will take about 110 m^3 of LHHP concrete. Two ready-mix trucks will provide sufficient surface delivery capacity. As binder and aggregate materials are confirmed to meet target specifications they will be used in the concrete batch plant. Slump and air content will be measured for each load prior to placement.

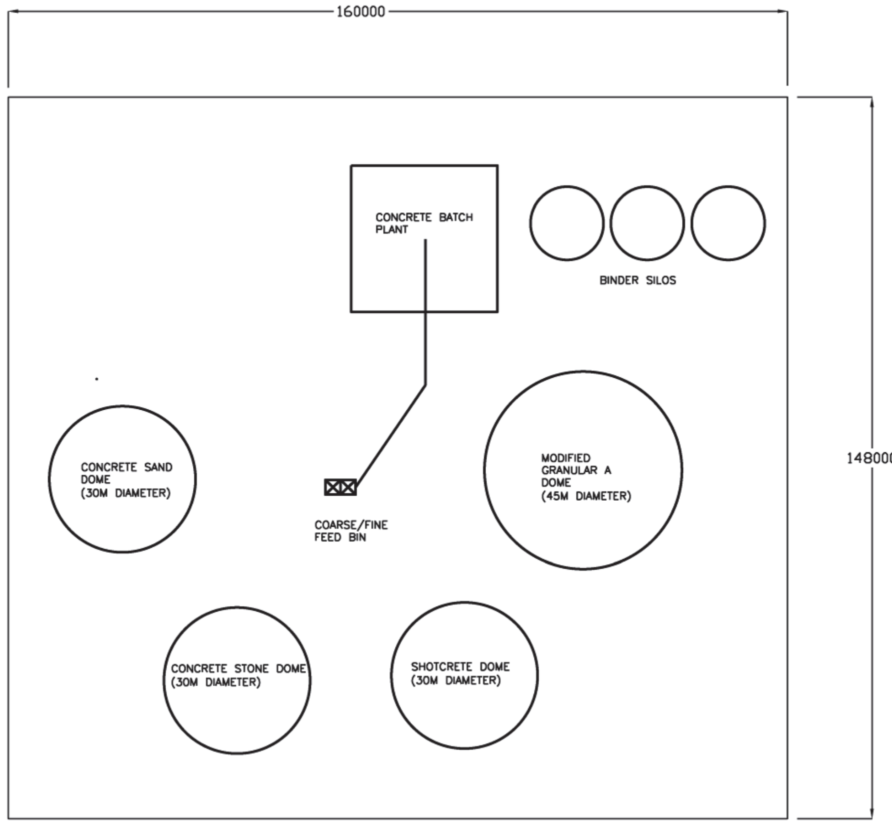


Figure 14: Aggregate Storage and Concrete Batch Plant Layout

3.8.6 SMC Plant Description

The SMC plant will produce spacer blocks, HCB blocks for the buffer box and for the room seals, and gap fill for filling void spaces between the buffer boxes and spacer blocks and the surrounding rock. The spacer block and gap fill components will be delivered from the SMC Plant to the Service Shaft inside the protected area via security gate for transfer underground. The HCB (buffer box) components will be directed to the UFPP. The plant and its associated storage bins are identified as Areas B6 and B3, respectively, in Figure 2. The conceptual layout in Figure 15 shows the SMC plant is divided into two primary sections:

- Raw materials storage, handling and mixing; and
- HCB block, spacer block, and gap fill material production.

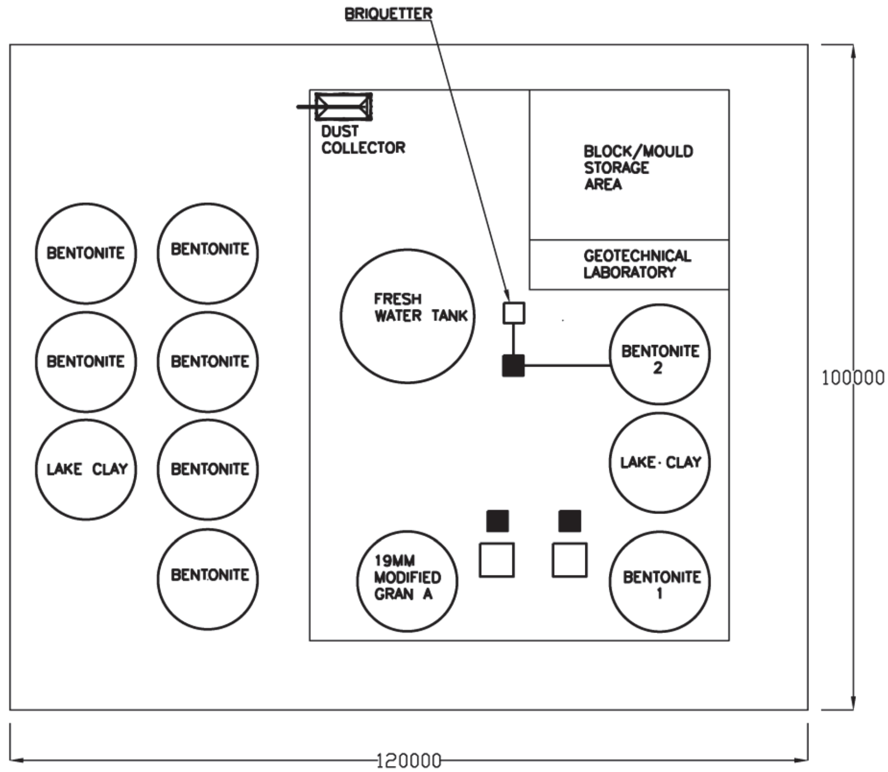


Figure 15: Sealing Material Compaction (SMC) Plant Layout

Bentonite and other clays will be delivered via tanker trucks to the plant. Ten exterior silos, each of a 150 tonne capacity, will be in place to dispense bentonite and clay using rotary valves, day bins and positive displacement blowers. Modified granular A, conveyed to a 150 tonne storage silo in the enclosed plant, will be dispensed with the bentonite and clay into weigh hoppers and then to a batch mixer. Water is subsequently added to the mixer to produce a homogenous material after blending. The bentonite and other clay storage silos will accommodate the equivalent of approximately two weeks of material consumption.

Blended gap fill will be discharged from the batch mixers to a briquetting circuit operating under negative pressure to reduce the infiltration of dust to the surroundings. The material would be loaded into tanks on rubber-tired trolleys for transportation to the underground repository or storage.

The presses that will produce the buffer and spacer block materials will be specialized items designed to suit this purpose. They will be hydraulically driven units with custom fabricated moulds. Their power requirements will be significant. A depiction of the type of press envisioned for the production of these clay-based blocks is shown in Figure 16.

Figure 16: Example of Closed-Die Compaction Press

Figure 17 shows an example of a small portable press that produces blocks through uniaxial, two-sided compression. This device has been demonstrated as being capable of producing small blocks of highly compacted bentonite or backfill type materials at a very high rate.

Figure 17: Portable uniaxial brick maker and trimmed HCB brick

Based on initial estimates about 110 to 160 hours of compaction machine time will be required to produce HCB segments to fulfil 1 week demand. Additionally, spacer blocks would require an estimated 35 to 50 hours of pressing time per week, depending on the size of block ultimately produced. The target dry density for the HCB blocks is 1.6 g/cm^3, for the DBF blocks it is slightly higher at 2.1 g/cm^3.

Specially designed equipment will be used to lift the HCB and DBF products out of the moulds. One example of such an approach is the vacuum suction system illustrated on Figure 18, which is normally attached to an overhead crane. This technique is a non-intrusive yet proven method to safely and effectively handle these types of compacted materials. The SMC plant may be outfitted with a similar system where the molded components are to be brought to cars and subsequently transported to storage, the Service Shaft (for delivery underground), or to the UFPP (for the buffer box assemblies).

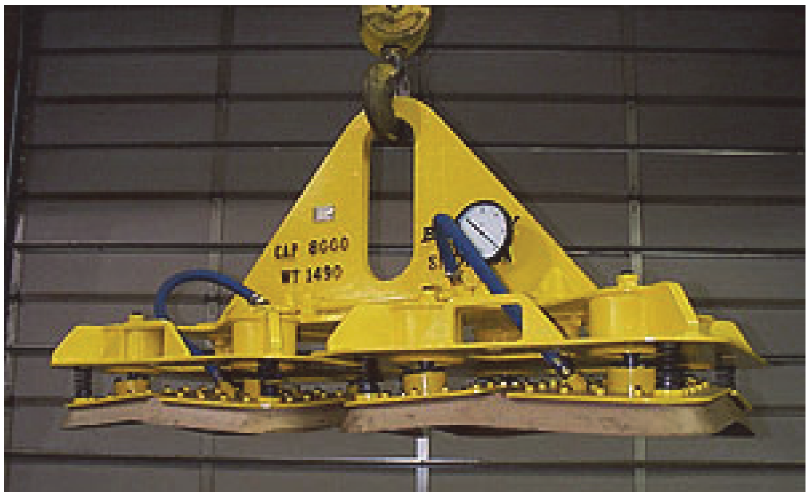


Figure 18: Vacuum Lifting Device

A second viable option for handling densely compacted block materials (demonstrated on smaller size blocks than the current reference geometry) may be through the use of robotic lifting arms (Figure 19).

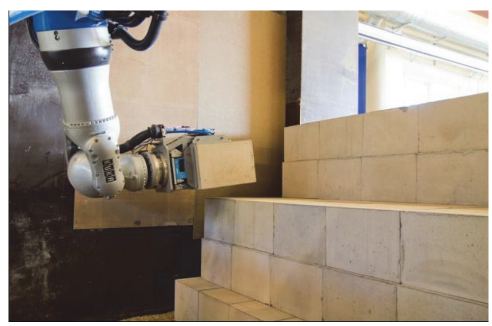


Figure 19: Robotic Lifting Arm

The SMC plant will be a highly automated facility, operated by a small number of skilled workers on the plant floor. Such workers are likely to include a plant supervisor and foreman, control room and floor operators, and a geotechnical quality control technician.

The SMC plant and its compacted or pelletized materials' storage areas will be enclosed to maintain climate and humidity control (to minimize moisture absorption and ensure the integrity of the finished products). The exterior silos or storage domes will also have heated concrete floors (as required) to protect stockpiles from freezing. The enclosed structures will further help to prevent wind erosion effects that can cause fugitive dust emissions. A multi-chamber dust collection baghouse will be in place to collect any dust generated by the sealing materials operations.

A quality control laboratory and geotechnical technicians will be housed in the SMC plant. The laboratory will be responsible for materials testing of the imported aggregate and clay materials, as well as for testing of the products from the concrete batch plant and SMC plant.

3.9 GARAGE / WAREHOUSE / HAZARDOUS MATERIALS STORAGE

Areas B5 & B7

The garage / warehouse / hazardous materials storage areas will be housed in a one-storey building and it will include maintenance shops, repair bays and a space allocated for hazardous materials storage.

The building will be a single structure with partition walls between the distinct areas, and a limited-access area for hazardous materials storage. The garage area and one portion of the storage warehouse will be heated while another section of the warehouse will be unheated. While separate entrances will be provided for the garage and warehouse areas, a wide opening sliding double-door will be provided for off-loading supplies in the main warehouse through the garage. Firefighting equipment will be available in all rooms. Additional details are as follows:

- Maintenance and repair bays – the garage area will have three vehicle maintenance bays as well as benches and extra space for machining, welding, etc. While major vehicle and equipment repairs will generally not be handled at the DGR (instead being carried out at designated and proximate authorized facilities), the maintenance and repair bays will be available to deal with emergency and routine requirements.

  The maintenance and repair area will be equipped with all of the tools and small machinery needed including hydraulic jacks, ramps and lifts as well as an overhead crane. An air compressor will be supplied for pneumatic tools and equipment and stored lubricants will be available for routine maintenance;

- Truck wash bay – a single bay will be provided for washing buses, trucks and other equipment. Discharged water will collect in a holding pond where suspended particles will settle out. A separator in the pond area will collect oils for containment and removal before the wastewater is re-used or discharged to the environment. The collected water will be topped up with fresh water as required; and

- Warehouse – a warehouse area, with forklifts, will be provided for the bulk storage of all equipment, parts and items required for the areas of the DGR facility without their own storage. This warehouse will also be used as a staging area for distribution to other buildings. Warehouse space will be split as further described below:

  - An unheated area for storing bulky items (not associated with used nuclear fuel waste) at the far end of the building;
  - A heated storage area for mechanical and electrical equipment, spare parts, workshop items, benches, jacks and toolkits;
  - A heated area for construction related items including cement, geotextile membranes, pipes, couplings, etc.; and

- A separate and limited-access (fenced-off) heated area for hazardous materials storage including any reagents for water or wastewater treatment, laboratories, etc.

3.10 WATER STORAGE, TREATMENT AND DISTRIBUTION

Areas B10, B11 & B12

Raw water for the DGR facility will be sourced from a local river or water body. The required water supply rate for the surface facilities is expected to be approximately 97–134 m^3/day which would be sufficient to meet the demands as listed in Table 8.

Table 8: Surface Facilities Average Water Demand

Area	Facility	Process / Consumer	Daily Demand
P1	Used Fuel Packing Plant	Module Decontamination Active Cell Wash Down Cask Decontamination Building Utilities	22.8 – 39.9 m^3
P5	Auxiliary Building	Laundry and Change Rooms Building Utilities Cafeteria	27.2 – 29.2 m^3
P7	Waste Management Area	Cleaning of Package Exteriors	0.1 m^3
P14	Quality Control Offices and Laboratory	Cleaning and Samples Building Utilities	1.2 – 1.6 m^3
B2	Administration Building	Building Utilities Cafeteria	13 – 22 m^3
B5	Garage	Building Utilities Truck Wash Bay	1.0 – 3.4 m^3
B6	Sealing Materials Compaction Plant	Bentonite Compaction Building Utilities	15.5 – 18.2 m^3
B13	Concrete Batch Plant	Concrete Production Building Utilities Truck Wash Bay	1.3 – 4.3 m^3
N/A	Site-Wide	Dust Control (Spray Truck)	15 m^3
		Estimated Total	**97 – 134 m^3/day**

The sourced raw water will be held in the water storage tanks (Area B10). These tanks will be located adjacent to the water treatment plant and pump house building (Areas B11 and B12, respectively). The pump house area will accommodate the potable, fresh and firewater distribution pumps in a single storey engineered structure.

Measures will be in-place to provide a total fire water demand of about 1,360 m^3 with 100% redundancy based on the duration of 2 hours at 340 m^3/h as stipulated by NBC 2010 and CSA N393-2013. This volume will be stored at the site in a shared fresh/fire water tank. The fire water volume will be kept separate from the raw water by using different draw off points from the tank. Fire water pumps will be packaged as a set containing a diesel, electric and jockey pump.

The water will be distributed through pressure pipes (a dedicated fire main) feeding fire hydrants situated at visible and accessible locations within the vicinity of buildings and other facilities exposed to fire hazards conforming to applicable requirements of CAN/ULC-S520-07, "Standard for Fire Hydrants", as well as those contained in AWWA C502, NFPA 24 and other applicable provincial fire standards and specifications. The Fire Hydrants will generally be located at 60 m spacing to meet the minimum Fire Hydrant spacing requirement as listed in the NBCC.

Potable water will be produced on site at the water treatment plant using the fresh / fire water tank as a supply source. The water treatment plant will be capable of full treatment to provincial safe drinking water standards and a 24 hr supply of treated water will be stored in a potable water storage tank. The treatment plant will be complete with a filtration and sterilization system, filter backwashing equipment with air blowers, backwash pumps and inter-connecting pipework. The final water quality will be monitored for chlorine residual and turbidity.

A dedicated supply system will distribute potable water to all buildings. The system will be capable of providing a peak flow rate of four times the average daily flow rate. Two duty potable water distribution pumps and one standby pump will be installed. A central operations room in the pump house will permit remote control of these pumps.

3.11 SEWAGE TREATMENT PLANT

Area B19

Sewage collected from all serviced buildings will be piped to an on-site sewage treatment plant for treatment to provincial standards prior to discharge to a local water body. The plant (Area B19 on Figure 2) will be sized to handle 100% of the produced potable water plus a peaking factor of four for the shift changes. Sewage waste from below-ground operations will also be treated in this plant.

A packaged sewage treatment unit such as rotating biological contactor (RBC) or similar system will likely be utilized to handle the liquid waste. The RBC technology employs a fixed growth media process whereby bacteria are grown on a media surface that is rotated into and out of the wastewater. The RBC rotor is enclosed in a steel tank and the system also includes a primary clarifier, final clarifier, ultra-violet disinfection system, controls, switchgear and piping.

Such a modular sewage treatment system can accommodate variations in flow and is fully enclosed, eliminating any tanks and unsightly ponds. Organic loading fluctuations are dealt with easily without affecting the treatment process or effluent quality. Sludge accumulated in the plant would periodically be pumped to a mobile sludge tank and taken off-site for further treatment.

Treated effluent from the plant will be monitored for compliance before being discharged to a natural watercourse or for other uses (e.g., dust control). Laboratory tests will be conducted regularly to ensure that the effluent quality is maintained at the design levels.

3.12 PROCESS WATER AND STORMWATER CONTROL

Areas P10, P17, B15, B26A & B26B

Five ponds will be established on the DGR site, to manage either process water or stormwater run-off. All of the ponds will be lined, as required, over their base and embankments for protection and to prevent water infiltration back into the ground. Collected flows will, in all cases, be quality monitored and potentially treated before being directed to any downstream uses (e.g. landscape irrigation) or discharged off the site. With regards to the latter, water quality will be analyzed for compliance with the applicable limits as set out in permit for the pond before the pond water is released to a natural watercourse.

The ponds will be designed to settle out suspended particles with any collected mud and silt deposits cleaned out on a periodic basis to maintain design retention volumes and times. The ponds may be used for the temporary storage of snow and ice removed from the access roads and parking areas during winter months.

Storm Water Management Pond (Area P10)

A perimeter ditch around the Protected Area will direct falling precipitation to this stormwater management pond. The runoff collection ditches, conveyance pipes and culverts as well as the storage pond will be designed for the 1-in-500 year storm event with the pond discharge weir normally closed. The pond dimensions will be about 60 m by 90 m and it will have a depth of approximately 5 m.

Mine Dewatering Settling Pond (Area P17)

Mine water pumped from the underground dewatering sumps will be piped to a dewatering settling pond. An estimated 550 m^3/day of groundwater has been assumed to be pumped from the sumps and discharged to the settling pond. The pond will be designed to have a retention period of 5 days. An allowed freeboard and adjustable weirs on the outlet side of the pond will control the discharge rate and retain floating material such as oil residue collected in the underground sumps.

This pond water may contain sediment, nitrogen compounds (arising from blasting residue of excavated rock), high salinity (due to saline ground water inflow into underground repository) and possibly uranium (crystalline rock only; when exposed to oxygen, the uranium in the granite becomes soluble). If concentration of these potential contaminants is above acceptable levels, then it may be necessary to treat the pond water before discharge into a receiving water body.

Process Water Settling Pond (Area B15)

Process water high in suspended solids will be directed to this pond which will be designed for a 7-day retention time. Pond dimensions are expected to be about 45 m by 40 m and it will have a depth of approximately 4 m.

Storm Water Management Ponds (Area B26A & B26B)

Two detention ponds located at opposite ends of the DGR site will receive stormwater run-off collected from the Balance of Site. Similar to the stormwater pond in the Protected Area (Area P10), the ponds will be sized for the 1-in-500 year storm event. The water will be routed to the ponds through a system of conveyance pipes, ditches and culverts, also designed for the storm event. The ponds will have a bypass arrangement to directly discharge into the local watercourse if the storm event is continuous, to prevent damage to pond embankments.

One pond will measure about 120 m by 50 m and the other pond will be about 90 m by 60 m. Both ponds will have approximately 5 m depth.

3.13 ROADS, PARKING AREAS, BUS SHELTERS AND COVERED PEDESTRIAN ROUTES

Areas B27, P15, B22, & P16

Access Roads

There will be a paved two-lane access road to the DGR site from the existing local highway. In addition, the site facility itself will require a total of about 5 km of road network within the Protected Area and the Balance of Site as well as an approximate 2 km access road to the Ventilation Shaft complex. Private vehicle traffic allowed into the controlled zones will be kept to a minimum with most DGR employees using the main / primary parking lot.

The main access road from the highway will be constructed with a compacted base course and asphaltic surfacing and be provided with shoulders and ditching on both sides. The main access road from the highway will be designed for frequent transfer of heavy loads. The roads and parking pads within the facility will be paved and will be complete with drainage ditches but without any shoulders. Collected on-site runoff from these roads and parking lots will be directed to the aforementioned stormwater management ponds.

Parking (Areas B27 & P15)

Parking will be available in several locations at the DGR site with the primary parking lot (Area B27) situated adjacent to the Administration Building. This lot will be of sufficient size to accommodate cars, buses and trucks requiring parking services at the DGR facility. Unobstructed parking will further be ensured for all fire and security vehicles. An additional parking area (Area P15) will be provided in the Protected Area near the Auxiliary Building and the quality control offices and laboratory for deliveries as well as fire and security vehicles.

Bus Shelters (Areas B22)

Bus shelters (Areas B22-A & B22-B) will be located in the main parking area adjacent to the Administration Building as well as in the vicinity of the water treatment plant and air compressor building (Areas B11 and B8, respectively). All shelters will be complete with sliding doors, benches and heat to keep the occupants warm during winter.

The bus shelters in the main parking area are expected to be used by staff commuting to the DGR site.

Covered Corridor / Pedestrian Routes (Area P16)

Covered corridors or pedestrian routes will be established to facilitate personnel movement between the Administration Building, Auxiliary Building, UFPP and the Service Shaft complex. The covered corridors will allow easy access and movement between buildings during winter and other harsh weather conditions.

Corridors will be located so as to allow vehicle traffic to circulate the facility in an efficient manner. Adequate space will be provided for pedestrians to share the passageways with handcarts. The corridors will be climate controlled (insulated and heated). Windows and doors will be installed as required for safety, and fire protection measures will be in place along the corridor lengths.

3.14 OTHER SURFACE FACILITIES
Areas B8, B9, B18, B21 & B23

Air Compressor Building (Area B8)

Air compressors are required for pressurizing and supplying service and breathing air for the surface facilities and underground repository. Service air to be supplied at a rate of 1 m^3/s will be delivered using 3 rotary screw compressors (one standby) each with a capacity of 0.5 m^3/s. Breathing air, required only for underground emergency situations, would be delivered at a rate of 0.15 m^3/s by the same compressors that supply service air.

Fuel Storage Tanks (Area B9)

A fuel storage facility will have a 100,000-litre diesel fuel tank and 25,000-litre gasoline fuel tank where both tanks will hold a two week supply of fuel for DGR site vehicles and equipment including the emergency generators. Fuel will be stored in accordance with applicable requirements listed in the NFPA 30, Flammable and Combustible Liquid Code. The tanks will be located within a concrete-lined containment area with sufficient capacity to hold the volume of the largest tank plus 10%.

Diesel fuel storage capacity is based on an average diesel consumption of 300 litres/day per piece of equipment for 20 units, this does not include the UFTP transportation which will be factored in later. The back-up generators will require about 1,000 litres/day. Gasoline storage capacity is based on average gasoline consumption of 50 litres/day per vehicle. Tanker fuel pumps or dedicated loading pumps will be used to fill the storage tanks and fuel will be dispensed through a metered fuel dispensing station. Card readers will be in place at the dispensing station.

Storage Yard (Area B18)

The storage yard will be an open area reserved for the laydown and temporary storage of new and decommissioned equipment and materials. It will have a granular surface and be fenced with lockable access gates.

Helicopter Pad (Area B21)

An area adjacent to the main parking lot will be dedicated for a helicopter landing pad. The helipad's clear area will be 30 m in diameter and will be capable of receiving a single helicopter while also allowing for parking on the pad. The landing pad will be designed with proper navigational aids and lighting requirements.

Weigh Scale (Area B23)

A weigh scale will be provided to properly monitor the receipt of bulk materials to the DGR facility as well as the shipping of excavated rock off-site. The scale will be sized to accommodate a fully loaded tractor and a double trailer for an overall length of 25 m. The scale will be supported by fully automatic controls, signal lights for traffic management and a motion detection system.

3.15 EXTERNAL FACILITIES AND OPERATIONS

This section describes the off-site facilities (i.e. those outside the security boundaries of the DGR facility) that will be established to support the DGR facility development and operations. Such facilities include an area for management of excavated rock, accommodation for construction personnel and a Centre of Expertise. A pumphouse will also be situated off-site for supply raw water to the DGR facility.

3.15.1 Waste Rock Management Area
Area B1

It is expected that most of the excavated rock will not be suitable or required for concreting, road works or backfill, and the unused excavated rock will need to be properly managed. Excavated rock will not be used for production of LHHP concrete and various sealing materials (see Section 3.8.4). The primary area for management of the unused excavated rock will be located off-site. It is assumed that this facility is located within a 25 km distance of the DGR site and occupies an area equal to about 18 Ha. It will be fenced but without full-time staff.

The area will initially be prepared using dumped crusher wastes to directly fill any low-lying depressions. Additional excavated rock will then be placed in layers on the prepared ground surface. Access routes and paths will be prepared for loaders, dumpers and trucks to move around and up the piles easily.

The area will include a storm water runoff pond (Area B20) to collect and monitor the effluent before being released to the environment. The potential contaminants of concern in the run-off from the rock pile will likely be various chemical constituents due to the dissolving of minerals in the excavated rock into the water and release of nitrogen compounds from residual explosives on the excavated rock.

3.15.2 Accommodation for Construction Personnel

During the initial construction period, accommodation will be required for the construction personnel. These workers could be housed in the community and surrounding area, or there could be a need to develop a nearby temporary infrastructure to provide sleeping quarters, kitchen, dining, laundry, medical and recreational facilities. NWMO will work with the community and surrounding area to plan for and contribute to the development of community infrastructure required during construction and operation to house and integrate personnel into the area. It is assumed that accommodation is required for about 600 construction personnel which is about half of the peak construction workforce.

A typical temporary facility to provide construction accommodation will be developed in collaboration with the community. Typically they will be two storey buildings with units whose internal layout will vary depending on the intended occupancy. Some units will feature rooms with larger sleeping quarters and private bathrooms and be intended for management and supervisory personnel. Other units will comprise rooms with one or two beds and shared toilet facilities. Common areas will also be provided.

In addition to the residential structures, required support facilities and systems will include the following:

- Security fencing including access gates around the facility as well as area and security lighting;
- Access roads and parking;
- Power generation and distribution systems (electrical power will initially be supplied by generators) and fuel supply;
- Water, stormwater, sanitary sewage and solid waste facilities as well as a telecommunications system;
- Fire detection and protection systems;
- Kitchen, dining, laundry and recreation facilities; and
- Medical centre (e.g., nursing station).

3.15.3 Community Infrastructure

It is currently assumed that the DGR site, while relatively remote, will be within 30 km of a small existing community of approximately 1,000 people. Also, while some basic infrastructure will be available, it may not be sufficient to support the new influx of about 3,000 people anticipated to be either directly or indirectly associated with the development and operation of the DGR. An improvement and expansion in services and infrastructure may be needed, and new infrastructure may be required, subject to discussions between the NWMO and the community.

No specific assumptions have been taken at this time regarding the influx of entrepreneurs who will move into the area as the population increases. As any infrastructure development could create private sector opportunities, the strengthened municipal tax base will, in turn, encourage additional self-sustaining growth for the community as a whole.

3.15.4 Centre of Expertise

A Centre of Expertise will be established in the community selected for detailed site evaluation. The centre will be located in or near the community, as determined with people who live in the area. Its purpose will be to support the multi-year testing and assessment of the site on technical safety and community well-being related dimensions, which are key components of the site selection process. The Centre of Expertise will be home for an active technical and social research and technology demonstration program during this period, involving scientists and other experts in a wide variety of disciplines, including geoscience, engineering, and environmental, socioeconomic and cultural impact assessment.

An engineering test facility will be re-located to the Centre of Expertise. Activities in the engineering test facility will include container laser welding and copper coating development, bentonite buffer shaping and forming development, as well as the development of container placement equipment for the underground repository. The engineering test facility will also house production demonstration equipment to show the complete repository packaging and container placement process.

The Centre of Expertise will be expanded to support construction and operation of the deep geological repository. The centre will become a hub for knowledge sharing across Canada and internationally.

Design details of the Centre of Expertise will be developed with the interested community, potentially affected First Nation and Métis communities and surrounding municipalities with their preferences in mind.

Figure 20: Examples of Centre of Expertise

4. SHAFTS AND HOISTS

This section addresses the surface to underground conveyance structures (shaft complexes, head frames and hoisting plants) required to support the construction and operation of the DGR. Three shafts are to be established: Main Shaft, Service Shaft and Ventilation Shaft which are identified as Areas P2, P4 and P21, respectively, on Figure 2. Each shaft serves one or several functions such as UFC / buffer box transfer, excavated rock hoisting, personnel movement, materials handling and ventilation.

The location of the shafts relative to one another are fixed by the layout of the underground works, as discussed in Section 5.3.

4.1 HOISTING SYSTEM DESIGN

The shafts will be serviced by a total of five hoists, with three in the Service Shaft, and one each in the Main Shaft and Ventilation Shaft. The Main Shaft Cage, Service Shaft Cage and development skips (large hoists) will be friction hoists. The remaining two hoists will be Blair type hoists of much smaller size and lower utilization. The following sections describe the various hoisting systems to be used at the DGR facility.

4.1.1 Main Shaft Hoist

The Main Shaft will serve as the exclusive conveyance structure for the surface-to-underground transfer of the Buffer Boxes (with UFCs) for placement in the underground repository. Additionally, and when there is a need, the Main Shaft will also accommodate the transfer of any retrieved UFCs from the repository level to the surface.

The Buffer Box weight and dimensions are described in Appendix A. The intended mode of buffer box transfer to the underground repository is via trolley as outlined in Section 6.1. Each Buffer Box with a UFC will be loaded into a transfer cask and then placed onto a trolley. The loaded trolley is expected to have a mass of about 57 tonnes.

The Main Shaft will use a friction hoist. Such a hoisting plant will have a nominal 100-year life, assuming the adoption of appropriate preventative maintenance practices and component upgrade schedules. The Main Shaft's hoist friction hoist system, comprising one main cage with a counterweight in balance, would be configured as noted in Table 9.

Table 9: Main Shaft Hoist System

Item	UFC Hoist
Configuration	Koepe Friction Hoist
Weights / Payloads	
➢ Tare with Attachments	50,000 kg
➢ Payload	56,600 kg
➢ Counterweight	82,000 kg
Suspended Load	280,000 kg
Hoist Speed	2.5 m/s
Required Motor	1,000 kW

4.1.2 Service Shaft Hoists

The Service Shaft is a multi-purpose hoisting facility for the underground repository, and incorporates the only excavated rock handling installation for the DGR. The Service Shaft will be set up with five compartments to accommodate two counterbalanced skips, a main service cage and counterweight, and an auxiliary cage for off-shift or secondary egress hoisting. The details of the Service Shaft hoist systems are presented in Table 10.

Excavated Rock Hoist

The excavated rock or skipping hoist will handle the excavated rock generated by the development of the underground repository both during initial construction and during operations phase. It will comprise two bottom dump skips in a balanced layout. Excavated rock or muck will be directed to a grizzly-protected raise that feeds a loading pocket. The loading pocket will consist of two bins or flasks that are weigh-to-meter controlled, that will fill the skips when they are in position.

Service Hoist

The service hoist (one cage with a counterweight in balance) will accommodate personnel and consumables, and will be used to move equipment in and out of the underground repository. It will also be used to move sealing material components such as pre-compacted bentonite blocks from the surface to the repository. It will be able to carry up to 50 personnel or handle loads up to 10 tonnes.

The Service Shaft, as a waste rock handling shaft, will require additional maintenance relative to the other two shafts. Because there is a possibility that loose rock will fall down the shaft, the muck handling compartments will be separated over the full height of the shaft by brattice panels. Brattice panels are frames with cladding on the inside which act as a physical barrier between compartments and will prevent loose rocks from falling into the other hoisting compartments.

Auxiliary Hoist

The auxiliary hoist will be available in the Service Shaft to move personnel on an as-needed basis using an auxiliary cage. In the event that main electrical power supply is lost, electrical power will be supplied by emergency power generators (see Section 3.5.3).

Table 10: Service Shaft Hoist Systems

Item	Hoist for Excavated Rock	Service Hoist	Auxiliary Hoist
Configuration	Koepe Friction Hoist	Koepe Friction Hoist	Blair Multi-rope Hoist
Weights/Payloads			
➢ Tare with Attachments	10,000 kg	10,000 kg	2,300 kg
➢ Payload	6,500 kg	10,000 kg	1,800 kg
➢ Counterweight		15,000 kg	
Suspended Load	40,000 kg	50,000 kg	7,000 kg
Hoist Speed	5 m/s	2.5 m/s	2.5 m/s
Required Motor	300 kW	300 kW	75 kW

4.1.3 Ventilation Shaft Hoist

The Ventilation Shaft will serve as a secondary means of egress from the underground repository. This is provided via a Blair type auxiliary hoist and cage. Like the Service Shaft auxiliary hoist, in the event that main electrical power supply is lost, electrical power will be supplied to the auxiliary hoist by emergency power generators (see Section 3.5.3). The details of the Ventilation Shaft's hoist system are as shown in Table 11.

Table 11: Ventilation Shaft Hoist System

Item	Auxiliary Hoist
Configuration	Blair Multi-rope Hoist
Weights/Payloads	
➢ Tare with Attachments	2,300 kg
➢ Payload	1,800 kg
Suspended Load	7,000 kg
Hoist Speed	2.5 m/s
Required Motor	75 kW

4.2 SHAFT DESIGN

The primary design elements, including shaft diameter, associated with the Main Shaft and Service Shaft were dictated by hoisting requirements for personnel, materials and equipment, emergency egress considerations and services entry needs (see Section 5.5). The Ventilation Shaft diameter was set by ventilation requirements and, in particular, a requirement to maintain the up-cast air velocity in the shaft outside the range of 7 to 13 m/s to avoid suspension of water droplets. With the current underground ventilation system design and estimated volumetric airflow rate in the Ventilation Shaft (see Section 5.8) and also considering practical size for shaft sinking, the diameter was set at 5.6 m. The inside shaft diameters are as follows:

- Main Shaft must have a diameter of at least 7 m;
- Service Shaft must have a diameter of at least 6.5 m; and
- Ventilation Shaft must have a diameter equal to 5.6 m.

Using these shaft diameter requirements, conceptual layouts were undertaken for each of the shafts. For the following discussions, reference should be made to Figure 22, Figure 23 and Figure 24 (all located at the end of Section 4.4) for the Main Shaft, Service Shaft and Ventilation Shaft, respectively.

Headframes for the three shafts will be of slip-formed concrete construction for a durable and easily maintainable structure, one that will provide a high level of protection against meteorological impacts. Further, all shafts will be concrete lined.

4.2.1 Main Shaft

The Main Shaft (Figure 22) will have a finished internal diameter of 7 m and have two compartments; one supporting the large cage used to transfer the UFCs and one for the counterweight. As the hoisting plant will operate at only 2.5 m/s, alignment integrity and guide wear will not be an issue with respect to ongoing maintenance needs. Redundant shaft services installed in the Main Shaft (i.e. duplicating those found in the Service Shaft) will include service water piping, power and communications cables.

The Main Shaft's headframe will support the final hoisting plant. The plant will include the head frame and collar house, which will house the loading facility for the UFCs onto the cage. The head frame will have various floors, including one floor for the Koepe hoist, a deflection sheave floor, the collar floor and a sub-collar floor, in descending order.

4.2.2 Service Shaft

The Service Shaft's final finished internal diameter, as determined by its multiple hoisting requirements, is 6.5 m. All conveyances will run on steel guides. The Service Shaft is illustrated in Figure 23.

Installed utilities will include service water piping, power and communications cables. Piping will be required for the transmission of compressed air and water (both water supply underground and dewatering quantities removed to surface), as well as for concrete slicklines to support the development / construction of underground installations.

The Service Shaft plant will include the head frame, collar house and a bin house for handling development muck brought to surface. The head frame will have 7 floors, consisting of 3 hoist floors, one power floor, one dump floor, the collar floor and a sub-collar floor, in descending order.

In the shaft, loose rocks from mucking operations will be prevented from falling into the other hoisting compartments using installed panels. At the bottom of the Service Shaft, the loading pocket will have some spillage. A ramp will be developed to the shaft bottom so that equipment can travel to the shaft bottom on a regular basis to remove broken rock.

4.2.3 Ventilation Shaft

The 5.6 m diameter Ventilation Shaft (Figure 24) is the simplest of the three shaft installations, with a tower that has a single operating floor to support the hoist, plus the collar floor and sub-collar. The collar house will be able to support mine rescue or evacuation efforts and the main exhaust fans will be located adjacent to the headframe.

The Ventilation Shaft complex is situated about 1.6 or 1.7 km (crystalline or sedimentary geospheres, respectively) from the DGR's outer perimeter fence. This shaft location serves as a convenient emergency egress location for persons working at the farthest reaches of the underground repository.

4.3 SHAFT SINKING REQUIREMENTS

The three shafts will be developed using a conventional controlled drill and blast sinking approach. It is envisaged that the three shafts would be sunk utilizing temporary head frames in lieu of using the final headframes. This will reduce wear and tear on the final headframe structures and associated equipment.

The design of the shaft liner and grouting system (if grouting is required), will be completed after the location of the shaft (and site) is established. The shaft liner typically serves two purposes; first it is a measure of ground support, preventing minor ground shifts or loose rock from falling into the shaft, and second it may act as a mean to prevent seepage of water in the shaft. As discussed in Section 5.1, it is expected that the host geosphere for the underground repository will consist of a very good quality rock mass, one that is only moderately to sparsely fractured and with a low permeability. However, it is possible that the near surface rock will have permeable features where water could flow into the shaft excavation. These zones of higher inflow rates will be addressed through grouting and the liner design.

The shaft sinking process itself involves several steps, which include;

- Collaring or starting the shaft;
- Setting up the equipment needed to sink the shaft;
- Sinking the shaft to its full depth; and
- Dismantling the equipment used for sinking.

4.3.1 Shaft Collaring

Collaring the shaft requires the establishment of the shaft centerline via survey, and usually requires the drilling of a borehole to confirm rock type and quality. The borehole will be drilled within the finished diameter of the planned shaft.

Once the location is confirmed, the shaft excavation will commence. This involves the use of controlled dill & blast techniques to establish the rough diameter of the shaft to an approximate 30 m depth. Removal of excavated rock or muck is accomplished using a crane equipped with a bucket, with a small excavator being lowered into the excavation to load the bucket. Once the desired depth is achieved, a set of forms are installed close to the bottom, and the permanent concrete liner for the collar is poured into place.

If the shaft is first excavated through overburden, then a similar process takes place, with the excavation through ground being carried out with a small excavator that is captive in the hole until bedrock is reached. During excavations, temporary support of the walls is provided using liner plates and ring beams, which are bolted into place. Once bedrock is reached, a drill is lowered into the hole and a 5 m cut is sunk into the excavation's bottom to act as a water-proof socket for the shaft liner, preventing influx at the rock / overburden interface. With the cut completed, a set of shaft forms are lowered into the hole, and the concrete collar is poured from the bottom up.

4.3.2 Sinking Plant Set-up

Once the collar is established, the equipping of the sinking plant can commence. The sinking plant has four main elements as listed below:

- Sinking hoist;
- Sinking winches;
- Sinking headframe; and
- Galloway (or sinking stage, see Figure 21).

The sinking hoist will be a double drum hoist, equipped with two sinking buckets to both move personnel and material into the shaft excavation, and to remove excavated rock from it as it is excavated. The sinking winches (2 to 4 required) are smaller low speed hoists used to raise and lower the Galloway as required during the sinking cycle.

The sinking headframe will be a steel structure that supports the hoist and winches as well as a set of chutes for dumping the excavated shaft muck into a bunker for removal via payloader. The headframe will be approximately 40 m high to accommodate travel room for the hoisting plants, and to allow for the lowering of items like drill jumbos and mobile equipment into the shaft. A temporary enclosure attached to the headframe, called a collar house, will be in place to shelter workers from the elements and to temporarily house material and equipment.

The shaft sinking stage or Galloway is a multi-decked structure that is supported by the sinking winches in the shaft (Figure 21). The stage is not attached to or supported by the shaft walls, it hangs independently. It is an integrated development and excavation system, wherein all aspects of the shaft development effort are completed from the one structure including drilling, mucking, ground control and liner installation. It contains all working needs, including small tools, shaft sinking drills or jumbos, and shaft liner forms.

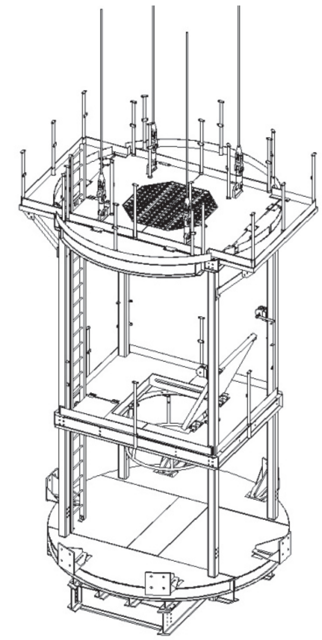


Figure 21: Typical Galloway

Each deck within the Galloway has a different function, and each Galloway is unique to the shaft under construction. As the shafts in this case are close to the same diameter, utilizing the same Galloway design may be possible.

4.3.3 Shaft Sinking Operations

The basic process of sinking a shaft is methodical and repetitive, as follows:

- The face (or exposed bottom) of the excavation is cleaned and prepared for drilling;
- The shaft jumbo is lowered to the face and the round is drilled;
- The jumbo is lifted clear and the holes are loaded with explosives;
- The workers are brought to surface, the Galloway is lifted clear to a safe distance and the round is blasted;
- The shaft is ventilated to clear blast gases prior to workers being allowed to re-enter;
- Workers begin excavating the bottom of the shaft and installing ground control (i.e. rockbolts, screen) in the shaft walls. Geological inspections may also be undertaken across the shaft walls and face during this time;
- The shaft liner is formed and poured, extending it down closer to the face; and
- Once the face is cleared of excavated rock, the cycle continues.

An average rate of advance for the shafts is between 2.5 m and 3.5 m per day.

4.3.4 Dismantling the Sinking Gear

Once the shaft bottom is reached, the entire sinking system will be dismantled to allow for production equipping. This requires that the shaft sinking stage or Galloway be taken apart and hauled to surface. The shaft sinking buckets are then removed, the various ropes used are re-wound and taken off of the headframe and then lastly the headframe is removed from the collar. At that point, the permanent headframe can be constructed in its place.

4.4 SHAFT OPERATIONS AND MAINTENANCE

The three shafts have been designed to promote uniformity wherever possible, so that repeat maintenance events will be as similar as practical in terms of the sequence of events, equipment required, and manpower needs.

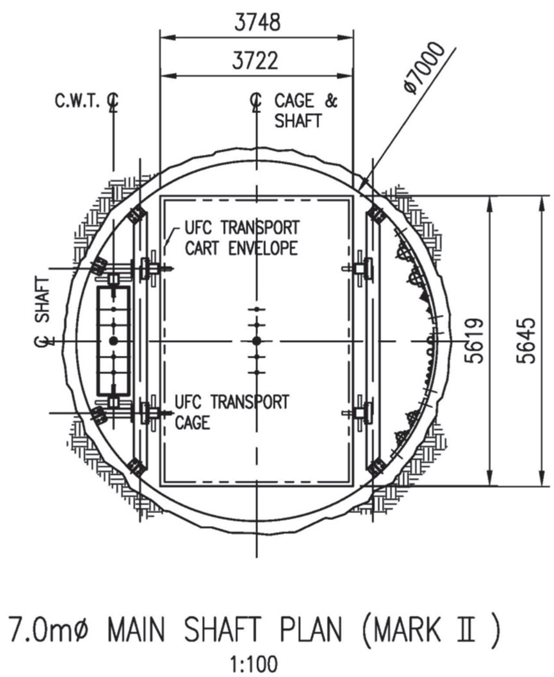
During normal operations, required inspections will be carried out each week, as well as regular testing of the hoisting plant braking systems. The hoisting plants, including ropes, conveyances and hoisting equipment will also be inspected on a periodic basis to ensure that they are in proper condition and fit for continued use.

Hoist ropes will be periodically changed, and will also be subject to regulatory requirements to have sections cut from the ends for destructive testing. This will require that conveyances be temporarily banked or supported at the collars while head ropes are disconnected for inspection or change-out. Likewise, for the friction hoists, new tail ropes will be required to be installed using small tuggers or winches to pull the ropes up the shaft during these operations. The systems will be relatively simple to maintain and change out as required.

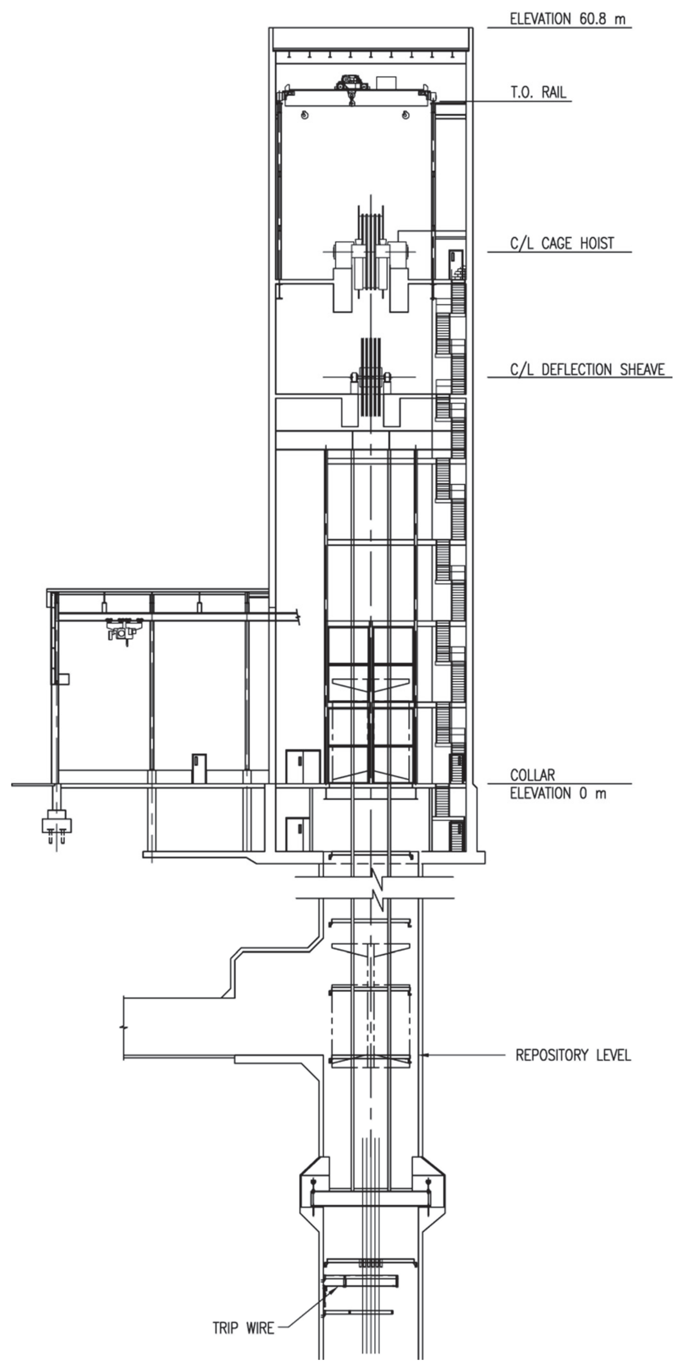
A general maintenance / replacement schedule is presented in Table 12. The Service Shaft, as an excavated-rock-handling facility, will require additional maintenance as compared to the other two installations.

Table 12: Shaft / Hoist General Maintenance Table

Item	Replacement Frequency	Notes
Hoist Ropes	5 to 7 years	Depends on the findings of rope inspections.
Hoist Conveyances	5 years for skips 10 years for cages	If conveyance is not displaying fatigue or wear, it may be used longer.
Hoist Brake Liners	5 years	
Hoist Bearings	25 years	Depends on hoist alignment and balancing. Well balanced and lubricated machines will last longer.
Hoist Motors	25 years	
Hoist Drives	25 years	Will be impacted by obsolescence and availability of spares (may need to replace components sooner).
Hoist Replacement	50 to 100 years	Few hoists have approached 100 years in age. Full hoist replacements assumed in 50 years.

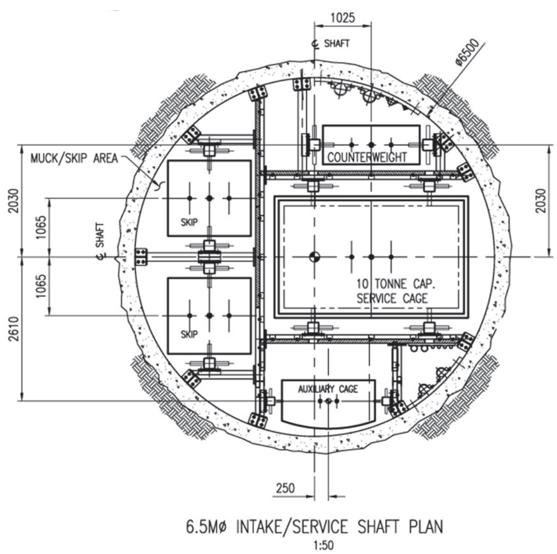


Shaft Plan

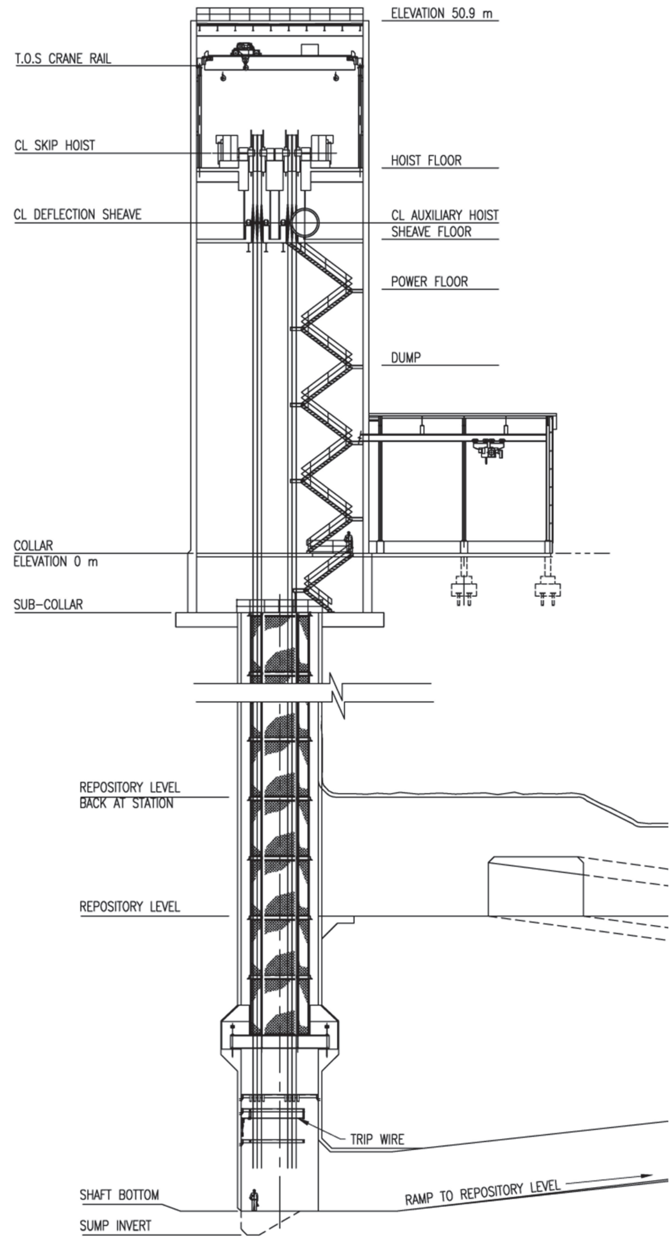


Shaft and Headframe Section

Figure 22: Main Shaft

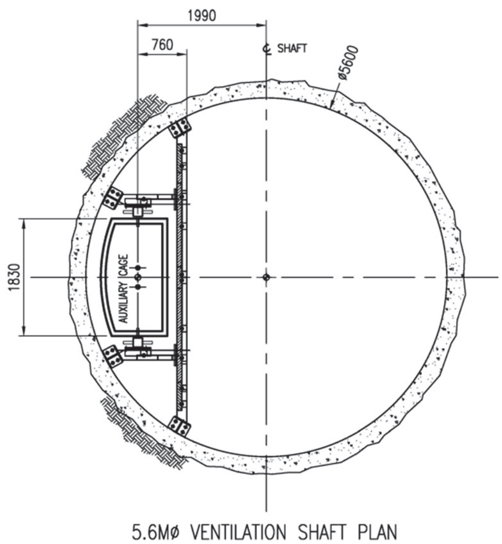


Shaft Plan

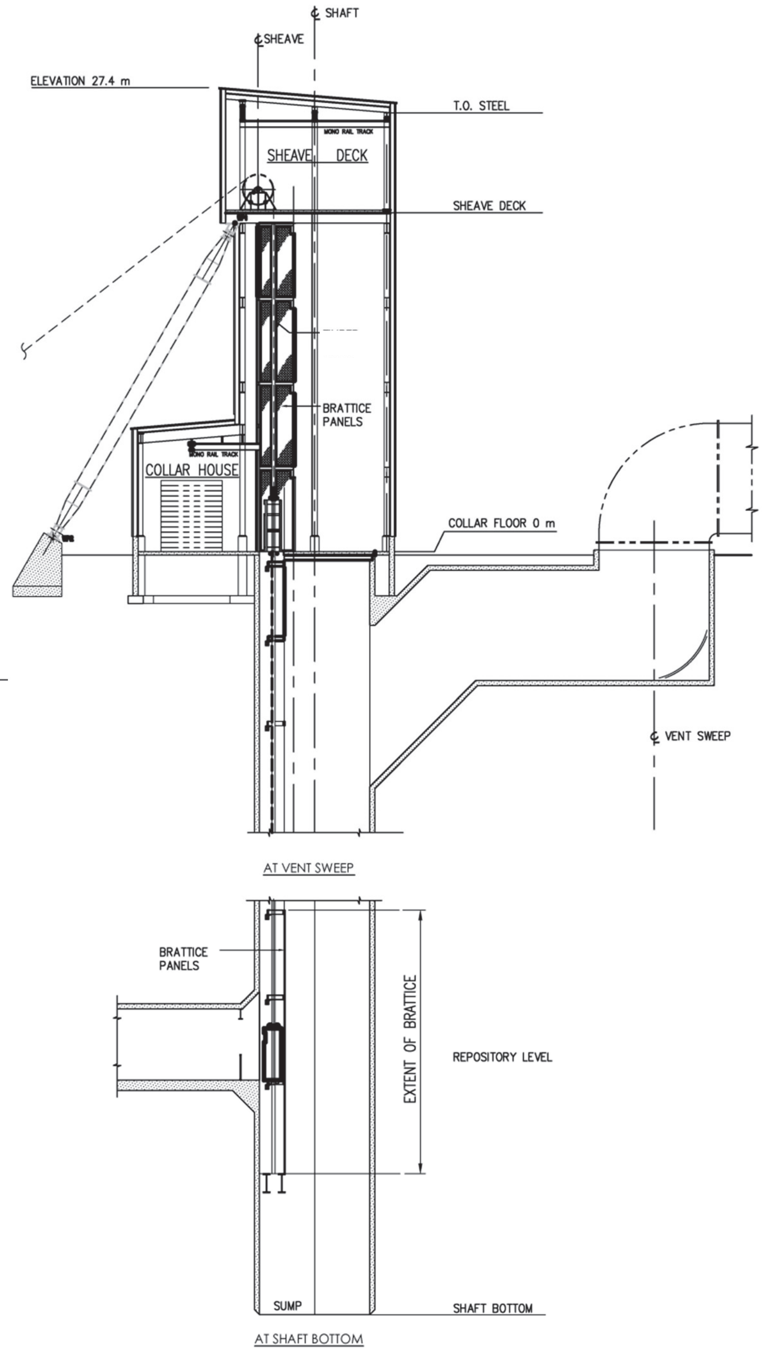


Shaft and Headframe Section

Figure 23: Service Shaft



Shaft Plan



Shaft and Headframe Section

Figure 24: Ventilation Shaft

5. UNDERGROUND FACILITIES

There are two main components to the underground operations of the DGR: the Underground Services Area and the main repository with placement rooms that will contain the buffer boxes (with UFCs). The Underground Services Area would provide a range of facilities to support the DGR's operations including:

- Underground Demonstration Facility;
- Refuge station, offices, washrooms;
- Maintenance shop and warehouse;
- Battery charging station (for battery-powered forklifts for placing buffer boxes);
- Underground diesel fuelling station and equipment / material storage areas;
- Explosives and detonators magazines;
- Main electrical substation; and
- Truck dump equipped with grizzly and rockbreaker.

During the initial construction period, the Underground Services area, including the UDF, the perimeter tunnels, the central access tunnels and two panels of rooms would be developed. Following the start of operations, excavation of placement rooms would proceed concurrently with placement activities. Sequencing of the development (excavation) and UFC placement activities will provide for adequate separation of these two major activities from a manpower, ventilation and equipment perspective

The basic arrangement of the underground repository involves a series of parallel, dead-end placement rooms, organized into panels. All underground openings will be excavated by controlled drill and blast methods. The placement rooms will have a rectangular shape of nominal dimensions 3.2 m wide by 2.2 m high. There will be room-to-room spacing of 20 m and 25 m, and an in-room container-to-container spacing of 1.5 m and 1.7 m for the crystalline and sedimentary rock layouts, respectively.

The in-room placement of the Buffer Boxes will involve a two-high stacking arrangement of the boxes. The rows of boxes will be separated by spacer blocks. The buffer boxes will be placed in a retreating arrangement within the placement room with any remaining voids in the rooms backfilled with loose bentonite pellets.

For the crystalline geosphere, the underground repository covers an area approximately 2,000 m in length (Service Shaft to Ventilation Shaft centerlines) and 1,400 m in width or about 280 Ha. Each panel of placement rooms requires an area of about 350 m by 700 m or about 25 Ha. Figure 25 shows the underground repository layout in crystalline rock with a capacity to hold 4.6 million used-fuel bundles.

For the sedimentary geosphere, the repository covers an area approximately 2,200 m in length (Service Shaft to Ventilation Shaft) and 2,000 m in width or about 440 Ha. Each panel of placement rooms requires an area of about 390 m by 880 m or about 34 Ha. Figure 26 shows the underground repository layout in sedimentary rock with a capacity to hold 4.6 million used-fuel bundles.

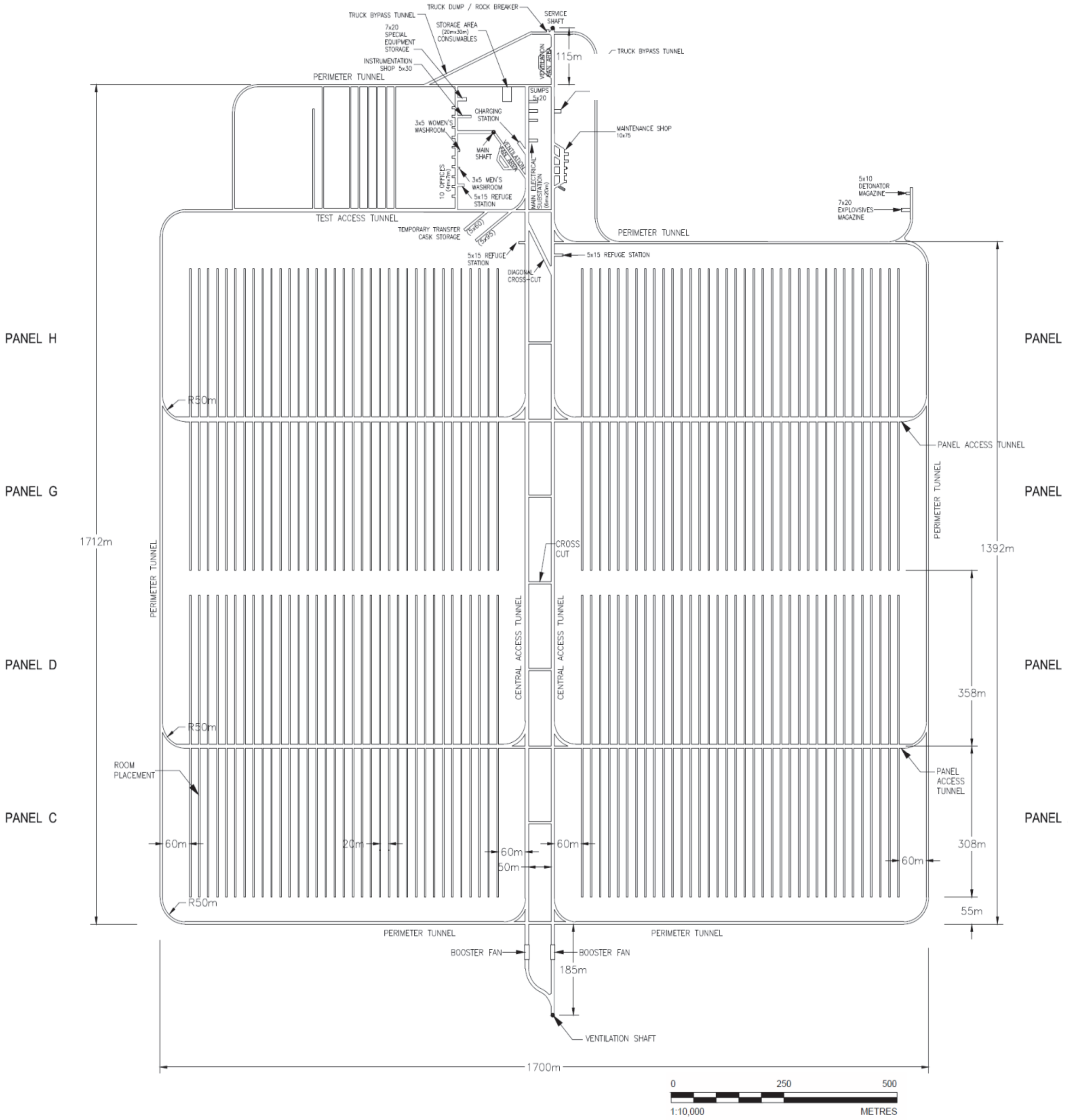


Figure 25: Repository Layout (Crystalline Rock)

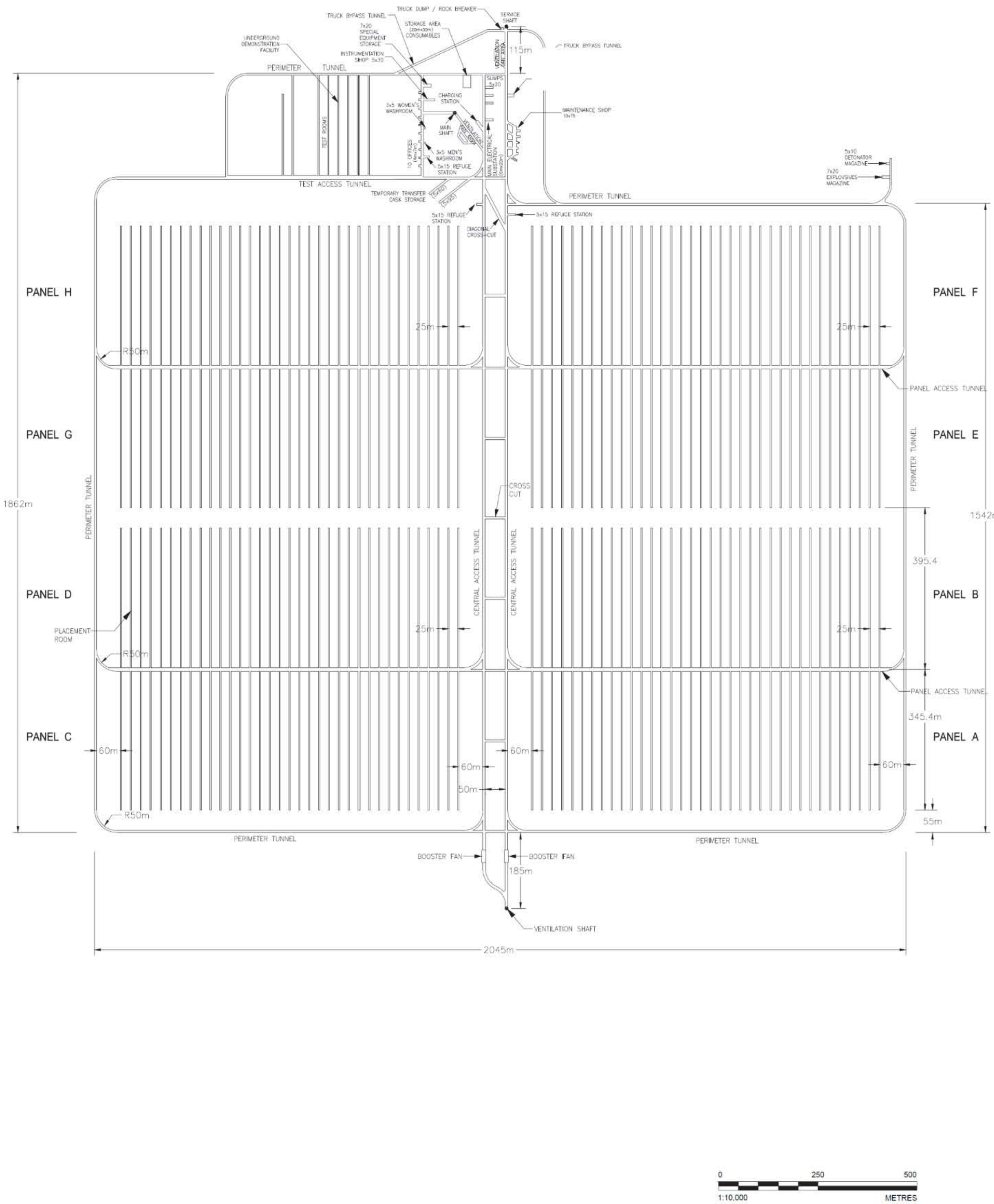


Figure 26: Repository Layout (Sedimentary Rock)

Three primary airways will be used to ventilate the repository. One shaft (Main Shaft) will constitute the dedicated fresh air passage and the other two shafts (Service Shaft and Ventilation Shaft) will constitute the exhaust air passages. A series of surface fans and underground booster fans will be required to achieve the design flow distribution in the underground repository. A surface-based fresh air heating plant will be used to heat air in winter months. Auxiliary fans and ducting will direct airflow into placement rooms.

These aspects of the underground repository are described in the following sections, following a brief description of the expected geosphere conditions.

5.1 GEOSPHERE

Given that a location has not yet been selected for the establishment of the DGR facility, a hypothetical site setting was postulated for the design of the underground works. This site setting was envisaged as being either in a crystalline or sedimentary rock environment.

5.1.1 Crystalline Rock Geosphere

The 'reference geosphere' for a crystalline rock setting has attributes that closely match those of a typical Canadian Shield site. The geosphere is assumed to be an elastic, isotropic, homogeneous, undamaged and generally sparsely fractured rock. The rock mass is assumed to be of a very good quality with a hydraulic conductivity of about 10^{-11} m/s or less. However it is possible that the near surface rock will be of a lower quality and have permeable features.

5.1.2 Sedimentary Rock Geosphere

The reference sedimentary geosphere is hypothetical and it is assumed that the repository will be excavated within a thick layer of good quality, low permeability limestone, overlain by a thick layer of low permeability shale. The limestone formation is assumed to be elastic, isotropic, homogeneous, and sparsely fractured. The rock mass at the repository depth of approximately 500 m would be defined as a very good quality with a hydraulic conductivity of about 10^{-14} m/s. However, it is possible that the near surface rock will be of a lower quality and have permeable features.

5.2 UNDERGROUND DEMONSTRATION FACILITY

An Underground Demonstration Facility (UDF) will be constructed at the DGR site as part of the first approved stage of site preparation and construction. Studies that would be conducted as part of the UDF include verification of geological conditions, demonstration of excavation and construction methods, validation of placement procedures for used fuel containers and sealing materials, long-term studies of engineered barrier materials or processes, and/or monitoring of specially instrumented emplaced containers.

This two-stage approach will be similar to Finland. In that case, there was a federal Decision-in-Principle to proceed with the Olkiluoto site, based on an EIS process. The Decision-in-Principle allowed construction of an underground rock characterization facility (called Onkala), consisting of shafts, an access tunnel, demonstration tunnels, and technical / auxiliary rooms. This underground rock characterization facility is intended to be used as part (i.e., access to) of the final repository. This was followed by approval to construct the repository and remaining surface facilities (i.e., encapsulation plant, emplacement rooms).

The Underground Demonstration Facility (UDF) will be constructed as soon as possible after the Service Shaft reaches the shaft station and rock handling system is installed. Work in the UDF would start when it is safe for the testing and demonstration personnel to enter this area. The UDF will be constructed:

1. To carry-out geoscience verification activities;
2. To initiate and perform long-term sub-surface testing, monitoring and demonstration experiments;
3. To demonstrate placement and retrieval of empty buffer boxes;
4. To demonstrate rock excavation methods; and
5. To practice the required safety culture and quality needed for facility construction and operations.

Table 13: Examples of Potential Experimental, Demonstration and Routine Monitoring Programs to be Conducted for Short & Long-term Safety

Programs	Locations	Duration
Rock Mass Characterization		
➢ Geologic mapping of underground excavations ➢ Thermal property tests ➢ In-situ Rock Mass Stress state measurements ➢ Displacement monitoring (at underground openings) ➢ Seismic monitoring ➢ Geophysical monitoring	Shafts, test rooms, and perimeter tunnels	Throughout initial construction (some tests continuing during operations)
Rock Mechanical Experiments		
➢ 3D stress rotation experiment to support 3D modeling ➢ Large scale strength tests (for spalling and scaling) ➢ Creep tests to determine the time and thermal dependent behaviour ➢ EDZ experiments around the underground spaces	Test rooms and perimeter tunnels	During tunnel excavations and throughout initial construction and operations
Hydrogeological Experiments		
➢ Straddle packer hydraulic testing of rock mass and fracture zones (if detected) ➢ Hydraulic interference and tracer transport experiments in detected fracture zones ➢ Monitoring of hydraulic pressures	Boreholes from test rooms and perimeter tunnels	Throughout initial construction and operation
Geochemistry Experiments		
➢ Long-term diffusion ➢ Radionuclide retention ➢ Microbial experiments ➢ Monitoring of groundwater chemistry ➢ Matrix pore waters geochemistry	Boreholes from test rooms and perimeter tunnels	Several years throughout initial construction and operation
Excavation and Mining Engineering		
➢ Optimize drill and blast techniques to minimize EDZ ➢ Optimal geometry / layout of placement rooms ➢ Long-term rock support performance	Test rooms	Emphasis during first years of initial construction

Programs	Locations	Duration
➢ Bulkhead Performance (including LHHP concrete interaction with bentonite bulkhead seal) ➢ Floor and wall smoothing experiments ➢ Grouting experiments		
Demonstration of Placement and Retrieval Equipment		
➢ Radiation shielding and bentonite sealing systems ➢ UFC / buffer box placement using specialized equipment ➢ UFC / buffer box retrieval using dedicated equipment	Test rooms	Throughout initial construction and operation
Long-term Full Scale Demonstrations		
➢ Instrumentation and monitoring equipment ➢ Long-term corrosion studies ➢ Performance of heated (empty) UFCs, bentonite sealing systems and near-field rock and groundwater ➢ Placement and long-term assessment of UFCs ➢ Retrieval of UFCs / buffer boxes with dedicated equipment ➢ Shaft, tunnel and room seals	Test rooms	Throughout initial construction and operation

A rigorous verification and demonstration program would be carried out with possible areas of investigation listed in Table 13. After an overview description of the UDF, there is a further elaboration of selected programs in the following sections.

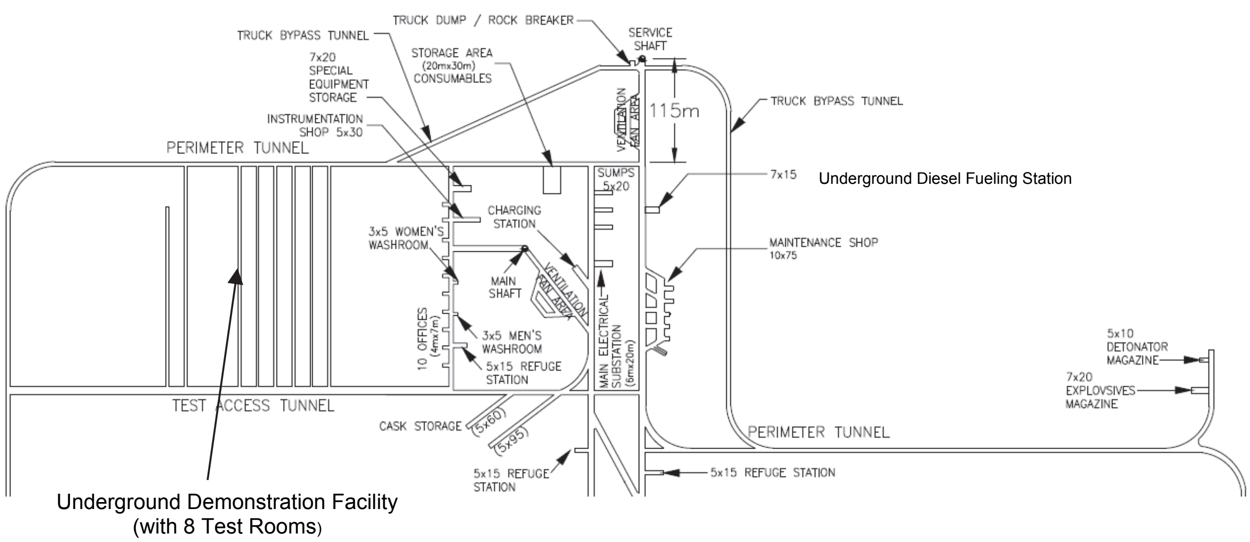


Figure 27: Underground Services Area

(see Figure 25 and Figure 26 for location)

5.2.1 UDF Location and Configuration

The UDF will be designed to integrate with the overall underground repository but will be located so as to be separate from the repository placement rooms. This will ensure that facilities common to both the UDF and the repository are centrally located to both operations.

The UDF would be situated close to the Main and Service Shaft complexes as shown in Figure 27. The personnel offices and associated facilities are located nearby. This area will be connected to the shaft complex and other facilities through the access tunnels.

The close proximity to the Shafts will minimize the initial development required to place the UDF into operation. It also minimizes travel times and materials handling coordination during the initial room development. The technical staff involved in the experiments and demonstration work will have access to underground offices and specialized storage and repair facilities. These facilities will allow technical staff to undertake their support work close to where testing and demonstration work is being performed, thus reducing time in travel to and from the surface.

To simulate operating conditions as closely as possible, the test rooms would be designed and arranged so that their cross-sectional geometry and spacing are identical to that of the repository placement rooms (room spacing is discussed later in Section 5.6.3).

The test room lengths would be designed to provide sufficient lateral area to allow setup of preliminary placement systems and their testing, and to accommodate any potential modifications as may be required while testing prototype equipment. In addition, the test room lengths are envisaged to incorporate sufficient space to allow for a production style operation of the finalized placement equipment configurations. This will ensure that the equipment systems can be successfully transferred from test to actual production conditions while also providing training to initial DGR crews in a near production mode environment.

5.2.2 UDF Life and Expandability

The UDF would be constructed during initial construction phase and would operate on a stand-alone basis for about 5 years prior to start of operations. The UDF would be developed to create a location to perform geoscience verification activities and to pre-test most aspects of the underground construction and operations. The UDF could continue to operate over the complete life of the repository, to demonstrate, monitor and confirm simulated UFC placement results and provide feedback on the effectiveness of the design approaches.

The underground repository's operational life is forecast to be about 40 years, which translates into a 45 year life for the UDF. The additional 5 years, prior to start of operations, allows for test room development and the evaluation of various operational aspects of the underground works before UFC placement activities. It is possible that the UDF may operate longer than 45 years if it continues to operate in the extended monitoring period following the end of UFC placement activities.

5.2.3 Geoscience Verification Activities

Geoscience verification activities will be carried out in the UDF and at other locations in the underground repository for the purpose of verifying assumptions and geoscience data used in the safety case. In particular, data will be gathered to confirm that the host rock formation will be able to act as a long-term barrier and will be able to contain and isolate the used fuel. The results of these geoscience investigations and monitoring activities, among others, will be used in the application seeking approval for full construction of the repository, and eventually in the application for an operating licence.

Geoscience verification would also include investigations and monitoring activities to verify assumptions and geotechnical data used in the design of various underground openings. The data could be used to further optimize the design of various underground openings.

Geoscience verification activities at the repository level would begin upon completion of the Service Shaft and when a second egress is available. The characterization work will be performed in the area near the Main and Service Shafts and then progress into the UDF area. Characterization work would continue into the operations phase in various tunnels and placement rooms.

The data related to the baseline in-situ parameters such as rock strength, stress, temperature and permeability will require collection at an early stage of repository development to assess changes, if any, brought about by excavation activities. Measurement and the collection of representative samples for testing would, in part, be carried out through cored boreholes. Restriction on borehole location and orientation would be in place to mitigate the possibility of creating sub-surface pathways for groundwater and solute migration.

The excavation of the test rooms and the subsequent demonstration of placement and retrieval activities will impact the behaviour of the rock. Rock behaviour will be assessed by visual observation, physical measurement and geophysical techniques. For example, pre-installed stress cells, extensometers and inclinometers could be used to measure response of rock to excavation of test rooms. These same techniques could also be used to measure rock behaviour during access tunnel and placement room excavations and various other demonstration activities in the test rooms. Geophysical techniques such as seismic tomography and ground penetrating radar could be employed to observe changes in properties inside the rock mass. Micro-seismic monitoring can also be used to assess the energy imparted by the various excavation techniques.

5.2.4 Long-term Testing, Monitoring and Demonstration Activities

Some long-term testing, monitoring and demonstration activities that are initiated during initial construction will continue into the operations phase. Examples of long-term testing activities are (Table 13):

- Long-term diffusion
- Radionuclide retention

Examples of long-term monitoring activities are:

- Hydraulic pressures

- Temperature
- Ground water chemistry
- Rock deformation / displacement
- Ground Support

Examples of long-term demonstrations:

- In-situ performance of heated (empty) UFCs and bentonite sealing systems
- Placement and long-term assessment of active UFCs
- Retrieval of UFCs / buffer boxes with dedicated equipment
- Performance of shaft and tunnel seals

5.2.5 Demonstration of Placement and Retrieval of Used Fuel Containers

The UDF provides an area prior to start of the full operations for site-specific testing and demonstration of various aspects of the eventual underground repository. The UDF would also be used for training operating personnel with mock-ups and actual equipment in a realistic environment. Some training areas could be employed to show visitors the operations of the underground works. Such interactions could be performed with little or no direct impact on the main repository's operation.

The UDF can be used to test all aspects of the equipment and associated methodologies for UFC placement and retrieval. The evaluation work can be performed in a number of test rooms with each component of the placement or retrieval cycle undertaken in a location or room dedicated to that particular aspect of future activity.

The main aspects of placement room construction and operations to be tested, demonstrated, evaluated and refined would include:

- Placement room floor and wall leveling, to reduce the need for fill materials;
- Buffer box and DBF block installations and stacking;
- Backfill placements for room sealing;
- Use of remote-controlled equipment for various placement and backfilling operations;
- Construction of room seal and concrete bulkhead for room entrance sealing; and
- Management of unsuitable volumes within a placement room and access tunnels due to fractures.

Two rooms would be developed at the far end of the UDF and will house an actual container placement facilities. One room would have empty buffer boxes (without actual UFCs) to simulate buffer box installations. The second room would accommodate the placement of the buffer boxes with heaters that will simulate heat loading from used fuel inside UFCs (within buffer boxes). Temperature data in the surrounding buffer and rock will be used to calibrate models that estimate temperature conditions in the used-fuel-filled underground repository. These two rooms would be isolated from the other test rooms to eliminate the possibility of any heating effect on local ground conditions interfering with ongoing training or equipment testing being performed in the other rooms. Rooms would also be provided to demonstrate buffer installation in the placement rooms (backfill blocks and bentonite pellets).

For these and other operational components, a demonstration room set-up can be established and associated equipment installed. Following initial testing and monitoring on surface mock-ups, the operational components may be refined and improved with final testing carried out underground.

Testing may also focus on the potential automation and monitoring systems required for the underground operations. Test rooms can be provided with the same data, communication and automation support infrastructure that would be installed throughout the DGR facility.

Long-term performance demonstrations of UFC / buffer box, buffer, backfill, sealing material(s) and geosphere over the period of operation of the DGR could be carried out. Tests could include dedicated demonstration rooms for monitoring the performance of both heated non-radioactive UFCs and UFCs containing fuel bundles. A component of this work would also examine the recovery of the buffer and backfill materials for geotechnical analysis, as well as the removal of the UFC / buffer box for corrosion assessments.

Placement methods for the UFC / buffer box can be assessed as well as extraction / removal operations. UFC retrieval method can eventually be refined and perfected to encompass the removal of the concrete bulkhead, as well as the fully saturated sealing materials.

5.2.6 Demonstration of Excavation Methods

The test room excavation work will provide an opportunity to demonstrate and refine drilling and blasting techniques intended for the placement rooms. Grouting and other measures that are to be used to seal small local fractures will be tested. In order to minimize potential pathways for groundwater movement after closure and to reduce the use of ground support in the placement rooms and tunnels, the blasting damage in the rock surrounding the created openings needs to be minimized and possible tolerances accordingly managed. This excavation damage zone (EDZ) can be controlled through the use of careful excavation techniques. Detailed mapping of the rock after excavation, and correlation of the EDZ thickness to the blast-hole pattern and blasting techniques (for example) will ensure that the methods adopted meet all requirements. Excavation methodologies for the various underground openings can, therefore, be optimized. Demonstration of quality requirements associated with excavation work will be tested and optimized.

With respect to ground support, there are a number of options available depending on the rock conditions encountered. The UDF can allow testing of a variety of systems to optimize the approaches used for the different opening sizes and configurations. Where automated installation equipment (e.g., remote controlled rigs to install rockbolts) is deemed appropriate for quality control, such equipment would be tested and modified to meet the requirements of the DGR. If required, suitable experiments will be performed to demonstrate the process associated with removal of ground supports.

5.3 UNDERGROUND REPOSITORY LAYOUT

The underground repository has been configured with tunnels and crosscuts equipped to ensure minimal crossover and interference between development mining equipment and UFC placement equipment. In general, the excavation-related equipment will travel in tunnels around the outer perimeter of the repository. UFC-related transfer operations are concentrated in the central access tunnels and from there directly to the placement rooms. All rock is trucked in the outer perimeter tunnels to prevent interference with UFC transfer operations.

The general layout for the envisaged repository is illustrated in Figure 25 and Figure 26, for the crystalline and sedimentary geospheres, respectively. Placement room lengths are about 300 m (crystalline rock) and 340 m (sedimentary rock) which will reasonably accommodate development work by limiting ventilation ducting runs to practical lengths. This room length also allows the repository to be divided into a series of stand-alone panels with some flexibility in their location to avoid poor geosphere conditions, if encountered. It will further facilitate room development and UFC placement activities to operate independently of one another. As panel placement activities are completed, each placement room will be permanently sealed off with a room seal and concrete bulkhead.

The repository panels will be interconnected by two parallel and central access tunnels running from the Main and Service Shafts area to the exhaust Ventilation Shaft at the opposite end of the facility. Panel access tunnels will be developed at right angles to the central access tunnels with the placement rooms oriented perpendicular to the panel access crosscuts.

The various components of the repository layout (central access tunnels, panel access tunnels, perimeter tunnels, etc.) are described in the following sections.

5.4 TUNNEL EXCAVATION PROFILES

The excavation profiles discussed below for the various tunnels and placement rooms have been based on equipment sizing requirements.

Central Access Tunnels

The central access tunnels will be used as the main travel-ways from the shafts to the repository placement panels. These tunnels will be developed with widths to accommodate rubber-tired transport and foot traffic simultaneously, without requiring safety bays for people. The rubber-tired transport systems require an approximate 3 m width and an additional 2 m has been provided for people on foot (see Figure 28). The total excavation width will be 7 m to allow for larger vehicle traffic, including passing requirements. The height would be 5 m.

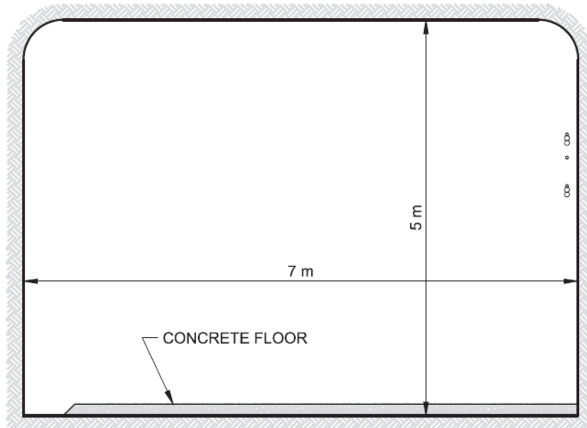


Figure 28: Central Access Tunnel

As the access tunnels are developed, the main services will be installed including compressed air lines, waterlines, drainlines, power cables and ventilation ducting. After tunnel development has been completed the concrete floor would be established. The concrete floor will provide a smooth driving surface for buffer box handling equipment and will simplify any clean-up operations required. Lighting will be provided for the full length of the tunnels to improve visibility and safety.

Panel Access Tunnels

Panel access tunnels would be developed similar to the central access tunnels except with dimensions of 9 m wide by 4 m high (see Figure 29). These tunnels will also accommodate foot traffic, without requiring safety bays for people. However, personnel on foot could stand in placement room entrances along the panel access tunnels to avoid passing mining equipment traffic during development, if necessary. When used on a daily basis lighting will be provided for the full length of the tunnels to improve visibility and safety.

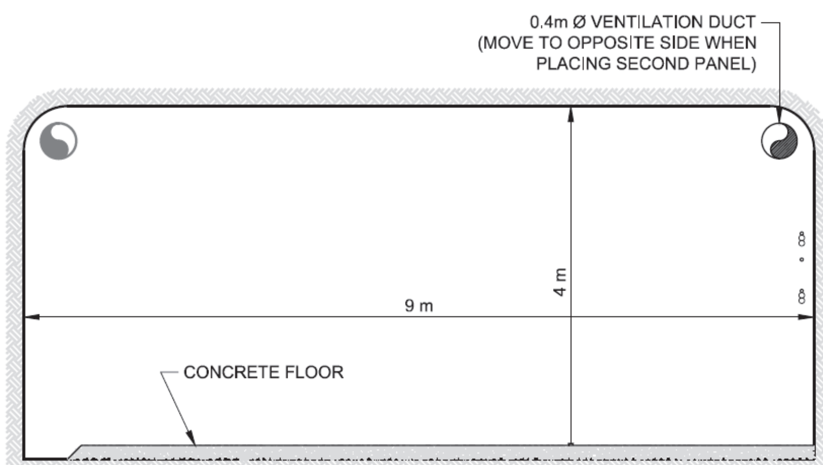


Figure 29: Panel Access Tunnel

Perimeter Tunnels

Perimeter tunnels, established as part of the initial repository construction phase, and subsequently used during operations for ventilation and development access purposes, would measure 5 m wide by 5 m high to facilitate equipment traffic and ventilation requirements (see Figure 30). The perimeter tunnels will contain a levelled gravel floor.

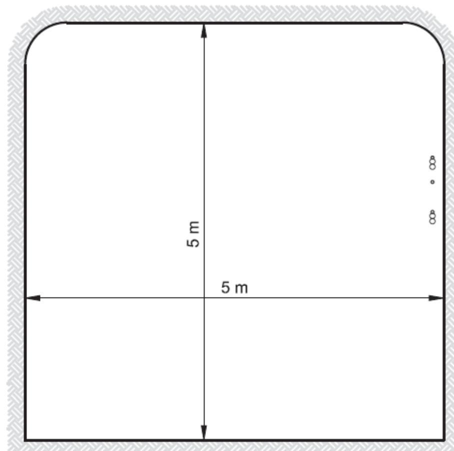


Figure 30: Perimeter Tunnel

Truck By-Pass Tunnels

Truck by-pass tunnels will be developed soon after the main access tunnels are completed to provide a return route to the Service Shaft during development of the perimeter tunnels and the panels. They would have the same dimensions as the perimeter tunnels.

5.5 SUPPORT SERVICES AND INSTALLATIONS

Services and installations to support development of the underground repository, UDF and operations would be installed in their permanent configuration during the initial construction of the underground repository.

5.5.1 Support Services

The main support (utility) services to be provided for the underground operations are discussed below.

Electrical Distribution

Electrical power will be supplied to the underground facilities via two separate 13.8 kV feeds through Main Shaft and Service Shaft. Both cables will be powered and interlocked so that they are kept “warm”. Either cable will be able to carry the entire facility load, providing 100%

redundancy. Loads on the underground repository level will be handled by mobile power centres that will transform power down to 4,160 V and 600 V, as required. On surface, the 4,160 V feed will drive the hoists, fans, and other power requirements for the shaft complexes. Lighting panels and welding plugs will be serviced via low-capacity, local transformers and panels.

Compressed Air

Compressed air will be supplied by 3 compressors located on surface (see Section 3.14). One compressor will always be on standby while the other(s) are operating. This main supply line will be located in the Service Shaft and will connect to the underground distribution system piping. A back-up line will be located in the Main Shaft

Service and Potable Water

Total annual service water requirements for drilling and other uses will be approximately 110 million litres, primarily based on estimated equipment and process water needs. The service water will be sourced from a local water body and up to 90% of the used water is expected to be recycled. All water pumped to surface will be cleaned of particulate matter in the mine dewatering settling pond before discharge to a receiving water body (see Section 3.12)

Water will be sent underground in a 200-mm-diameter pipe located in the Service Shaft along with an equivalent redundant line in the Main Shaft. This will feed the distribution lines underground. Potable water would be supplied to all lunchrooms / refuge stations and washrooms via a separate potable water pipeline connected to the surface potable water supply. Bottled water may also be used for the supply of drinking water.

Mine Dewatering

The primary dirty water sumps will be located in the Underground Services Area (see Figure 27) and additional sumps will be located as needed in the main repository footprint. Pumps placed in the sumps and dewatering lines will direct water to the main water collection sumps, for settling, recirculation and/or discharge from the mine. All sumps would be periodically cleaned to remove settled sediments.

Mine Communications and Controls System

A communications and data network will provide voice communications, PLC monitoring and control, data collection and dissemination via an underground computer LAN and video. A fibre optic cable backbone and wireless data and voice system will provide all applications required to operate the mine and undertake data handling and transmission to the surface.

5.5.2 Primary Support Facilities

The key primary facilities needed to support development and operation of the underground repository are discussed below. Additional support facilities not discussed below will also be in place (e.g., UFC temporary storage area, materials flat cars parking areas, etc.).

Maintenance Shop

A shop will be in place to perform all maintenance on the mobile equipment such as mining equipment, service vehicles and personnel carriers. The shop will be constructed off the central access tunnel leading to Service Shaft with a main shop area for working on larger equipment and satellite bays to service smaller equipment (Figure 27). The maintenance shop will also incorporate a wash bay, welding shop, parts storage warehouse, electrical room, lunchroom and a supervisors' office. All workstations will be connected to the communication system. Details of the maintenance shop arrangement are presented in Figure 31.

The main shop area will be approximately 75 m long, 12 m wide and 10 m high. Overhead bridge cranes and an overhead monorail crane will be in place to support the maintenance activities.

Underground Diesel Fueling Station

A diesel fueling station will be constructed near the maintenance shop with entry from a central access tunnel. It will be provided with a fire resistant roll-up door at the entrance which will separate the fueling station from other working areas in the event of a fire. The diesel fueling station will house 2 fuel tanks and 3 lube tanks.

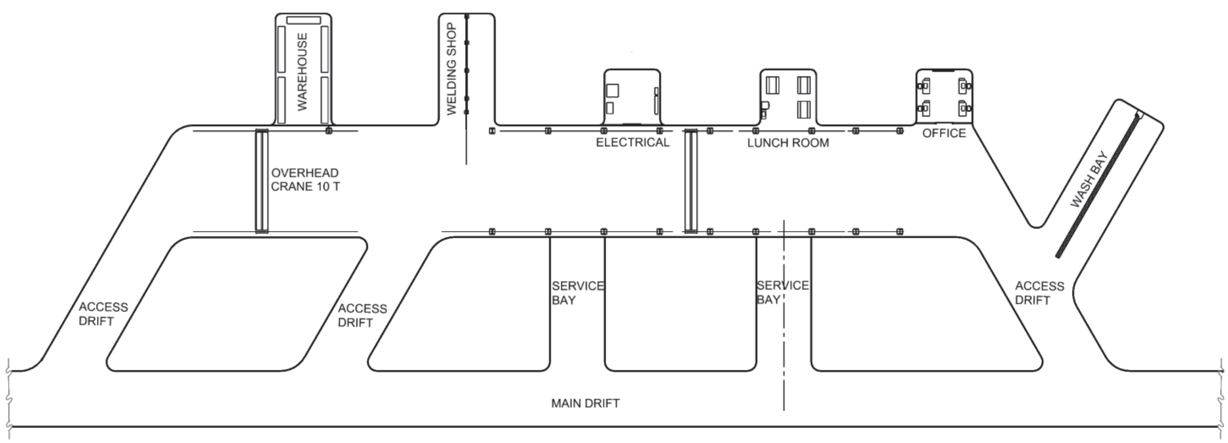


Figure 31: Maintenance Shop

Explosives Magazine

An explosives magazine will be located remote from the Underground Services Area and the panels of placement rooms (see Figure 27). However, it will be readily accessible for mobile explosives loading trucks. The magazine will be fitted with shelving for bulk explosives bags and stick powder and be equipped with a wall mounted jib crane.

Detonator Magazine

The detonator magazine will be located nearby to the explosives magazine but separated by a distance of at least 60 m (distance to be confirmed). It will be equipped with shelving for the stacking of detonator boxes.

Charging Station

A battery charging station will be located off a central access tunnel near the Main Shaft access tunnel (see Figure 27). It will be approximately 30 m long, 7 m wide and 6 m high. Two crane installations will be in place for vehicle batteries. Battery racks will also be installed on one side of the station along with battery charger units. Room will be ventilated to ensure there is no build-up of explosive gases or heat inside the room.

Materials Handling and Storage Area

A storage area for mining consumables including pipe and fittings, ground support materials, ventilation supplies, etc. will be developed near the Service Shaft. With a 20 m length, 7 m width and 5 m height, the area will include shelving and racking to safely store mining consumables. Rubber-tired vehicles will transport bulk shipments from the Service Shaft to the storage areas. Excavation related materials will, in turn, be distributed to the final working places by service vehicles.

Rock Dump and Rock Breaker

Excavated rock will be delivered to the rock dump by haul trucks. Before this rock is sent down to the loading pocket near the base of the Service Shaft, it would be reduced in size, as required, by the rock breaker. Broken rock would be loaded into a skip at the loading pocket for delivery to surface and, ultimately, to the excavated rock management area.

5.5.3 Ancillary Support Facilities

The Underground Services Area will include ancillary facilities for technical staff. Such facilities will include offices, specialized equipment repair areas, washrooms and combination refuge stations / lunchrooms (where, in the event of a fire or other emergency, personnel would gather for safety). A tunnel near the Main Shaft will provide access to the majority of these facilities (see Figure 27).

Offices

Space for offices will be developed on an as-required basis. Offices will be provided with a computer network connection to the DGR-facility-wide data and control network.

Refuge Station / Lunchroom

Three refuge stations will be established: one located near to the offices and two near the entrances into the placement area. The stations will be about 15 m long, 5 m wide and 4 m high. The general arrangement for a refuge station / lunchroom is shown in Figure 32. The stations will have 2 concrete walls with steel doors in the wall at the main entrance to the refuge station. They will include a main area for personnel, and an operations supervisor’s office at the back end of the station. The refuge stations will be equipped with safety and rescue equipment such as a fire extinguisher, eyewash station, first aid kit, emergency food and drink rations and stretchers. Under normal operations, the facilities will serve as lunchrooms for the underground activities. The piping network supplying breathing air to the refuge station will be designed to be in pressurized state (always ready to use) although breathing air will only be required during emergencies. All breathing air supplied to a refuge station will pass through an air purifier unit, which will be located underground inside the refuge station.

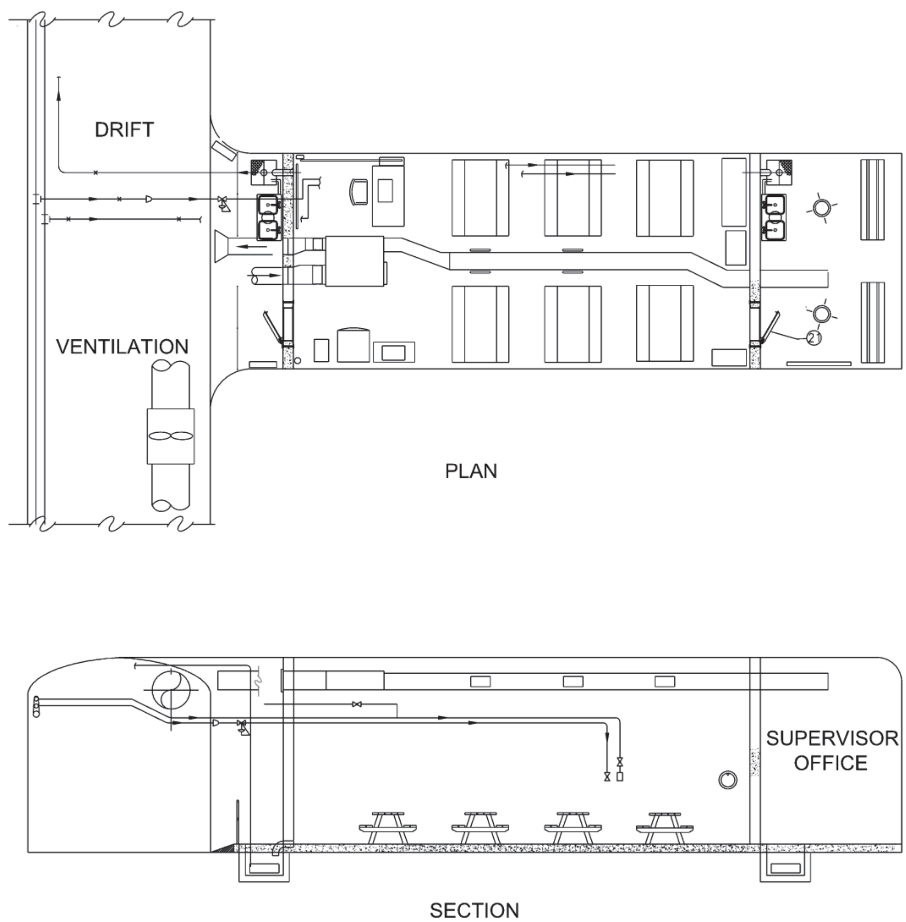


Figure 32: Permanent Refuge Station

Portable Refuge Stations

Portable refuge stations will be placed underground at suitable locations during construction and operation phases of the repository. These portable refuge stations will provide refuge to workers and visitors during an abnormal event when safe passage to a permanent refuge station is not possible. The portable refuge stations will use bottles of compressed air or a RANA compressed air system as opposed to a rigid airline supply from the surface compressors. The portable refuge station will also have a stock of bottled drinking water for the occupants.

Washrooms

Underground toilets (portable mining toilets) will be provided near the offices and refuge station. Wastewater from the washrooms will initially be held in local holding tanks. These tanks would be pumped out on an as-required basis to a larger transport tank for transmission to the surface for treatment. During the subsequent development of the underground repository, additional portable toilets will be provided, as needed, near working areas.

Instrumentation Shop

An underground instrumentation shop will be provided across from the offices to store and repair specialized equipment used in testing activities. The shop will be 30 m long by 5 m wide and 4 m high. It will be equipped with work benches, shelving and repair and calibration tools. Other storage areas for specialized tools and parts used in the UDF testing rooms will be developed across from the offices or near the rooms themselves.

Special Equipment Storage

This area will be used for the storage of special equipment used for either testing or monitoring in the UDF or elsewhere in the underground repository. The area would have climate control to protect the equipment while in storage.

Temporary Transfer Cask Storage

There are two rooms that can be used for the temporary storage of transfer casks. If a placement room is not ready to receive a transfer cask with buffer box, then the cask could be taken to these areas for temporary storage. Similarly, empty transfer casks could be stored in one of these rooms while awaiting delivery back to surface via the Main Shaft.

5.6 PLACEMENT ROOMS

The placement rooms will be developed at a single horizon along with the various facilities, and infrastructure. Each placement room will be dead-ended and a series of rooms are arranged in rectangular-shaped panels. Rectangular room section geometry has been adopted with a vertical height of 2.2 m and a room width of 3.2 m. This is illustrated on Figure 33 which shows a placed buffer box (with UFC) as well as the clay-based sealing components.

5.6.1 Placement Room Arrangements

The repository layout is centered across two central access tunnels connecting the Main Shaft complex to the Ventilation Shaft complex (see Figure 25 and Figure 26). As described in Section 5.2.2, a perimeter tunnel outlines the basic repository footprint for long-term access and ventilation uses. Parallel placement rooms are then excavated in a series of panels.

Within the placement rooms, the buffer boxes will be stacked two high, separated by spacer blocks (see Figure 13). Bentonite gap fill pellets would be used to fill any remaining voids after placement. Following the completion of buffer box placement within a particular room, it will be sealed (see Figure 35 and Section 6.2)

The placement density of the buffer boxes (with UFCs) is designed to minimize the areal extent of the DGR, while satisfying established design parameters including heat dissipation and structural integrity. The actual configuration will be a function of the characteristics of the rock mass, and particularly the accommodation of any structural discontinuities or other geological features that may be encountered during development.

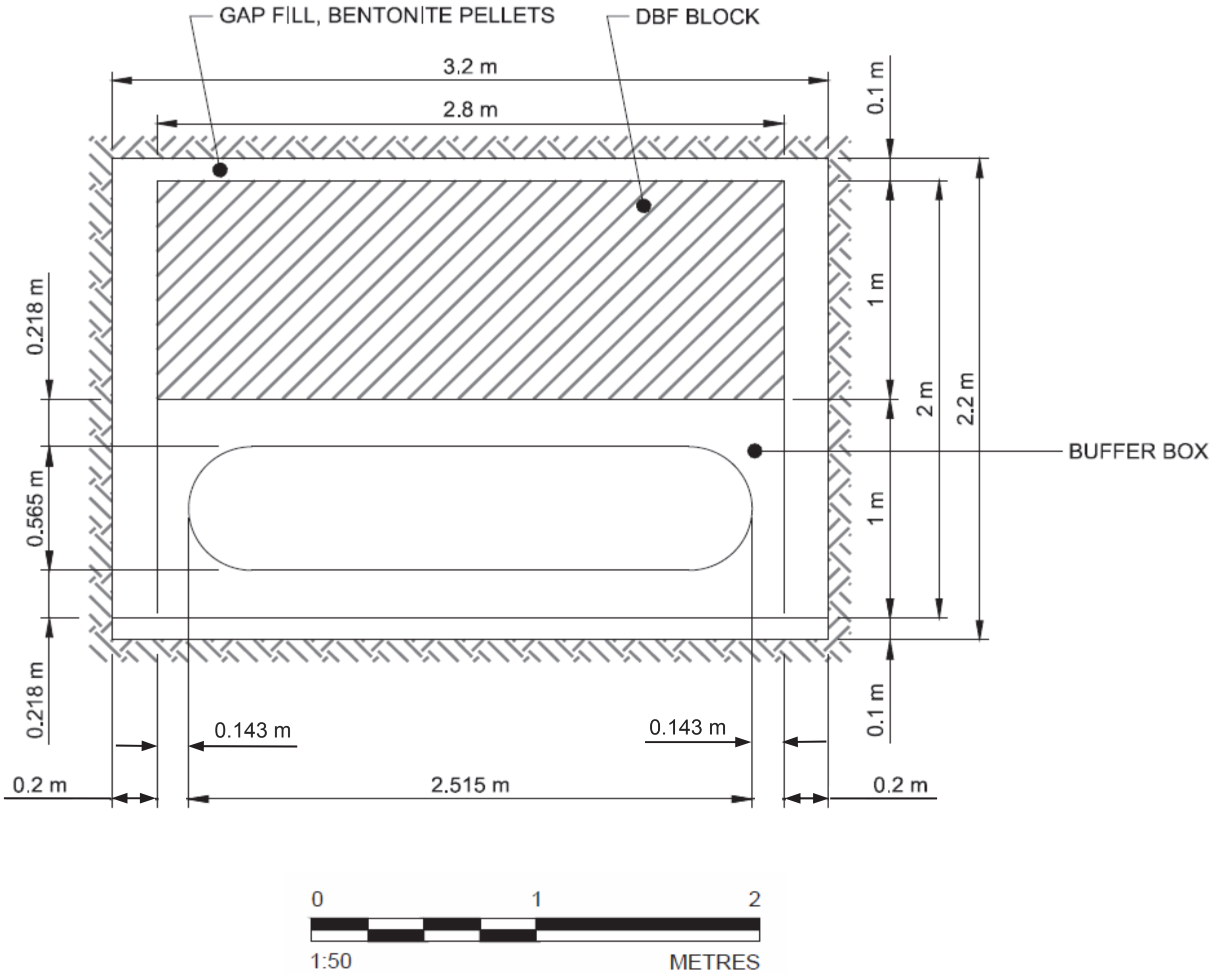


Figure 33: Placement Room Cross-Section

Placement room lengths are based on the assumption that 10% of the buffer box positions will be rejected. Rejection would be due to unacceptable groundwater seepage ingress or other unsuitable rock conditions encountered in the placement room. As approximately 10 buffer boxes will be placed per day, at least 2 placement rooms will always be required to be available for placement activities.

Prior to the buffer box placements, the full length of the placement room will be prepared with a 100-mm-thick bentonite leveling layer. Floor plates with integral ventilation ducts will be placed over the full length of the placement room on top of the bentonite layer to protect the bentonite and to allow equipment to travel in the room.

5.6.2 Placement Room Geometry

A rectangular room cross-section has been adopted to minimize the amount of gap fill material (bentonite pellets) required to fill the void space surrounding the stack of buffer boxes. A room cross-sectional dimension of 3.2 m wide by 2.2 m high was chosen which will allow buffer boxes to be stacked two high (see Figure 33). This room geometry is sufficiently large to permit access for the mining equipment and the buffer box placement equipment.

The repository host geosphere is expected to comprise a good quality rock with high strength and moderate in-situ stresses (see Section 5.1). The axis of the placement room would be oriented parallel, as far as practical, to the major principal stress orientation. This configuration will minimize stress concentrations about the perimeter of the placement room.

When designing the placement room geometry and the general arrangement of the placement rooms, possible rock loadings due to glaciation and/or a large earthquake event will be considered.

5.6.3 Buffer Box and Placement Room Spacing

Heat will be generated by the UFCs. Such heat and the resulting elevated thermal regime must be evaluated with respect to the requirement that temperature on UFC surfaces must be at or below 100°C at all times. The surface temperature of the used fuel container must be maintained below 100°C to ensure that the properties of the surrounding bentonite and the copper are not adversely affected. At elevated temperatures (~140 °C), the bentonite begins to convert to illite, a non-swelling clay and swelling performance requirements can no longer be met. These physical changes are irreversible and leave the used fuel container vulnerable to microbiologically influenced corrosion. At temperatures above 125 °C the electrochemical behaviour of the copper changes and more rapid corrosion is possible.

To ensure temperature does not exceed 100°C on surface of UFCs, the center-to-center spacing of the buffer boxes was set at 1.5 m for crystalline rock or 1.7 m for sedimentary rock. In addition the center-to-center spacing of placement rooms was set at 20 m for crystalline rock or 25 m for sedimentary rock.

5.7 DEVELOPMENT OF UNDERGROUND REPOSITORY

5.7.1 Drill & Blast

All excavations associated with the repository will be carried out by drilling and controlled blasting techniques. Drilling and blasting in normal mining environments inherently creates a damaged zone in proximity to the opening. Drill and blast is easily adapted to a range of rock conditions and customized tunnel shapes. The blasting designs can be readily accommodated to meet particular requirements. Further, the technology is mature and efficient. All drill and blast underground excavations will be undertaken using rubber-tired mining equipment.

Blasting operations include drilling holes in a converging pattern, placing an explosive and detonator in each hole, detonating the charge, and removing or excavating the excavated rock. The hole patterns are selected to minimize the quantity of explosive detonated per volume of rock broken. Boreholes are typically detonated in sequence from the center of the excavation outwards with each detonation creating an open face for the next volume of rock to break towards.

Between the blasting cycles, fumes are vented, scaling is undertaken to remove loose rock, ground support is applied as required, and the next round of blasting is surveyed. Typical standard drill and blast practices result in a rate of advance in the range of 5 m to 15 m per day based on one crew working multiple headings.

Under a controlled drill and blast approach, a closely spaced series of perimeter holes established around all sides of the opening would be loaded with decoupled low impact explosives (such as Xactex) and blasted last. The blasting of these holes would also be timed to ensure that ground movement is minimized in the walls and that minimum energy transfers from the main development round and perimeter hole blasting to the surrounding wall. Electronic blast initiators are utilized to provide maximum accuracy in blasthole initiation.

5.7.2 Ground Support Requirements

After the broken rock is removed from the various openings in the Underground Services Area and the various tunnels, a scissor-bolter-screener unit would install ground support. In case of permanent openings, such as the maintenance shop and offices or refuge stations etc. Permanent openings roof and walls would be secured with ground support initially and later will be shotcreted (if required). In the expected good quality rock environment of the host geosphere (crystalline or sedimentary), it is likely that minimal to no ground support will be needed within the various tunnels and placement rooms. In fact, for spans of up to 7 m or 5 m, for the crystalline and sedimentary geospheres respectively, bolting may not be required. For the 3.2 m by 2.2 m placement rooms, it is assumed that ground support will not be required. For the central access and panel access tunnels of 7 m and 9 m spans, respectively, which will be open for the duration of the repository life, it would be recommended that systematic bolting be installed on a pattern of 2.5 m x 2.5 m spacing. Patterned bolting will also be required for the intersection of tunnels, perhaps with some sort of support between the bolts (e.g., un-reinforced shotcrete or screen).

Where the development and placement rooms cross zones of poorer ground, additional support will be applied as required. It has been assumed that 10% of the tunnel lengths will require additional support based on encountered conditions.

Due to the long life of the repository, a monitoring program will be implemented to assess the long-term performance of the established ground support features. Maintenance or installation of additional support will be carried out as required.

[Note: The above support recommendations are preliminary and illustrative only. Ground support will need to be revisited after geotechnical characterization is performed at candidate sites.]

5.7.3 Development Schedule

Construction Phase

Once the sinking and equipping of the shafts is completed, they will be utilized to develop the Underground Services Area including the UDF. The diesel fueling station, sumps and main electrical substation will be completed first to support on-going development. Development of the other support facilities in the Underground Services Area (e.g. maintenance shop, explosives magazines, etc.) will follow. With the underground infrastructure in place, the UDF and the access tunnels will be developed and equipped. To achieve the development schedule, 3 crews will be active at any one time.

The first set of placement rooms (i.e. rooms in Panels A and B shown in Figure 34) would be established during construction phase and before the DGR facility is commissioned.

Services (compressed air, water, electrical, etc.) would be extended into the development openings as appropriate to the intended use of each area.

Operations Phase

During the operations phase, there will be concurrent construction and placement activities. That is, buffer boxes would be placed in placement rooms at the same time as additional placement rooms are being excavated. All placement rooms would be developed in a panel before buffer box placement operations are commenced in that panel.

The placement room panels would be developed to retreat from the Ventilation Shaft end of the repository to the Main Shaft end (see Figure 34). Retreating towards the Main Shaft ensures that personnel do not have to enter or pass by the completed areas to perform regular daily duties. It also ensures that all ventilation air passing through these areas is routed directly to the Ventilation Shaft and does not permit reuse of this air.

Separation of Construction and Placement Activities

Each placement panel will be completed in its entirety before commencing to the next panel so that panel development is completed prior to placement operations and to ensure that excavation and placement activities are isolated from one another (and excavation and placement equipment do not operate in the same panel simultaneously). Excavation activities will be concentrated in a series of panels on one side of the central access tunnels while placement activities are being performed in panels on the opposite side of the access tunnels. This will ensure that secondary vibration of already developed placement rooms, where placement activities are taking place, is minimized until the finished rooms are backfilled and sealed.

The sequence outlined in Figure 34 also illustrates the separation of activities. Each placement panel in the DGR would require about 3 years for development. UFC Placement activities within the panel of rooms would require 3.5 to 4 years. Because of the requirement to have two panels completed before UFC placement activities start, the development activities that occur during operations will end about ten years earlier than the placement activities.

Traffic Flow

Mining traffic will travel in perimeter tunnels to rooms being excavated and UFC handling equipment will travel in the central access tunnels to rooms receiving UFCs (inside buffer boxes). Main Shaft and associated underground shaft station area will generally only receive UFC handling equipment (i.e. will be “controlled areas”). The Service Shaft and associated underground shaft station area will generally only receive construction equipment traffic or equipment handling sealing materials.

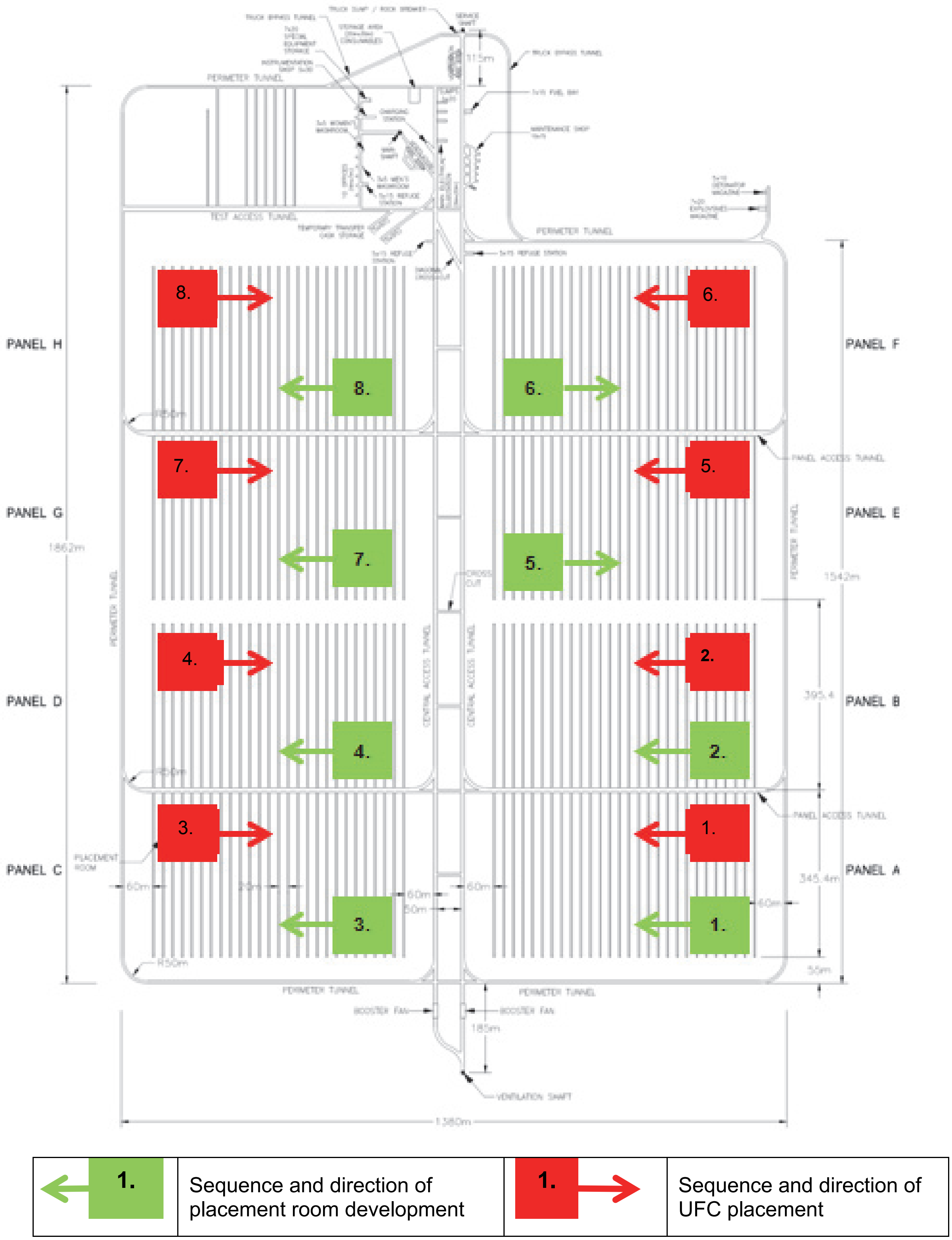


Figure 34: Sequencing of Development and UFC Placement Activities

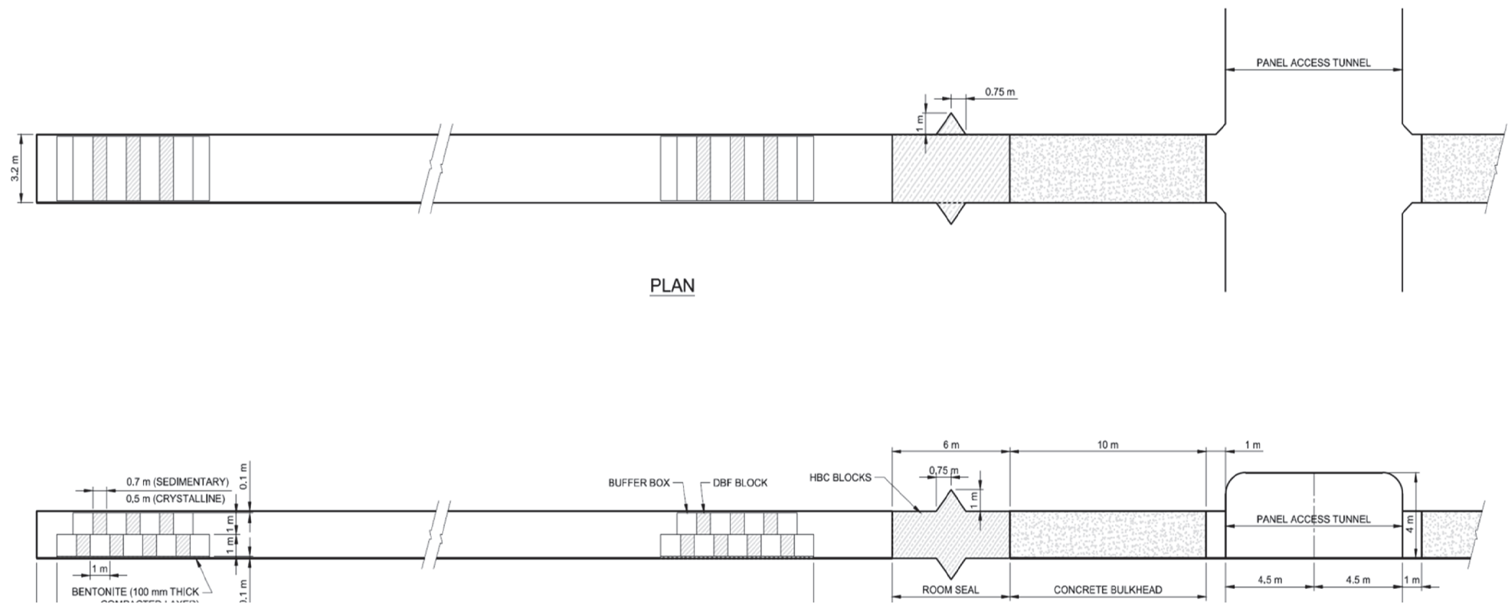


Figure 35: Section Through Placement Room

Sealing of Rooms

A conceptual longitudinal section of the placement rooms is included in Figure 35. Upon completion of placement activities, and backfilling of the placement room, a low permeability seal would be placed within the entrance of the placement room. This would consist of a mechanically excavated slot around the perimeter of the room that would extend to a depth beyond the EDZ within the annulus of rock immediately adjacent to room opening. Following placement of the EDZ seal, a low heat and high performance concrete bulkhead will be installed at the entrance of the placement room to contain seal materials.

5.7.4 Material Handling

Rock Handling

Broken rock would be loaded into the underground haul trucks at the placement room entrances. Loaded trucks would travel along the panel access tunnels to one of the perimeter tunnels and then to the truck bypass tunnel connecting to the truck dump near the Service Shaft. The trucks would unload their broken rock load onto a grizzly at the dump. A hydraulic rockbreaker would break any oversize rock left on the grizzly. The rockbreaker would be automated to allow remote operation by the skip tender or by a central control room operator. Material from the dump would flow to the loading pocket level for skipping to surface in the Service Shaft.

Materials Handling

Materials for development (e.g., explosives, rockbolts, pipe, etc.) would be transported on rubber-tired service vehicles in the Service Shaft and moved to the main storage area. The vehicles would be off-loaded and materials placed in the main storage area. Similar service vehicles will carry materials from the main storage area to working places throughout the underground development.

5.7.5 Equipment Requirements

The underground repository will be developed by utilizing rubber-tired diesel powered equipment.

Buffer boxes will be transferred to the underground repository using the Main Shaft. All personnel, equipment and development muck will be transported using the Service Shaft (see Section 4). Placement equipment consists of a customized vehicle to handle the buffer boxes in the placement rooms and a tow vehicle and trolley to move the transfer casks (loaded with buffer boxes) from the shaft to the placement rooms.

The use of electrical powered equipment will be maximized to minimize ventilation volume requirements. While some equipment will be powered by diesel, they will use electricity to power on-board systems, such as electric hydraulic drills, electric jacks, etc.

A preliminary list of mining equipment and quantities for both the initial construction of the underground repository and for on-going development during the subsequent operations phase is presented in Table 14.

Table 14: Underground Mobile Equipment List

Equipment Types and Numbers	
Load-Haul-Dump (LHD) Loaders (3)	Grader
32 tonne Trucks (3)	Service & Crew Trucks (3)
Development Jumbos (2)	Boom Truck
Scissor Bolter	Bucket forklifts (2)
Scissor Lift	Utility Vehicles (10)
ANFO Loader	Miller Carts (2)
Shotcrete Truck	Service Trade Vehicles (6)
Concrete Truck	

Note: table includes standby equipment

In all, the following concepts for underground equipment will be applied:

- All underground excavations will be carried out by rubber-tired equipment (jumbo's, LHD machinery and trucks);
- Rubber-tired equipment would be propelled by diesel motors. Semi-stationary equipment such as drill jumbos would be powered by electricity;
- Haulage of development rock to the shaft would be by diesel powered trucks;
- Transfer of buffer boxes (with UFCs) on trolleys to entrances of placement rooms and trolleys would be moved by rubber-tired tow vehicles ;
- Activities inside placement rooms receiving buffer boxes would be carried out by electrically-powered machinery; and
- The routing and scheduling of panel development and buffer box placement activities would be separated, with dedicated routes for each.

5.8 SUBSURFACE VENTILATION

Network modelling techniques (Ventsim software) were used to create a three-dimensional representation of the ventilation system, and to conduct ventilation simulations for the excavation and placement activities. Based on the results of modeling the primary surface fans, underground booster fans and the associated distribution ducting were sized.

Independent ventilation circuits were targeted for the placement and excavation areas of the underground repository. To the degree possible, the system was set up to ensure that underground work would be performed in a fresh air supply stream with the exhaust being directed through unoccupied areas. Ventilation requirements were based on providing dilution of excavation contaminants and dissipation of heat to provide a comfortable working environment.

5.8.1 General Description of Ventilation System

The system uses three vertical shafts and a combination of parallel airways to intake and exhaust the air from surface through the underground facility and back to surface. The system makes use of underground booster fans, auxiliary fans, ventilation doors, stoppings, and regulators to control airflow distribution and ensure a ‘one-pass’ ventilation system.

The main repository ventilation system conduits (central access, panel access and perimeter tunnels) provide relatively large airways. The overall circuit, including the shafts, can be described as a system with relatively low airflow resistance characteristics.

The primary ventilation network consists of a push-pull type system. At the Main Shaft, the surface fans would force fresh air through the surface plenum and into the shaft area (a small amount would be upcast in winter months through the shaft headgear to prevent freezing). Underground booster fans are then envisaged to take-over within the shaft system and pressurize the underground operation to allow for a positive pressure distribution in the repository. Ventilation control doors, booster fans, auxiliary ventilation and regulators would be used to direct and control the quantity of fresh air.

Fresh air is routed into the Underground Services Area to ventilate the maintenance shop, fuel station, main electrical sub-station, main sump, storage areas, offices and shops before being discharged into the Service Shaft. Exhaust air from the Underground Services Area is routed to the Service Shaft by an underground booster fan (two fans would be in place with one serving as a full spare). The return air is then exhausted to surface, assisted by one exhaust fan (again with a full back-up fan) installed at surface in the Service Shaft complex.

Air will be distributed throughout the placement area through the use of regulators and fans. Within a given panel, fresh air will be supplied via the central access tunnel and exhausted through the panel access tunnels to the perimeter tunnel. Fresh air will be distributed to the individual panels through axivane booster fans or regulators, depending on flow requirements. Exhaust air from the placement area would be routed to the Ventilation Shaft by two underground exhaust booster fans. The return air is then directed to surface by two parallel exhaust fans (one a full spare) installed on surface in the Ventilation Shaft complex.

Figure 36 illustrates the ventilation pathways for the placement area.

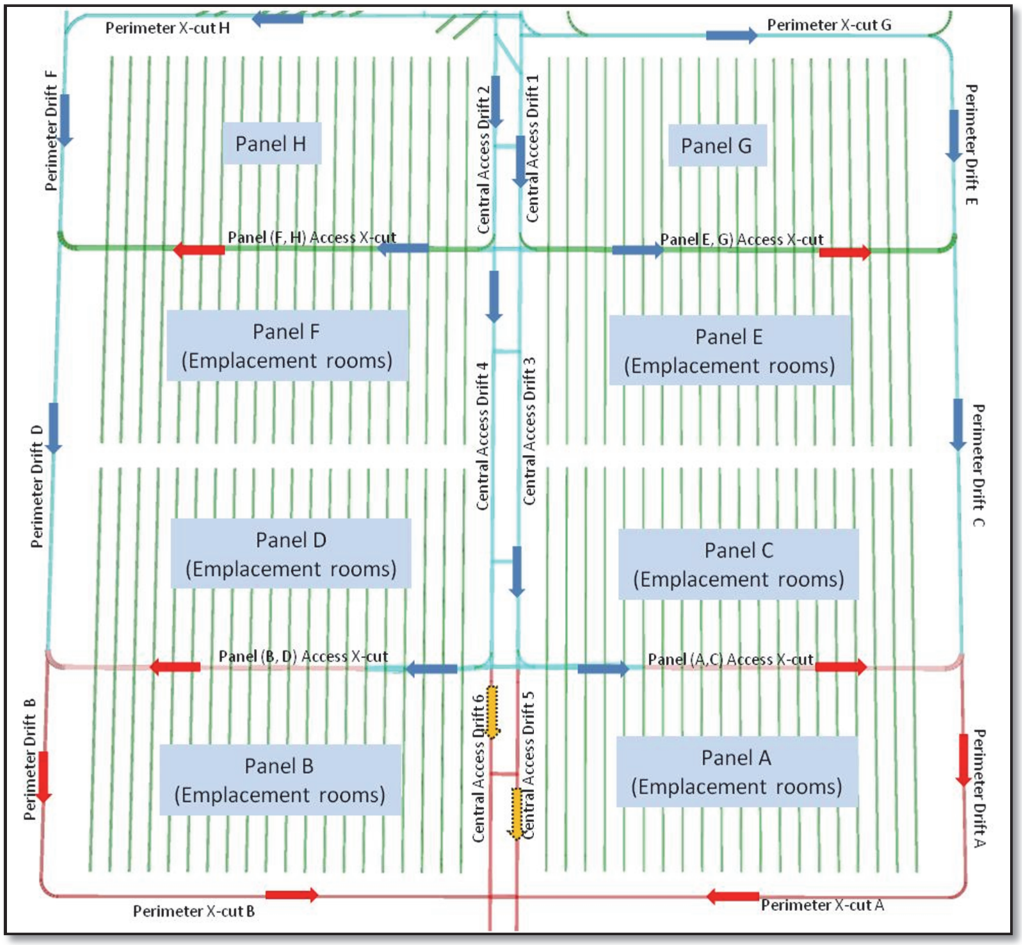


Figure 36: Placement Area Ventilation Schematic

5.8.2 Estimation of Air Flow Requirements

In assessing airflow requirements, the DGR was subdivided into two areas: the Underground Services Area and the placement area (i.e. 8 panels of placement rooms). These two areas are essentially ventilated independently. In both cases, airflow rates were generally established such as to provide dilution of diesel equipment contaminants and to allow a comfortable working environment for personnel. In the case of the placement area, airflows were based on the sum of that needed for repository development / excavation and for actual buffer box placement activities, since the two operations can be performed concurrently.

During buffer box placement, a minimum air velocity of 0.5 m/s in the access tunnels was maintained to provide a comfortable, effective air temperature for the work being undertaken. Based on this air velocity and the cross sectional areas of the different repository tunnels, tunnel-specific airflows were estimated.

During development of the placement rooms, the airflow needed at the working face area was calculated as 6.4 m^3/s. Two 55 kW fans in series operation will deliver the air quantity required. During buffer box placement, the airflow quantities needed at the working face area were determined to be 2 m^3/s. Two 18 kW fans in series are required to deliver air into room. As indicated below on Table 15, with all equipment needs and systems satisfied, the airflow quantity required underground for distribution would be 408 m^3/s.

Table 15: Overall Airflow Requirements

Location	Leakage	Excavation & Placement Activities
	%	m^3/s
Underground Services Area	10	62
Placement Room Excavation Area	20	246
Buffer Box Placement Area		100
Total Air Quantity Required		408

Shaft flows are presented in Table 16.

Table 16: Shaft Airflow Requirements

Location	Quantity
Main Shaft (intake)	408 m^3/s
Service Shaft (exhaust)	62 m^3/s
Ventilation Shaft (exhaust)	346 m^3/s

5.8.3 Main Fan Systems

The surface fans at the Main Shaft are designed to deliver fresh air to the shaft-plenum intersection where a small volume of air travels up to the headframe and the balance of the airflow goes underground. From within the shaft, air is drawn under the influence of the underground fresh air booster fans. Table 17 shows the data for all the fans including their calculated motor powers (all fans are vane axial in design).

Table 17: Primary Fans and Related Specifications

Description	Arrangement	Quantity per Fan (m^3/s)	Rounded Motor Power (kW)
Main Shaft - Surface fans	Trifurcated direct drive	223	2 x 350
Main Shaft - Booster fans	Bifurcated direct drive	204	2 x 700
Service Shaft - Surface fans	Single direct drive	85	1 x 75
Service Shaft - Booster fans	Single direct drive	62	1 x 150
Ventilation Shaft - Surface fans	Bifurcated direct drive	190	2 x 320
Ventilation Shaft - Booster fans	Trifurcated direct drive	173	2 x 300

A 10% allowance has been included in the fan motor requirements for events that may require additional power during operations. This can be due to friction factor changes due to mining systems or the movement of equipment in shafts and station areas. Further, all primary fans would be installed with a variable frequency drive, to have the flexibility of operating at different flow ranges depending on the required system conditions.

Main Shaft Fans: At surface there is a trifurcated fan arrangement (three fans in parallel) with two 350 kW fans operating at a 446 m^3/sec throughput. The third fan will serve as an installed standby in case of emergency or maintenance situations. There are two 700 kW booster fans underground (operating in parallel) with 408 m^3/sec throughput. In addition there will be one spare motor for the underground booster fans which will be kept in an on-site storage facility. The plenum that connects the surface fan installation to the shaft is 7.5 m wide and 5.5 m high.

Service Shaft Fans: At surface there is a bifurcated arrangement (two fans in parallel) with one 75 kW operating at a throughput of 85 m^3/s. The second fan will serve as an installed standby in case of emergency or maintenance situations. There are two 150 kW booster fans underground (two fans in parallel) with one fan operating at a throughput of 62 m^3/sec. The second fan will serve as an installed standby in case of emergency or maintenance situations. The plenum that connects the surface fan installation to the Service Shaft is 6.5 m wide and 5.1 m high.

Ventilation Shaft Fans: At surface there is a trifurcated fan arrangement (three fans in parallel) with two 320 kW fans operating at a 380 m^3/sec throughput. The third fan will serve as an installed standby in case of emergency or maintenance situations. There are two 300 kW booster fans underground (operating in parallel) with 346 m^3/sec throughput. In addition there will be one spare motor for the underground booster fans which will be kept in an on-site storage facility. The plenum that connects the surface fan installation to the Ventilation Shaft is 5.6 m wide and 5.1 m high.

All fans in the system would be linked to each other in case of an emergency. If one fan fails or electrical problems occur, the system of surface and underground fans will react to this change by either increasing or reducing airflows. The system would be automated for this purpose.

The target availability of all fan systems would be 100%, excluding scheduled outages. Spare fans would be in place to ensure the ventilation system can operate 24 hours/day, 365 days/year.

For the fan systems, the plenum is one of the most important components as poorly designed plenums can reduce the pressure capacity of a primary fan by as much as 50%. The primary contributors to pressure losses in a plenum are shock losses and the airway cross-sectional area. The plenums are thus sized to primarily reduce the air velocity head and hence, shock losses. The headframes are also critical to fan performance, since a leaky headframe will lower the system pressure capacity.

5.8.4 Fresh Air Heating System

The underground ventilation system will be designed to ensure reasonable underground temperature conditions. This will allow personnel to work, at all times of year, in normal indoor work wear (coveralls, work boots, etc.) as in a surface factory setting. A direct-fired heating plant in the ventilation network will be used to maintain working temperatures during winter months. Support offices and ancillary facilities will also be kept at temperatures where work can be performed in every day indoor work wear, without the need for heavy clothing.

The size of a heating plant is a function of the required temperature change. Considering a change in temperature from -25°C (surface outside) to +10°C (shaft), and after accounting for anticipated system inefficiencies, a 21 MW heating plant would be required.

The heating plant will use burners placed directly into the airstream. Common in the northern hemisphere, such systems have proven reliable and extremely safe. A draw-through system, in which the fan is located downstream of the line burner is proposed (see Figure 37). Direct propane fired heaters would consist of an intake section, burner section and air plenum. Integral blower burners are mounted directly in the airstream. A single control room would be located adjacent to the burner structure.

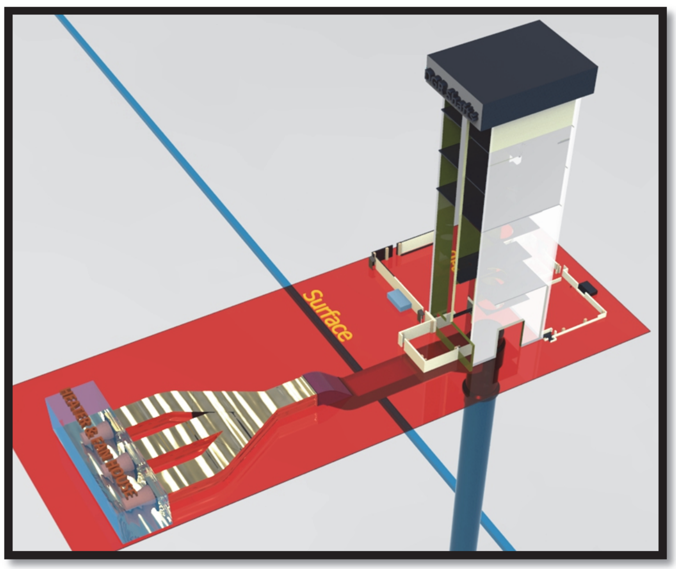


Figure 37: Main Shaft with Force Fans and Heater House

During winter months, the shaft headframes would need to be heated to prevent freezing. As previously described, a push-pull arrangement is to be established for the DGR's ventilation system using a force fan system on surface and exhaust booster fans located underground. All three shafts will have a headgear located on the top of the shafts. Therefore, to prevent freezing problems during winter months, small portions of the heated air streams would be directed into the shaft infrastructure.

5.8.5 Exhaust Air Filtration

High-efficiency particulate air (HEPA) filtration systems will be established where underground air exhausts to surface at the Service Shaft and Ventilation Shaft locations. These systems would be activated in the remote event that radioactivity is detected in the underground ventilation air at above-background concentration levels. They would be installed on surface in the exhaust ducting systems. For the Ventilation Shaft, the HEPA filters would be located as shown below (red coloured section); the exhaust fans are situated at the right-hand side of this image. The HEPA filters and exhaust fans would be enclosed in a structure(s) for protection from the elements (structure(s) not shown in concept diagram in Figure 38). The system would be routinely tested.

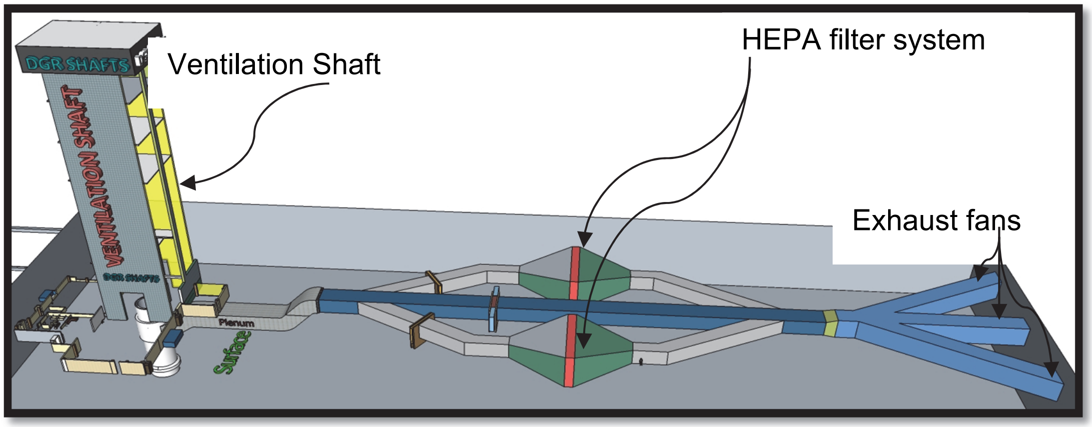


Figure 38: Ventilation Shaft with HEPA Filtration and Exhaust Fans

HEPA filters would also be installed on auxiliary ventilation ducts for the placement rooms and be available for use during UFC placement activities. A portable HEPA filter would be provided on the exhaust from each active placement room and each duct would be equipped with a radiation monitor and bypass damper. In the remote event that radioactive contaminants are detected, the damper will be activated and the air exhaust will be routed through the HEPA filters. At same time an alarm will be sounded for the evacuation of underground workers to a refuge station.

6. USED FUEL CONTAINER HANDLING AND PLACEMENT

The UFCs will be assembled into buffer boxes inside the UFPP (see Figure 4). Fully assembled buffer boxes will be staged in this area while awaiting transfer to the Main Shaft. After final inspection, each buffer box will be placed loaded into a shielded transfer cask and then loaded onto a rubber-tired trolley. Using a tow vehicle, the trolley with transfer cask will be moved to the Main Shaft and then moved into and secured within the cage. Upon arrival at the repository level, the trolley with transfer cask is removed from the cage by another tow vehicle and then taken to the entrance of a placement room.

The following sections and associated story boards describe procedures and equipment to be used in the handing and placement buffer boxes in the underground repository as well as associated room backfilling and room sealing activities. The handling and placement strategies are under development. The placement sequence described below will be optimized in the future after the surface based mock-up tests are completed.

6.1 UFC PLACEMENT IN REPOSITORY

The buffer box placement process is outlined below. It should be noted that all activities in the placement rooms will be remotely controlled once the first buffer box has been received at the room entrance.

- The transfer cask (with buffer box) will be received from the UFPP via the Main Shaft cage on a tire based trolley;
- Once underground, the transfer cask would be transported to a shielding canopy located at the entrance to a placement room. An ejection ram will allow the buffer box to be pushed out of the transfer cask;
- Prior to receiving the buffer boxes and the commencement of placement activities, a 100 mm bentonite floor-levelling layer will have been deposited in the placement room. Floor plates (with integrated ventilation ducts) would then have been laid on top of the bentonite levelling layer;
- Through the access window in the shielding canopy, the buffer box would be transferred to the placement vehicle waiting inside the shielding canopy;
- The placement vehicle would travel the length of the placement room to the final placement location;
- The placement vehicle would deposit the buffer box. The Buffer box center-to-center spacing would be 1.5 m and 1.7 m for the Crystalline and Sedimentary design cases, respectively. Vertically, the buffer boxes are stacked 2 high in a staggered pattern (see Figure 13);
- After the placement of two buffer boxes, two bentonite spacer blocks would be placed in a similar fashion to the buffer box placement;
- The placement vehicle would exit the placement room through the shielding canopy;
- The bentonite pellet placement system would enter the placement room through the rear door of the shielding canopy and perform the pellet placement operation – injecting loose bentonite pellets in the annular spaces around the buffer boxes. It would then exit the placement room;

- The placement vehicle with the magnetic floor plate removal system would enter the placement room through the rear door of the shielding canopy, remove a floor plate segment and then exit.

It is expected that the entire UFC / buffer box placement process will take approximately four hours per box. Further, it is anticipated that each phase of the process will take four operators to complete (connecting and operating equipment, etc.).

Graphical storyboards of the key steps in the transfer and placement of the UFCs / buffer boxes are provided as Figures 42, 43, 44 and 45 (found at the end of Section 6). The first of these illustrations provides a summary of the required placement equipment.

Two placement operations are expected to be performed in parallel to achieve the required annual 2,500 buffer box transfer rate.

6.1.1 Placement Equipment

Various pieces of equipment will be developed specifically for this project due to the unique nature of the work. The placement equipment to be used are illustrated in the legend located at the beginning of Figure 42.

Buffer Box Placement Vehicle: This remotely-controlled underground vehicle is based on a highly customized commercial electric forklift with various enhancements including built-in remote operation sensing, lighting, and camera equipment as well as a customized lifting attachment to accommodate the buffer boxes and spacer blocks. It will also have an attachment for placing the floor plates. At least four placement vehicles are expected to be needed, assuming two active placement rooms are working in parallel and two vehicles are held as spares for maintenance rotations.

Shielding Canopy: The buffer box placement concept relies on shielded operations for all activities that occur after the buffer box is received at the placement room entrance. This mobile canopy will permit shielded activities to take place inside, while also allowing use of the panel access tunnel by passing vehicles and personnel. The small annular space around the canopy perimeter can be covered by manually placed lead shielding packs to ensure no radioactive shine escapes around the edges, if required.

The canopy design features include shielded hinged access doors for vehicle access and for buffer box insertion. A shielded access window is also included to allow buffer boxes and bentonite spacer blocks to be passed through.

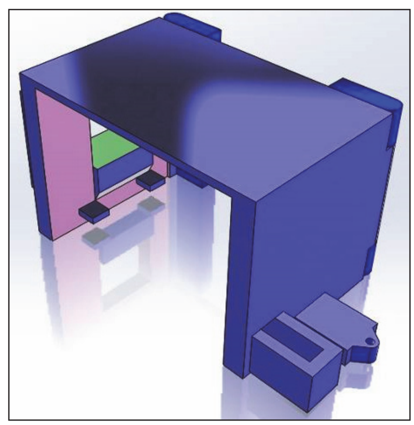


Figure 39: Shielding Canopy

Bentonite Pellet Injection System: For every two buffer boxes and two DBF spacer blocks that are placed, all annular spaces around the boxes will be filled with loosely-placed bentonite pellets (gap fill). Using a piece of equipment similar to the placement vehicle, the bentonite placement system will rely on pneumatic or augered insertion of the loose bentonite using ejection nozzles that can access all annular spaces around the buffer boxes.

Floor Plates with Ventilation Ducts: The use of temporary metal plates with integrated ventilation ducts will facilitate equipment access to the work face. Fresh air is delivered into the placement room via room cross-section. The air is then exhausted ("sucked") from the room via the ventilation duct which removes heat and dust from the room.

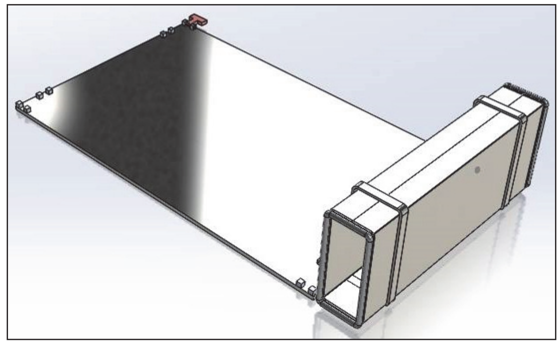


Figure 40: Floor Plate with Built-in Ventilation Duct

The floor plates would be installed before start of buffer box placement activities. As placement activities progress towards the room entrance, segments of floor plate will be removed. A magnetic attachment on the placement vehicle would be used to pick up the plate segments and bring them out of the placement room.

6.2 BACKFILLING AND SEALING OF PLACEMENT ROOMS

Once the placement room has been filled with UFC / buffer boxes, a stack of spacer blocks will be assembled after the last buffer box. The length of placement room between the last placed buffer box and the start of the room seal is 4 m. For the crystalline case two offset stacked rows of eight 0.5-m-thick spacer blocks will be required, and in the sedimentary case two rows of six 0.7-m-thick spacer blocks are needed. The annular space around the blocks will be filled with loosely placed bentonite pellets similar to the process used during buffer box placement.

The spacer block backfill process will require several pieces of equipment:

- Placement vehicle for spacer blocks;
- Shielding canopy and trolley;
- Bentonite pellet placement system;
- Floor plate handling system;
- Bentonite spacer block trolley; and
- Tow vehicle.

Once the room has been successfully backfilled, a room seal would be assembled. The room seal is comprised of large HCB blocks and bricks, as illustrated in Figure 41 (HCB blocks in red, HCB bricks in green). The annular space around the blocks will be filled with loosely placed bentonite pellets in parallel with the block placement process.

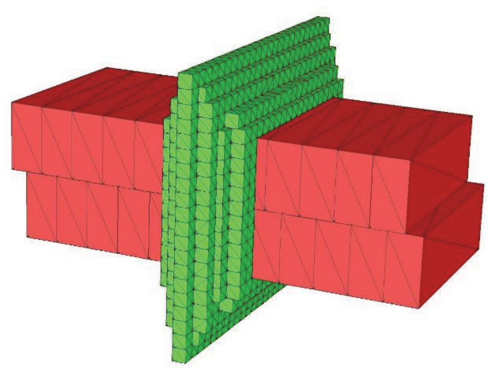


Figure 41: Room Seal

Equipment required for the room seal construction process will generally be consistent with that needed for placing the DBF spacer blocks. The two differences are that the placement vehicle for the spacer blocks and the shielding canopy will not be required. Once complete, the placed blocks are expected to provide adequate shielding from the buffer boxes to allow the room seal and concrete bulkhead construction operations to be completed without shielding.

A simplified graphical storyboard of the key steps involved in the backfilling and room seal construction process is included as Figure 46 (found at the end of Section 6). Immediately preceding the storyboard, a summary of the required equipment is provided in the legend.

Once the room seal is complete the concrete bulkhead can be assembled. The completed concrete bulkhead is recessed 1 m from the entry to the placement room.

6.3 HANDLING OF DEFECTIVE UFCS OR BUFFER BOXES

When non-destructive testing or visual inspection shows defects that do not fulfill requirements for placement in the underground repository, the UFC and/or its buffer box will be held in the UFPP for subsequent handling. Should a defective container be discovered, the normal packaging process will be stopped on that line to ensure that no additional vessels are produced with the same defect(s). The cause of the defect(s) will be investigated and any issues resolved before the packaging process will be allowed to resume.

The UFC will be transferred to the fuel handling cell where it will be opened, and the fuel is remotely grappled out and transferred to storage positions in the fuel handling cell. The UFC will then be transferred to the active mechanical workshop where it will be decontaminated and packaged for subsequent handling. If possible, the vessel will be re-used. It may also be decontaminated and shipped off-site for recycling.

Once the packaging process resumes, a new UFC will be docked to the fuel handling cell. The basket from the previous unloading of the defective container will be loaded into the new UFC for normal processing.

Legend for Container Placement Equipment

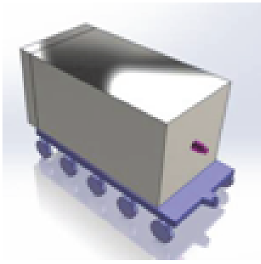
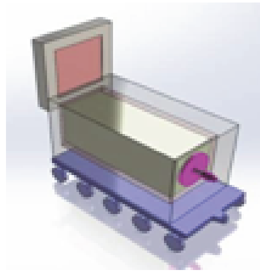
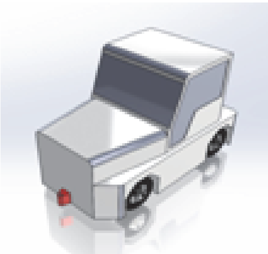
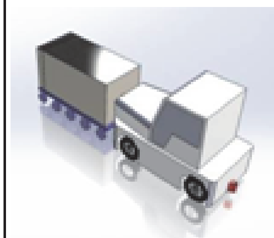
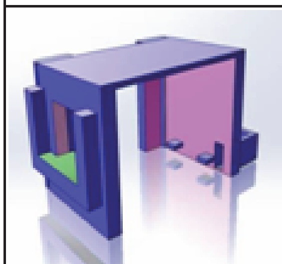
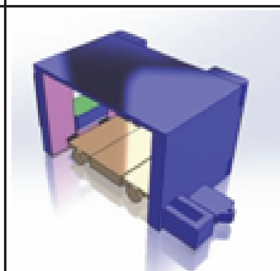
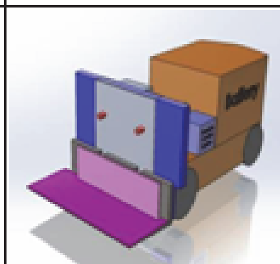
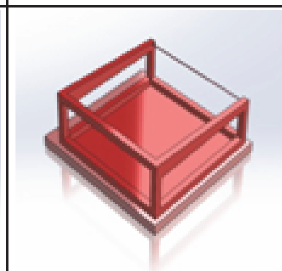
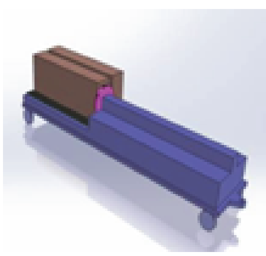
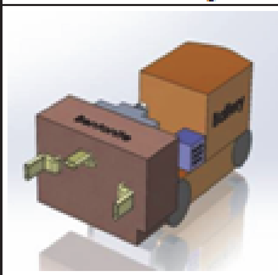
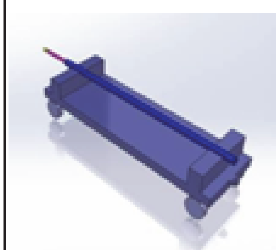
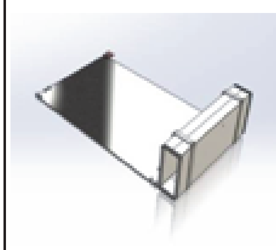
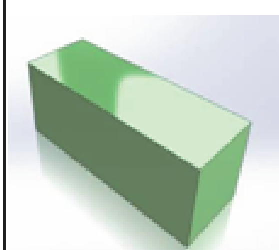
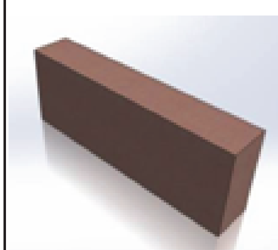
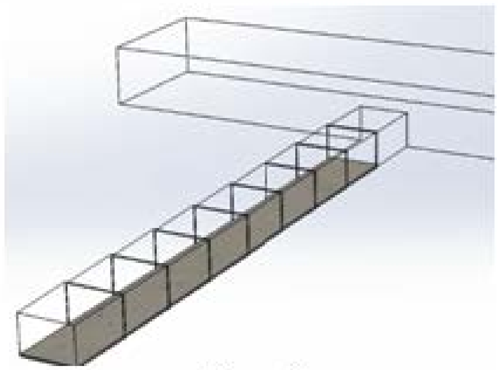
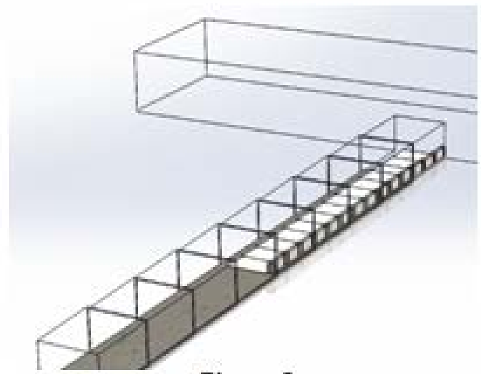
 UFC Transfer Cask & Trolley	 UFC Transfer Cask Door Open with UFC	 Tow Vehicle	 Tow Vehicle with UFC Transfer Cask
 Shielding Canopy	 Shielding Canopy with Trolley	 Placement Machine	 Floor Plate Handling System
 Trolley for Bentonite Blocks	 Bentonite Pellet Blowing System	 Hydraulic Cylinder Cart	 25-mm-thick Floor Plate with Ventilation Duct
 Buffer Box	 DBF Spacer Block	 UFC	

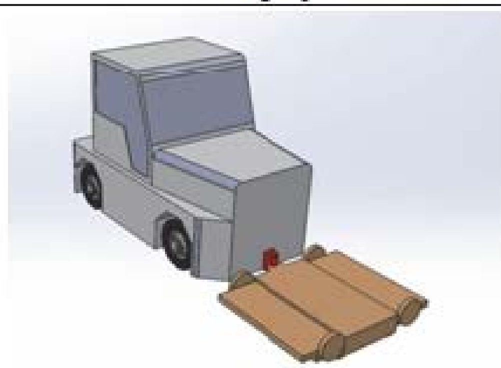
Figure 42: Preparation of Placement Room & Shielding Canopy - Sequence of Operations



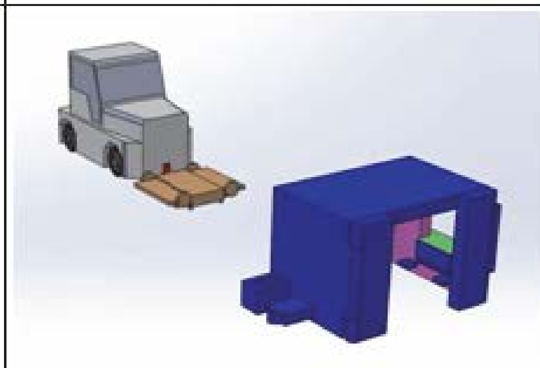
Phase 1
Placement of 100-mm-thick bentonite levelling layer



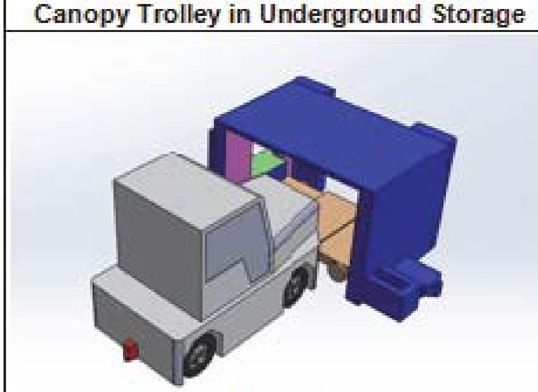
Phase 2
Placement of Floor Plates with ventilation duct



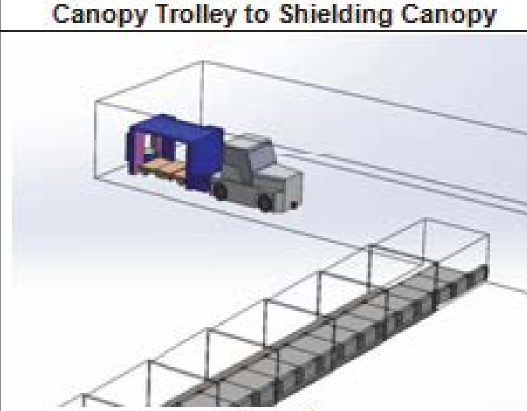
Phase 3
Connect Tow Vehicle to Shielding Canopy Trolley in Underground Storage



Phase 4
Move Tow Vehicle with Shielding Canopy Trolley to Shielding Canopy

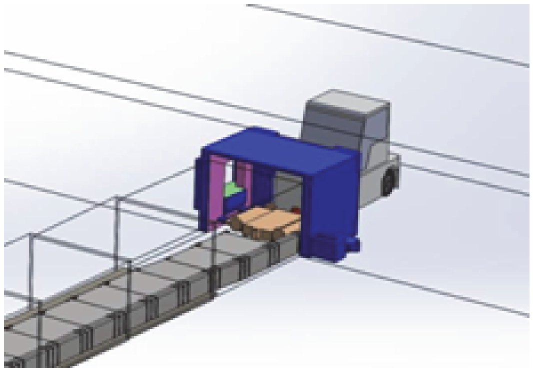


Phase 5
Connect Shielding Canopy Trolley to Shielding Canopy

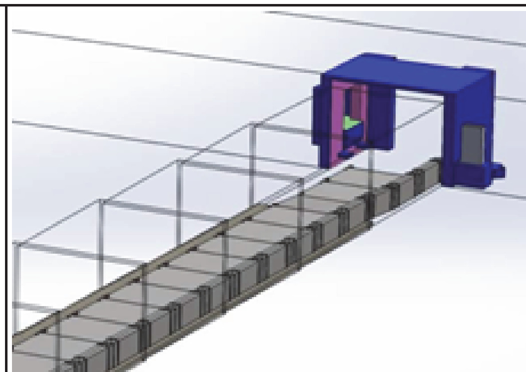


Phase 6
Move Shielding Canopy to the next Placement Room entrance

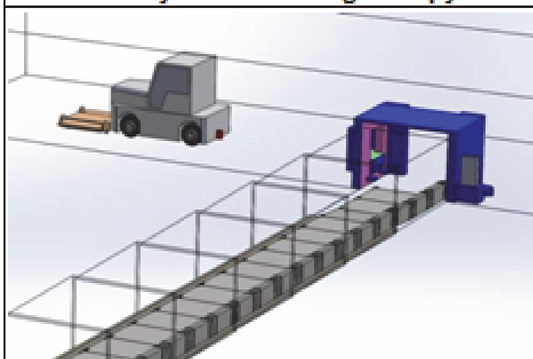
Preparation of Placement Room & Shielding Canopy - Sequence of Operations (continued)



Phase 7
Disconnect Shielding Canopy
Trolley from Shielding Canopy

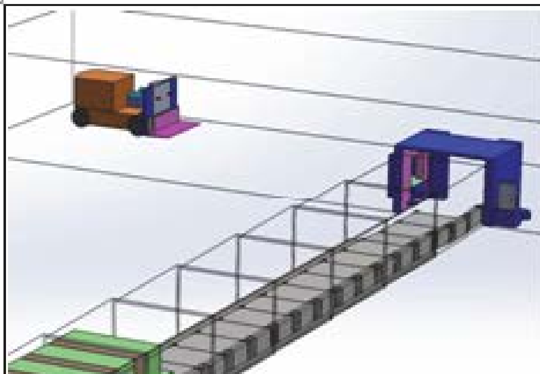


Phase 8
Connect Shielding Canopy
to ventilation and services

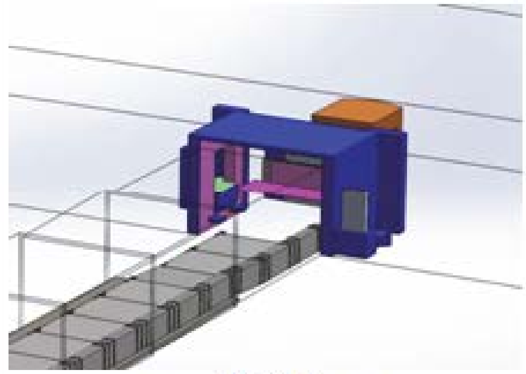


Phase 9
Move Tow Vehicle with Shielding Canopy
Trolley to Underground Storage

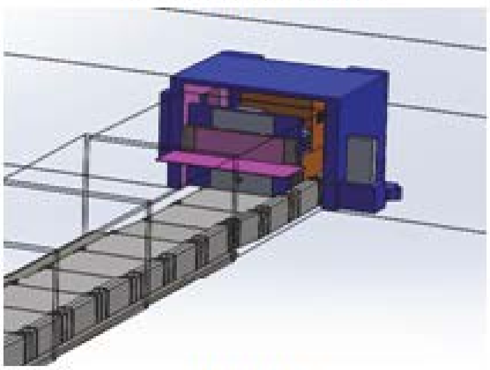
Figure 43: Container / Buffer Box Placement - Sequence of Operations



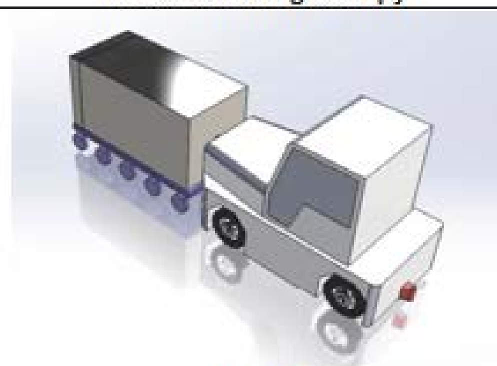
Phase 1
Move Placement Vehicle
to Shielding Canopy



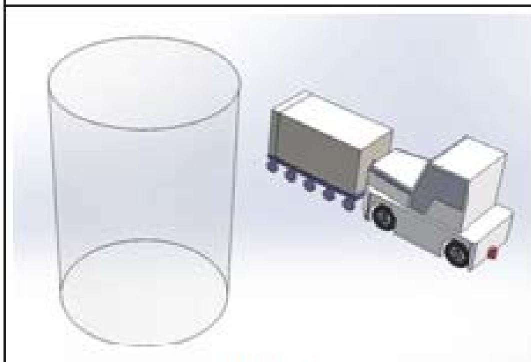
Phase 2
Move Placement Vehicle
inside Shielding Canopy



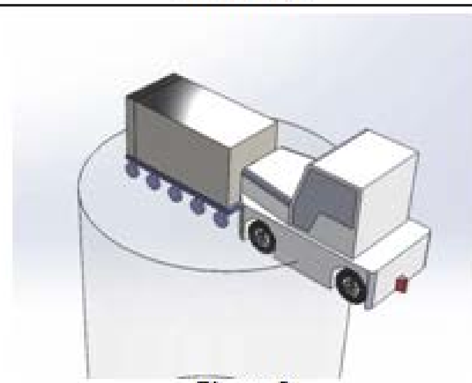
Phase 3
Close and secure Shielding Canopy Doors



Phase 4
Inside UFPP connect Tow Vehicle to Trolley
loaded with Transfer Cask containing
Buffer Box

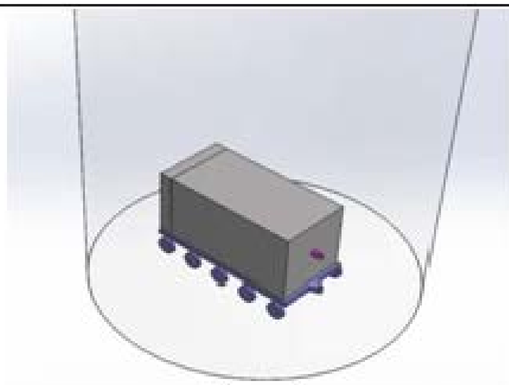


Phase 5
Move Trolley with
Transfer Cask to Main Shaft Hoist Area

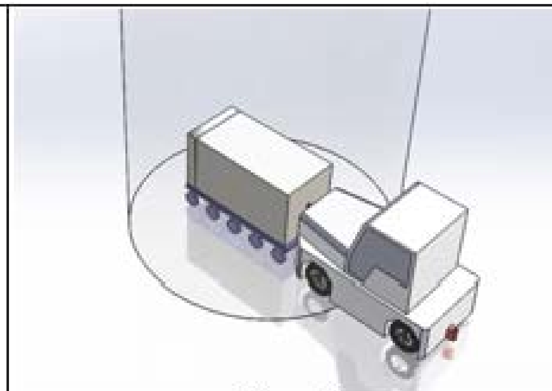


Phase 6
Move Trolley with Transfer Cask onto Main
Shaft Cage and secure

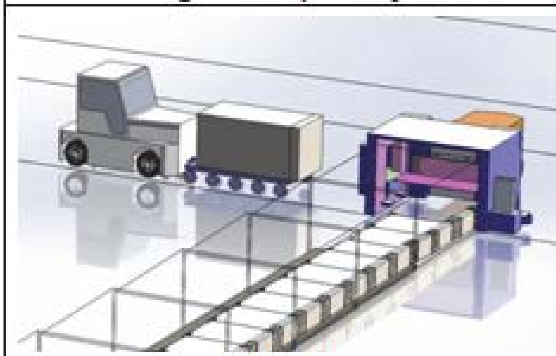
Container / Buffer Box Placement - Sequence of Operations (continued)



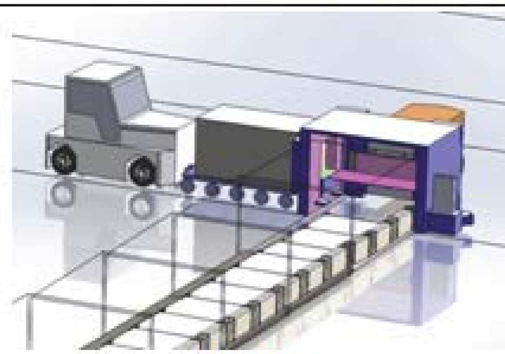
Phase 7
Trolley with Transfer Cask descend to Underground repository level



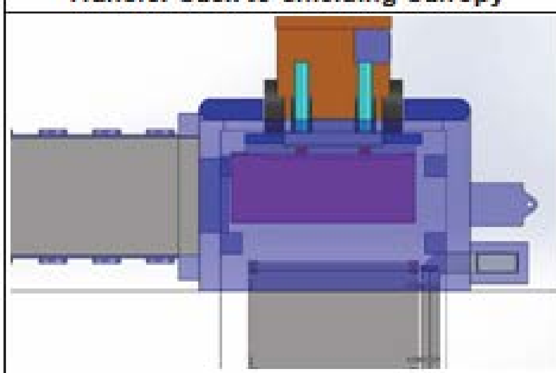
Phase 8
Unsecure and move Trolley with Transfer Cask off Shaft Hoist



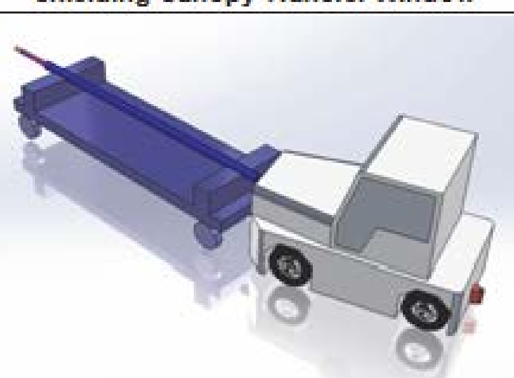
Phase 9
Move Trolley with Transfer Cask to Shielding Canopy



Phase 10
Secure UFC Transfer Cask to Shielding Canopy Transfer Window

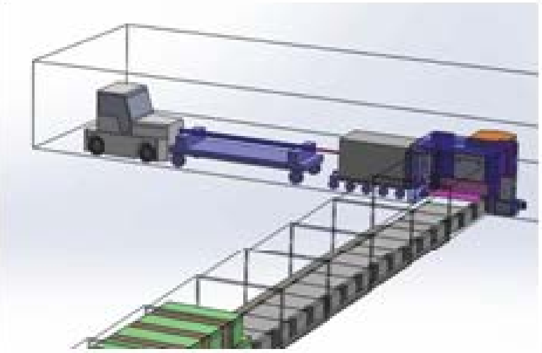


Phase 11
Verify alignment of Placement Vehicle Wedge Tray & UFC Transfer Cask

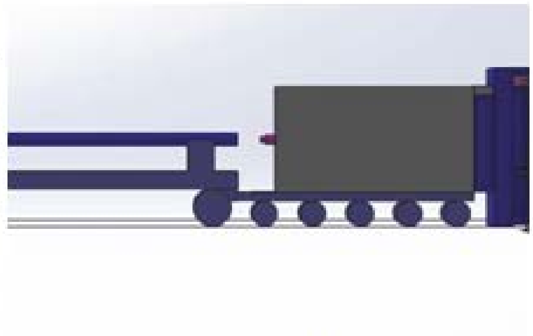


Phase 12
Connect Tow Vehicle to Hydraulic Cylinder Cart in Underground Storage

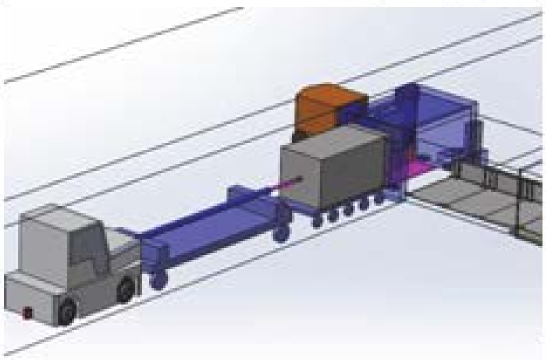
Container / Buffer Box Placement - Sequence of Operations (continued)



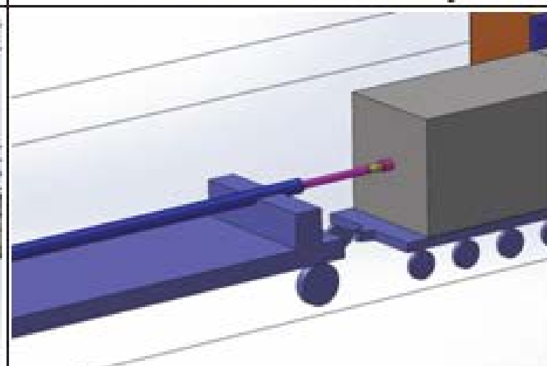
Phase 13
Move Hydraulic Cylinder Cart to Transfer Cask at Shielding Canopy



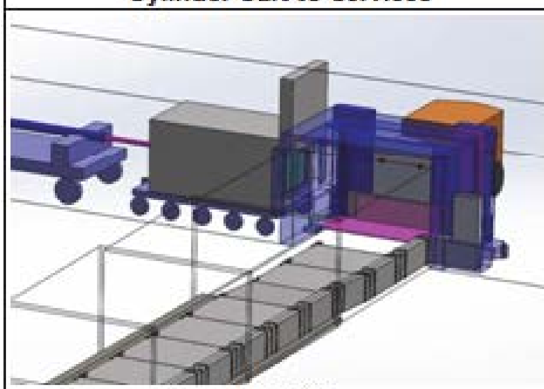
Phase 14
Connect Hydraulic Cylinder Cart to Transfer Cask Trolley



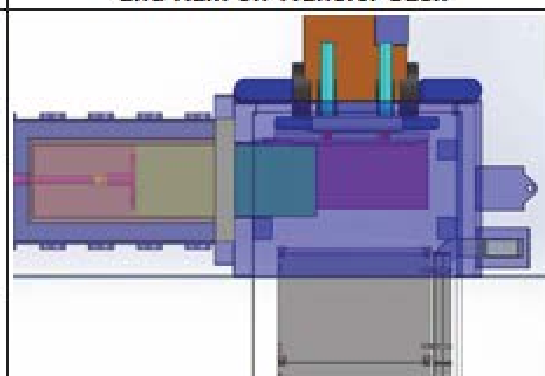
Phase 15
Connect Hydraulic Cylinder Cart to Services



Phase 16
Install Coupling between Cylinder and Ram on Transfer Cask

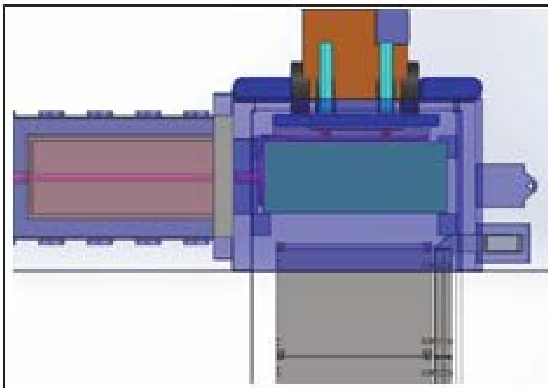


Phase 17
Open Transfer Cask Shielding Door

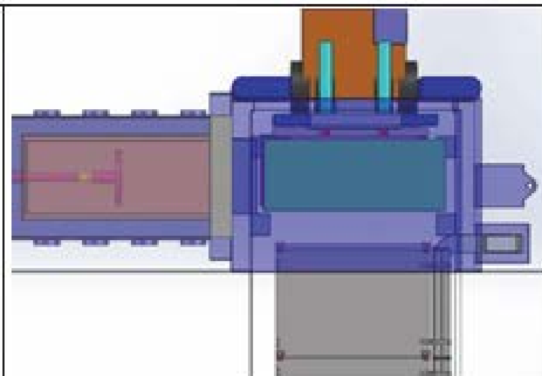


Phase 18
Push Buffer Box from Transfer Cask on low friction liner and window opening support

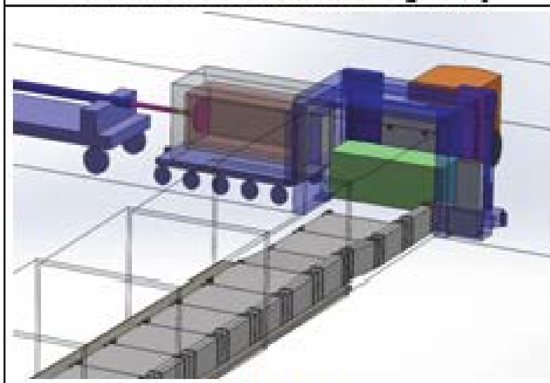
Container / Buffer Box Placement - Sequence of Operations (continued)



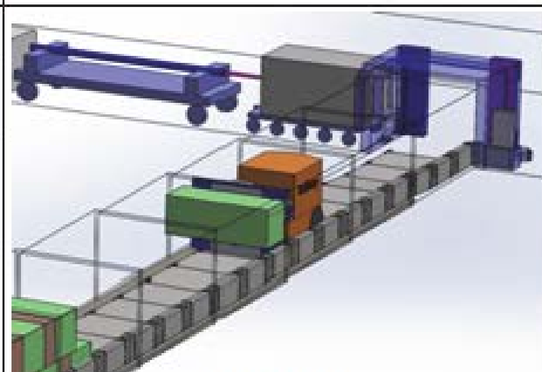
Phase 19
Verify position of Buffer Box on
the Placement Vehicle Wedge Tray



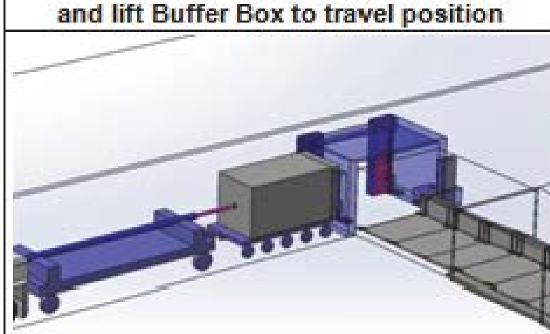
Phase 20
Retract Cylinder



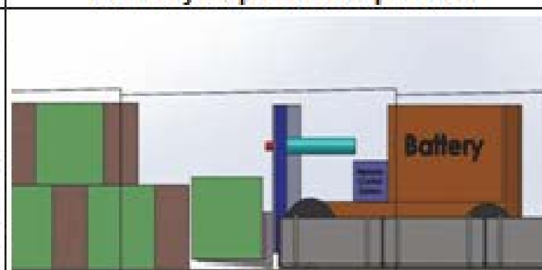
Phase 21
Close Transfer Cask Shielding Door
and lift Buffer Box to travel position



Phase 22
Move Placement Vehicle
remotely to placement position

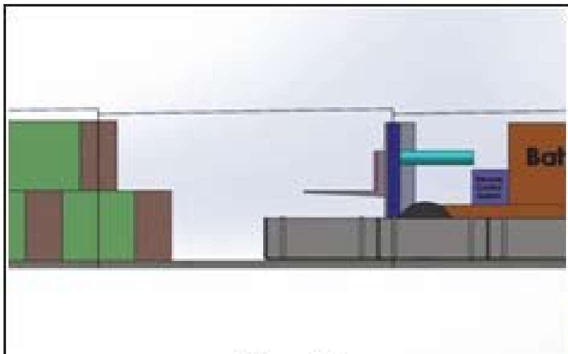


Phase 23
Disconnect Hydraulic
Cylinder Cart from Services

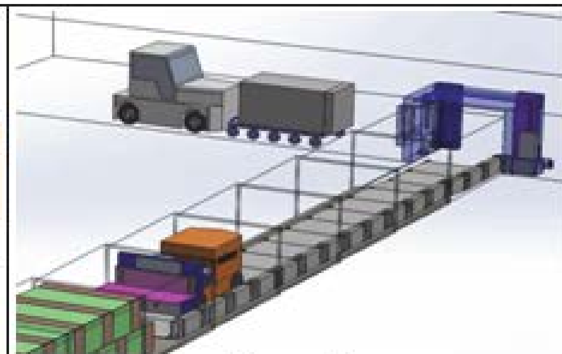


Phase 24
Position Placement Vehicle
Wedge Tray and eject Buffer Box

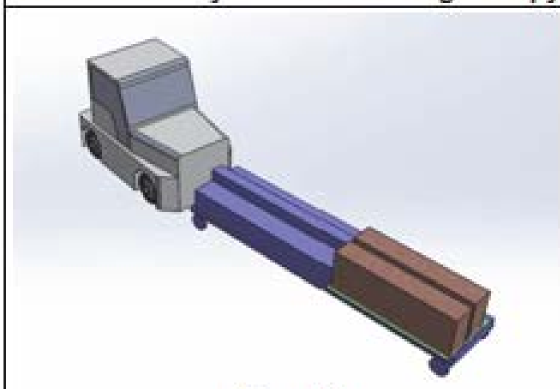
Container / Buffer Box Placement - Sequence of Operations (continued)



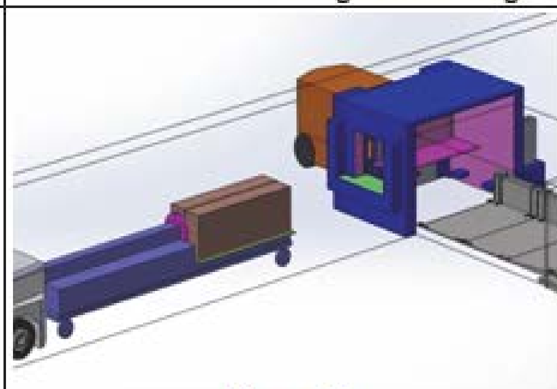
Phase 25
Position Wedge Tray and move Placement Vehicle remotely back to Shielding Canopy



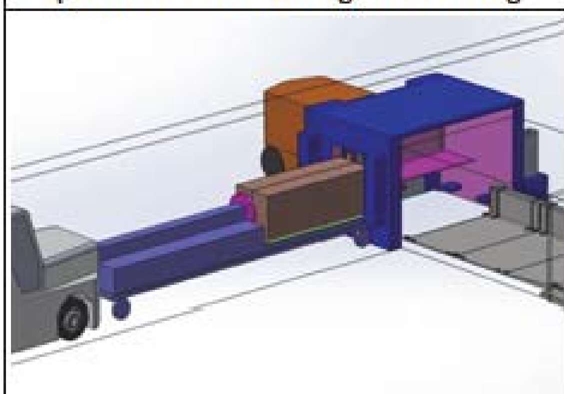
Phase 26
Move Trolley with empty UFC Transfer Cask to Underground Storage



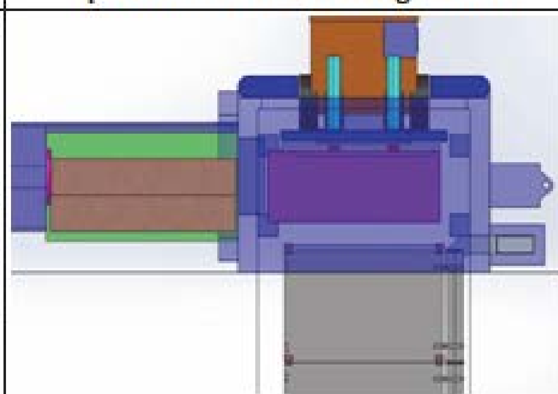
Phase 27
Connect Tow Vehicle to Trolley with DBF Spacer Blocks in Underground Storage



Phase 28
Move Trolley with DBF Spacer Blocks to Shielding Barrier

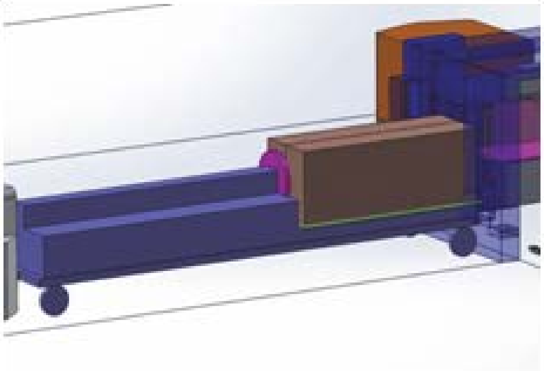


Phase 29
Secure Trolley with DBF Spacer Blocks to Shielding Canopy Transfer Window

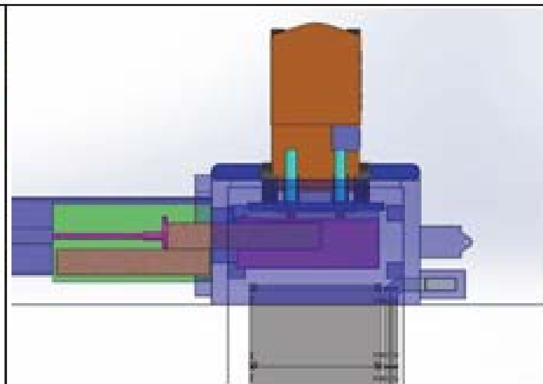


Phase 30
Verify alignment of Placement Vehicle Wedge Tray and DBF Spacer Block

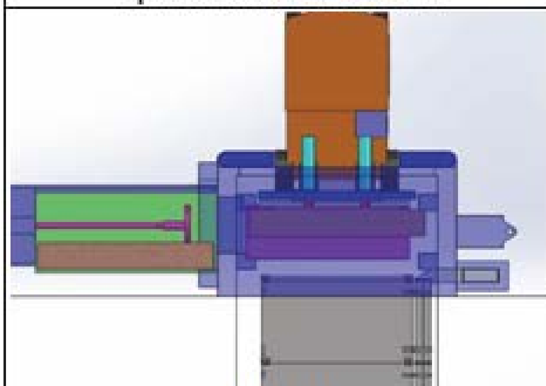
Container / Buffer Box Placement - Sequence of Operations (continued)



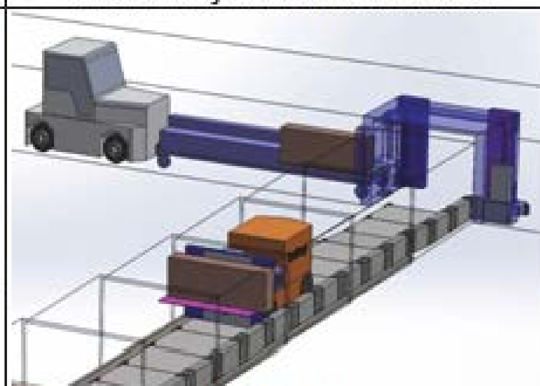
Phase 31
Connect Trolley for DBF
Spacer Blocks to Services



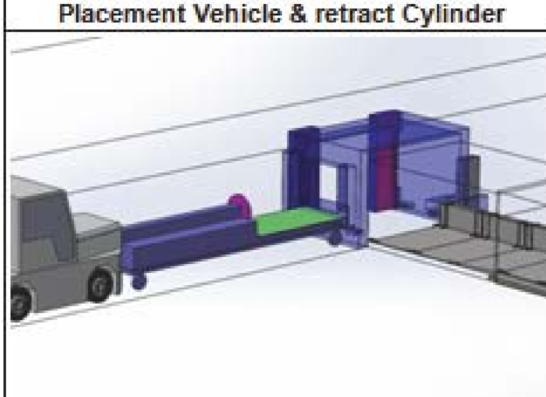
Phase 32
Move DBF Spacer Block
from Trolley to Placement Vehicle



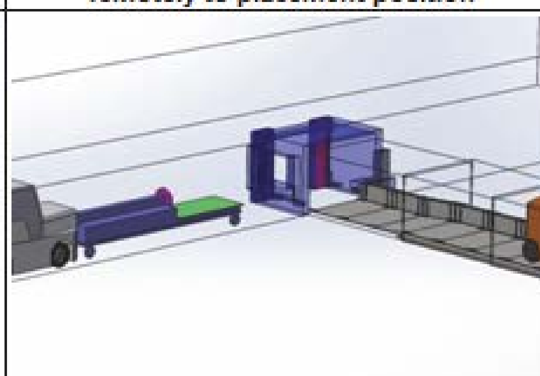
Phase 33
Verify position of DBF Spacer Block on the
Placement Vehicle & retract Cylinder



Phase 34
Move Placement Vehicle
remotely to placement position

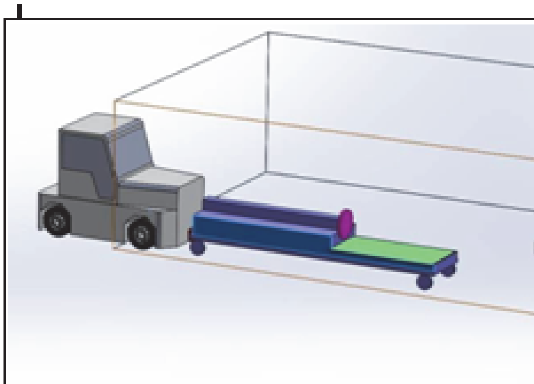


Phase 35
Disconnect Trolley for DBF
Spacer Blocks from Services

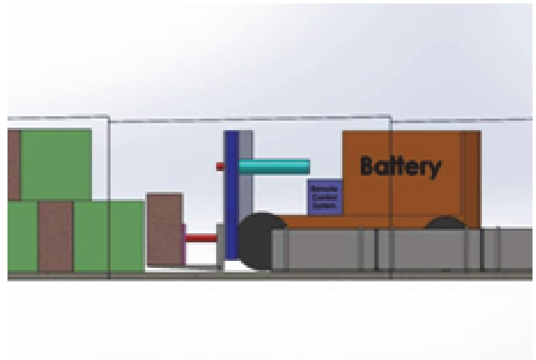


Phase 36
Disconnect Trolley for DBF
Spacer Blocks from Shielding Canopy

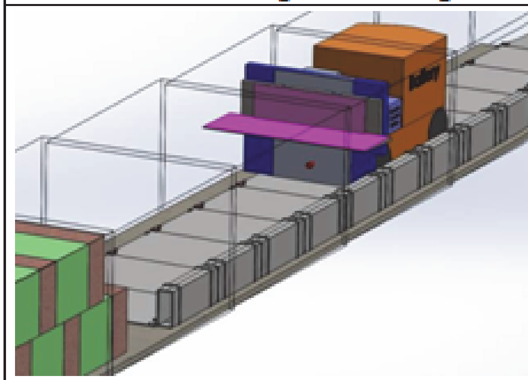
Container / Buffer Box Placement - Sequence of Operations (continued)



Phase 37
Move Trolley for DBF Spacer
Blocks to Underground Storage

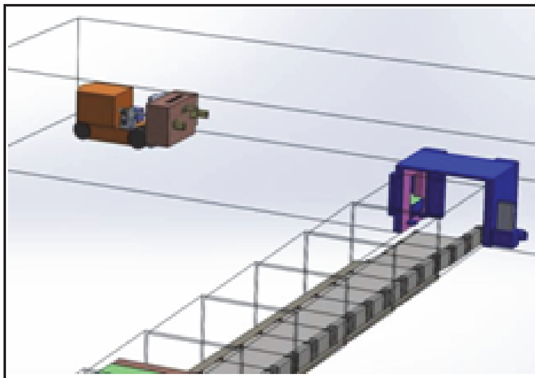


Phase 38
Position Placement Vehicle Wedge
Tray and eject DBF Spacer Block

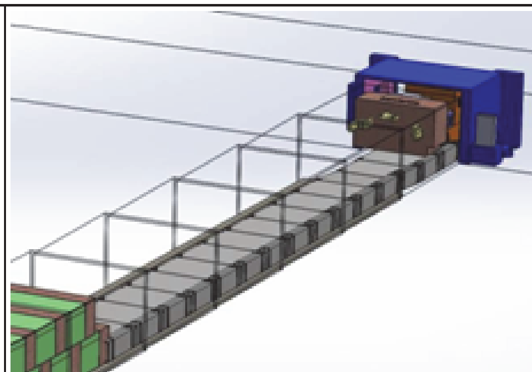


Phase 39
Position Wedge Tray and move Placement
Vehicle remotely back to Shielding Canopy

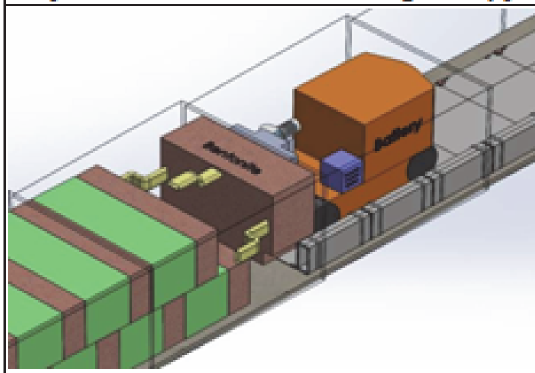
Figure 44: Bentonite Pellet Placement - Sequence of Operations



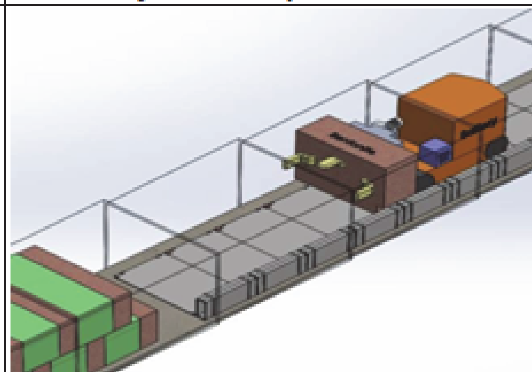
Phase 1
Move Bentonite Pellet Placement System Vehicle to the Shielding Canopy



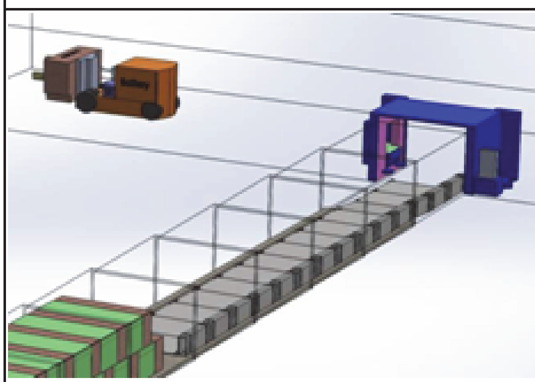
Phase 2
Move Bentonite Pellet Placement Vehicle remotely to the last placed Buffer Box



Phase 3
Blow in Bentonite Pellets

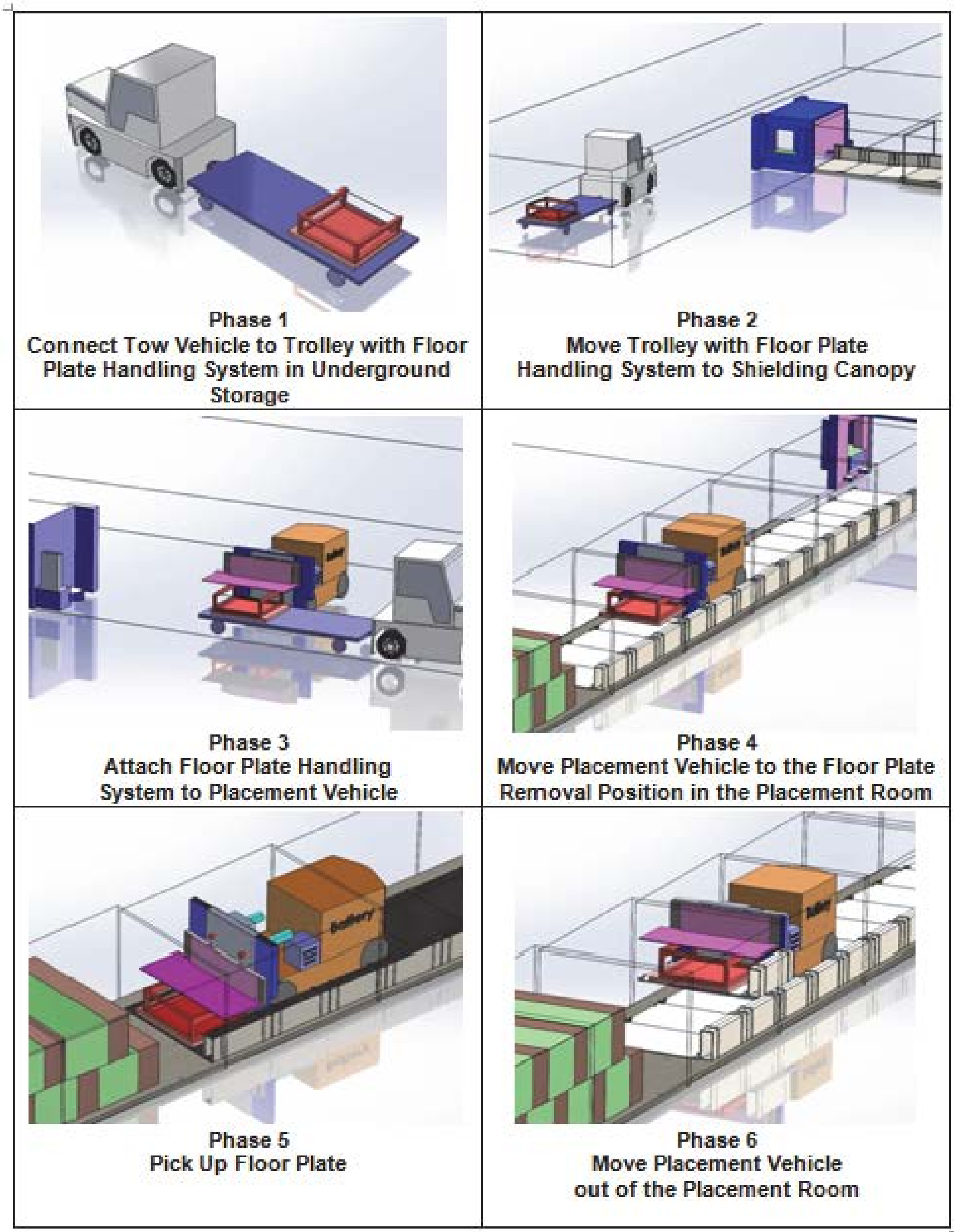


Phase 4
Move Bentonite Pellet Placement Vehicle out of the Placement Room



Phase 5
Move Bentonite Pellet Placement Vehicle to the Underground Storage

Figure 45: Floor Plate / Ventilation Duct Removal - Sequence of Operations



Phase 1
Connect Tow Vehicle to Trolley with Floor Plate Handling System in Underground Storage

Phase 2
Move Trolley with Floor Plate Handling System to Shielding Canopy

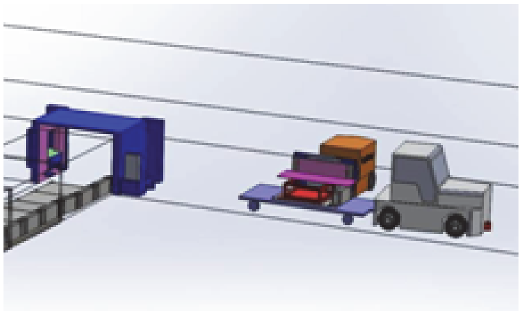
Phase 3
Attach Floor Plate Handling System to Placement Vehicle

Phase 4
Move Placement Vehicle to the Floor Plate Removal Position in the Placement Room

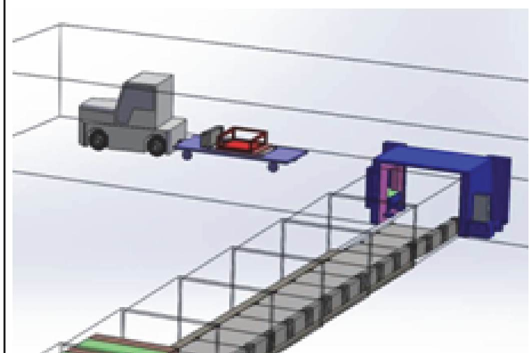
Phase 5
Pick Up Floor Plate

Phase 6
Move Placement Vehicle out of the Placement Room

Floor Plate / Ventilation Duct Removal Operation (continued)



Phase 7
Detach Floor Plate Handling System
and Floor Plate from Placement Vehicle



Phase 8
Return Floor Plate System with
Floor Plate to Underground Storage

Legend for Placement Room Sealing Equipment

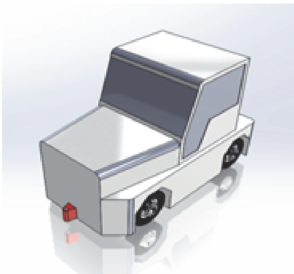
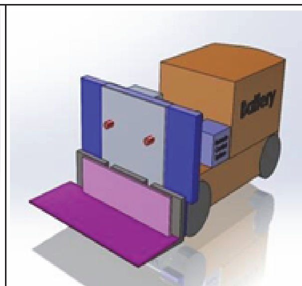
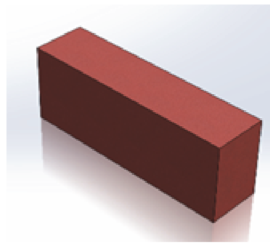
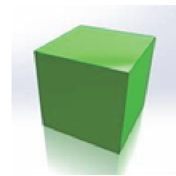
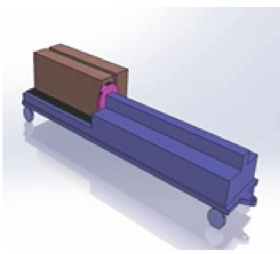
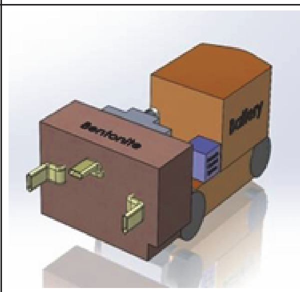
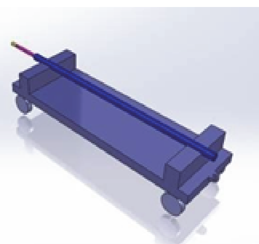
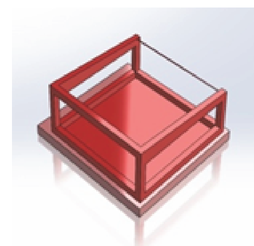
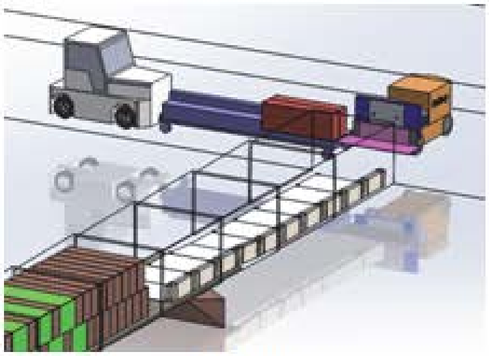
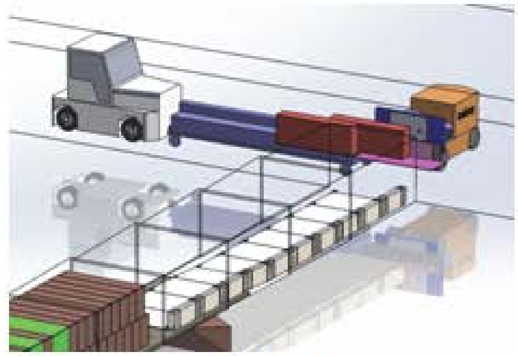
 Tow Vehicle	 Placement Vehicle	 Spacer Block	 HCB Bricks
 Trolley for HCB Blocks and Bricks	 Bentonite Pellet Placement System	 Hydraulic Cylinder Cart	 Floor Plate Handling System

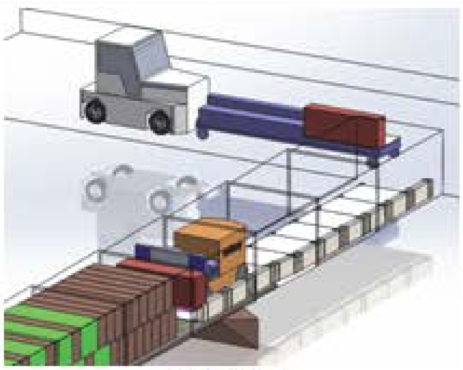
Figure 46: Sealing of Placement Room - Sequence of Operations



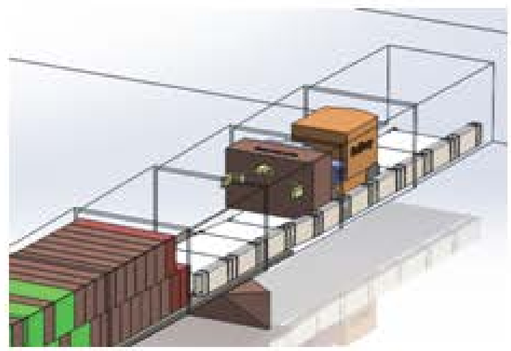
Phase 1
Align and connect Trolley with
Placement Vehicle Wedge Tray



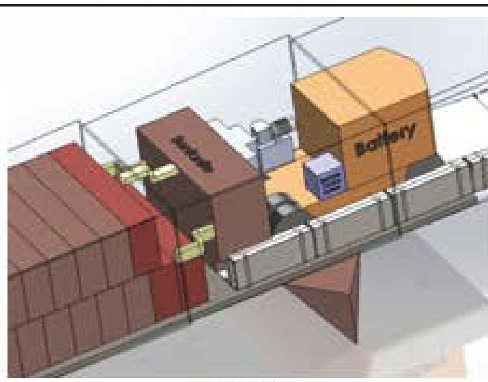
Phase 2
Move HCB Block from
Trolley to Placement Vehicle



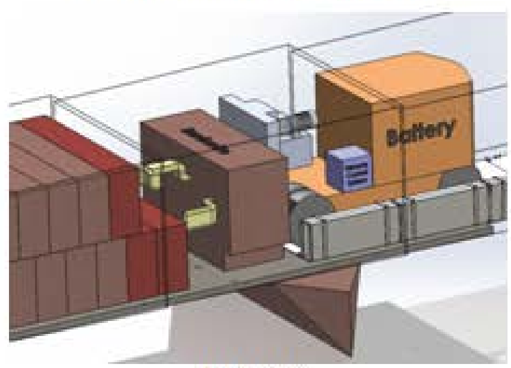
Phase 3
Position Placement Vehicle Wedge
Tray and eject HCB Block



Phase 4
Move Bentonite Pellet
Vehicle to the HCB Block wall

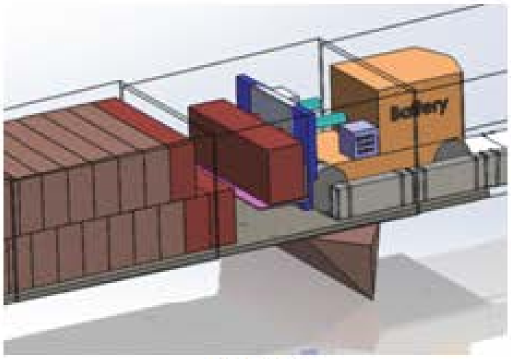


Phase 5
Fill gaps around
HCB Block with Bentonite Pellets

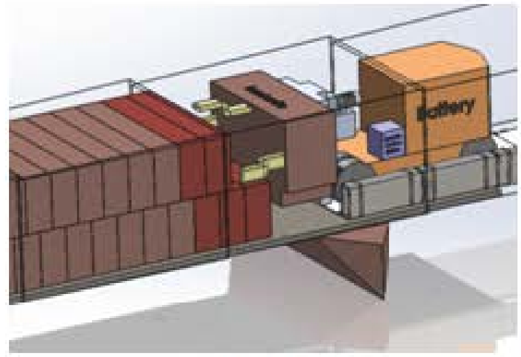


Phase 6
Manually Level Bentonite
Pellets in front of HCB Blocks

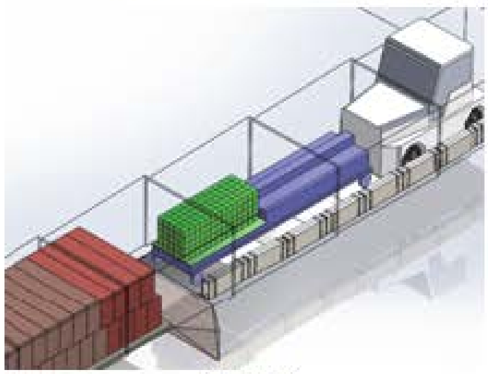
Sealing of Placement Room - Sequence of Operations (continued)



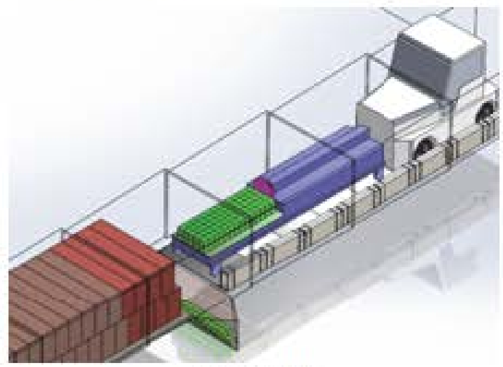
Phase 7
Position Placement Vehicle Wedge
Tray and eject HCB Block



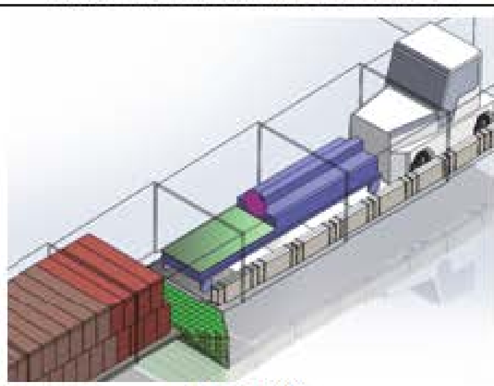
Phase 8
Blow Bentonite Pellets in EDZ
Notch with Bentonite Pellet Vehicle



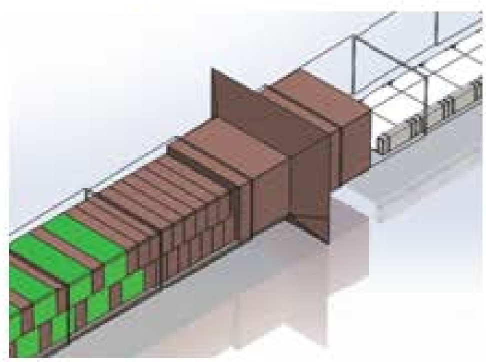
Phase 9
Position Trolley
with Bricks in front of EDZ Notch



Phase 10
Manually remove Bricks from Trolley and
place in EDZ Notch



Phase 11
Repeat Phase 8 to 10
until Notch is filled



Phase 12
Repeat Process until Room Seal is filled

7. CONTAINER RETRIEVAL

The following section describes the approach for a buffer box / container retrieval system to safely extract a UFC (inside a buffer box) from its location in the repository for subsequent transport to the DGR surface facilities. There are two major stages in the retrieval operation: providing access to the target buffer box with its UFC; and, retrieving the buffer box.

7.1 GAINING ACCESS TO TARGET UFC

Activities related to providing access to the target buffer box (with its UFC) will be significantly impacted by the location of the buffer box within a particular placement room as well as the length of time that has passed after its placement.

The immediate retrieval of a buffer box (and UFC) when the placement room is still open will not have to contend with the backfill used to seal the placement room. Secondly, and depending upon the extent that the placement room’s development has been completed, the room’s concrete bulkhead may or may not be in place.

The primary backfill materials in the placement rooms will be in the form of spacer blocks and pneumatically placed bentonite pellets. Of particular importance to the buffer box retrieval process are the characteristics of these materials, some of which may have been in place for an extended period of time. Over time, the placed backfill materials may evolve from an unsaturated to a saturated condition. Alternatively, the heat produced from the entombed UFCs may cause some of this fill to become dry and hard.

The amount of water saturation that the surrounding bentonite will experience is also important for buffer box retrieval. Bentonite swells with moisture becoming a significant barrier to water movement but, more importantly, the swelling will introduce a gripping pressure on the buffer box. The net effect of this pressure is that a simple mechanical means of pulling the buffer box from a placement room cannot be performed by extraction equipment until the gripping pressure has been relieved.

The immediate impediments to buffer box retrieval (removal of the concrete bulkhead, the room seal gap fill, and the dense backfill) are discussed below. As noted, in order to minimize mechanical disturbance to the placed UFCs from transmitted lateral forces, the reuse of drill & blast techniques previously employed for the development of the repository was not considered to be appropriate (material hauling vehicles, the LHDs and haul trucks, may still be used).

7.1.1 Concrete Bulkhead Removal

To remove the concrete bulkhead without mechanically disturbing any placed UFCs, a non-explosive expansion agent will be used. Under such an approach, boreholes would be drilled into the concrete bulkhead and loaded with an expansion agent. Commonly available as powder based materials that are mixed with water for activation, such agents can generate a high expansive stress without the ground vibration that is associated with drill & blast methods. The agent expands as it cures over a period of hours or days generating sufficient pressure to break the concrete (the bulkhead may require some cutting to allow room for expansion). The resulting concrete fragments are then removed through traditional mining material removal techniques.

7.1.2 Room Seal Removal

The room seal is comprised of a large number of HCB bricks placed in a stacking arrangement to fill the cross section of the placement room. Its removal process must result in a flat, structurally stable travel surface over this area for retrieval operations to be performed. The floor notch itself would be excavated and refilled with gravel or a suitable structure for vehicle travel. The removal work will need to either take into account protection for any manual processes or it must be accomplished in a completely remote fashion. As the room seal is removed, there will be progressively less radiation protection from the UFCs (inside buffer boxes) behind it.

7.1.3 Removal of DBF Spacer Blocks and Gap Fill

The backfill in the placement room is composed of a series of spacer blocks as well as gap fill. To effectively carry out the removal of this material without mechanically disturbing the placed UFCs, a hydrodynamic method will be employed. The basic premise is to wash away the backfill materials with a saline water solution. While potentially time consuming, the reasons for a hydrodynamic technological approach are:

- The approach has been demonstrated in other applications as an effective means to eliminate gripping pressures prior to attempting container retrieval;
- Simultaneous chemical and mechanical action on the buffer erodes the compacted bentonite in any state (ranging from dry and hard to fully saturated);
- The method can be applied in a continuous process with little risk of damage to the UFC; and
- No bulky load-bearing or positioning structural parts are needed (compared with equipment that uses some type of mechanical freeing technology).

The method essentially consists of two stages: slurrying of the backfill materials; and, dewatering of the generated slurry (which will contain a large volume of water).

Technology is currently available to deal with slurries (a common requirement in many mining applications) and a multi-stage separation process may be employed. The key component technology, however, will be based on the mechanical dehydration of sludge using a common decanter centrifuge process. Figure 47 shows a typical decanter centrifuge for bentonite slurries.

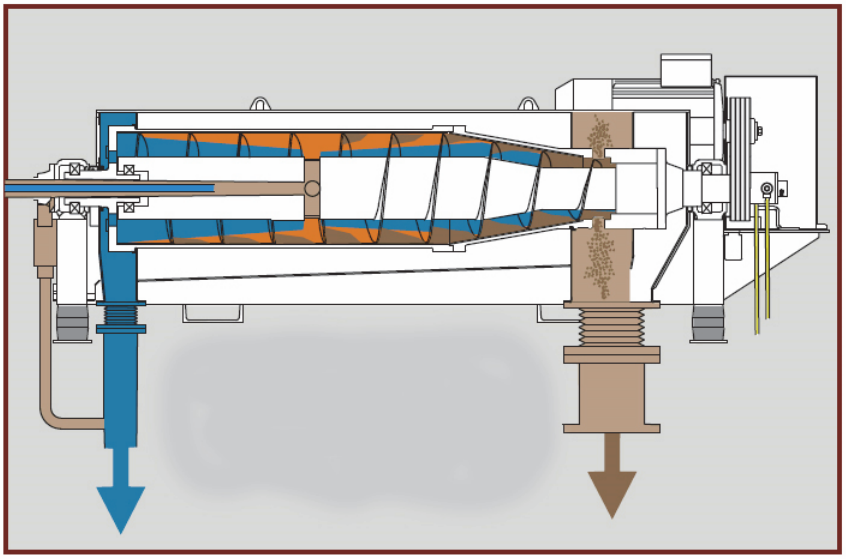


Figure 47: Typical Bentonite Decanting Equipment

The bentonite decanting system could be located outside the placement room in the access tunnel with hoses attached to the retrieval vehicle. Alternatively, the decanting system could be mounted on a unique piece of equipment similar to the placement vehicle. This would allow for a remotely controlled closed-loop bentonite collection and decanting system, integrated into an existing vehicle's power and control infrastructure.

It is possible that the slurry removed from the placement room may be classified as very low level waste (VLLW) or possibly low level waste (LLW), and would have to be managed accordingly.

7.2 UFC EXTRACTION AND RETRIEVAL

Once the backfill has been removed, the actual UFC retrieval process can be started. The envisaged process has primarily been influenced by the need to ensure a safe retrieval with continuous radiation shielding to allow unrestricted movement of personnel outside of the placement room as well as the effective re-use of placement equipment. The retrieval methodology has been based, to the extent possible, on the reversal of placement operations.

Some of the placement equipment can be re-used for retrieval. Such equipment will include the buffer box transfer cask, the shielding canopy and the associated trolleys. The shielding canopy and trolley, for example, would be outfitted with an ejection ram to allow the UFC to be pushed off the retrieval vehicle into the transfer cask. New equipment required for the retrieval operations will include a lift for the UFC, hydraulic cylinder carts and tow vehicles. Retrieval vehicles would be equipped with retractable spray nozzles for high pressure water, lifting forks with individual spray nozzles and, suction tubes for retrieving slurry. Further, equipment for recovery of solids from slurry (hydrodynamic removal and decanting systems) will need to be assembled.

A simplified version of the conceptual container retrieval system sequence is provided in pictorial storyboard form in Figures 48, 49, 50 and 51. These figures deal with discrete activities in the retrieval methodology. Operational sequencing is illustrated for: the preparation of the placement room and shielding canopy; gravel placement and leveling; and, retrieval of the UFC. It is expected that the retrieval process will take approximately 8 hours (per buffer box after the concrete bulkhead and room seal are removed). It is further anticipated that each phase of the process will take four operators to complete.

Prior to Figure 48 a legend is provided that shows retrieval equipment.

Legend for Container Retrieval Equipment

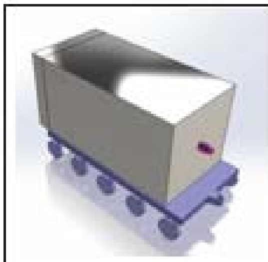
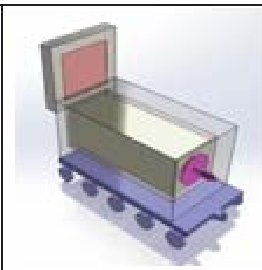
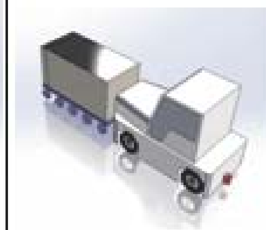
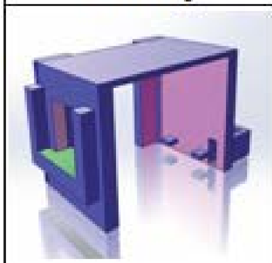
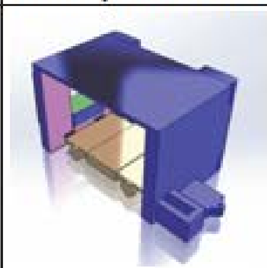
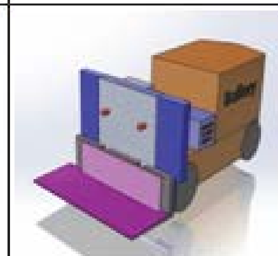
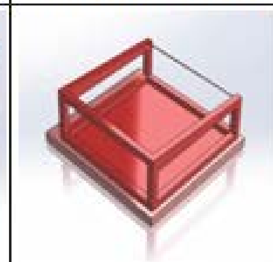
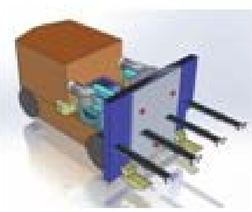
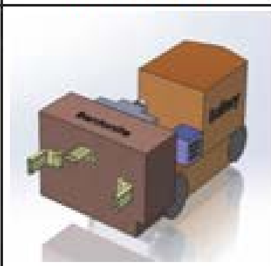
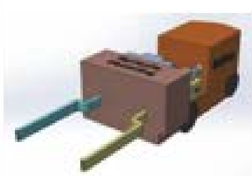
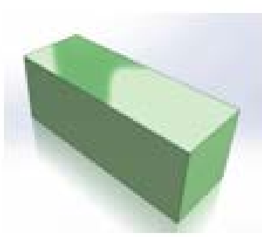
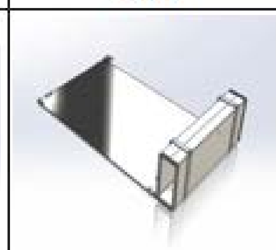
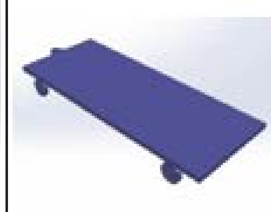
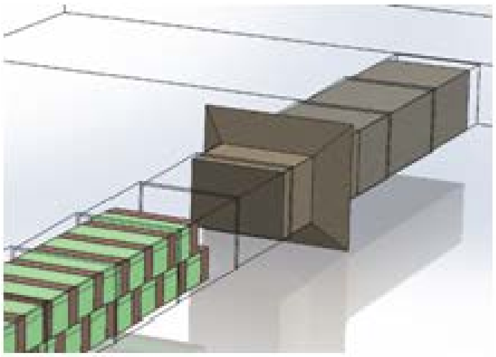
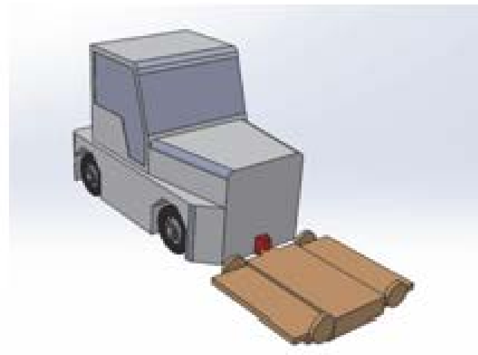
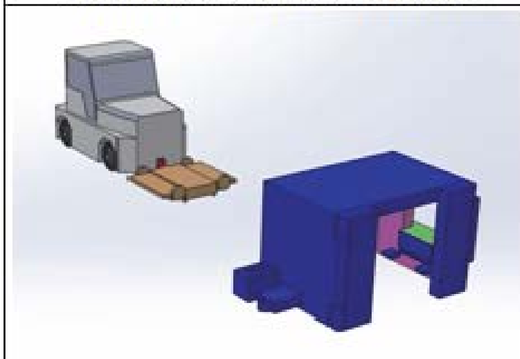
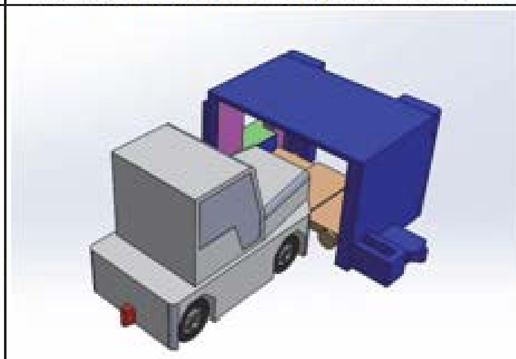
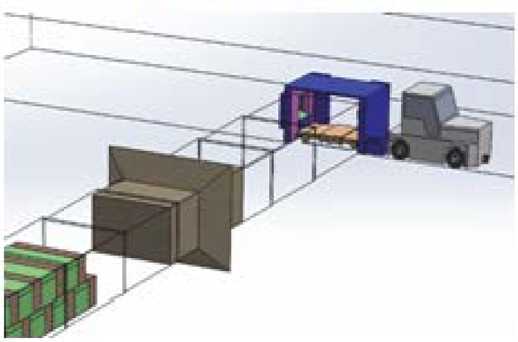
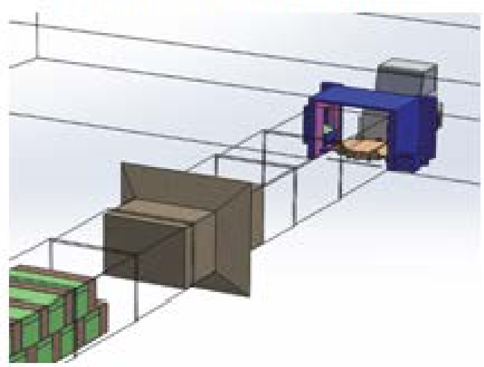
 UFC Transfer Cask & Trolley	 UFC Transfer Cask Door Open with UFC	 Tow Vehicle	 Tow Vehicle with UFC Transfer Cask
 Shielding Canopy	 Shielding Canopy with Trolley	 Placement Vehicle	 Floor Plate Handling System
 Retrieval Vehicle	 Bentonite Pellet Blowing System	 Hydraulic Cylinder Cart	 Gravel Placement Vehicle
 Bentonite Decanting Vehicle	 Buffer Box	 Floor Plate with Vent	 Trolley for Floor Plate Handling System

Figure 48: Preparation of Placement Room & Shielding Canopy - Sequence of Operations

 Phase 1 Removal of the concrete bulkhead at the entrance of the Placement Room	 Phase 2 Connect Tow Vehicle to Shielding Canopy Trolley in Underground Storage
 Phase 3 Move Tow Vehicle with Shielding Canopy Trolley to Shielding Canopy	 Phase 4 Connect Shielding Canopy Trolley to Shielding Canopy
 Phase 5 Move Shielding Canopy to the Placement Room entrance	 Phase 6 Disconnect Shielding Canopy Trolley from Shielding Canopy

Preparation of Placement Room & Shielding Canopy - Sequence of Operations (continued)

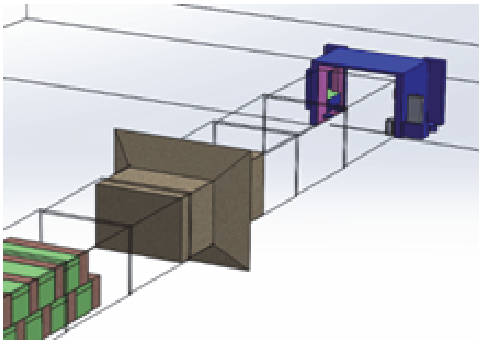
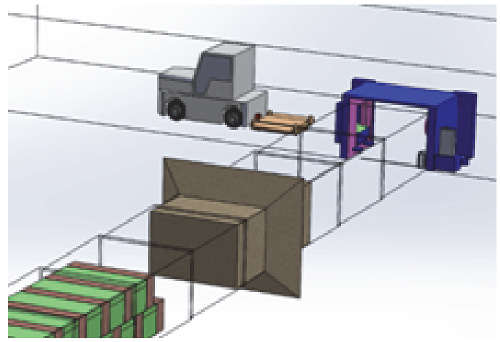
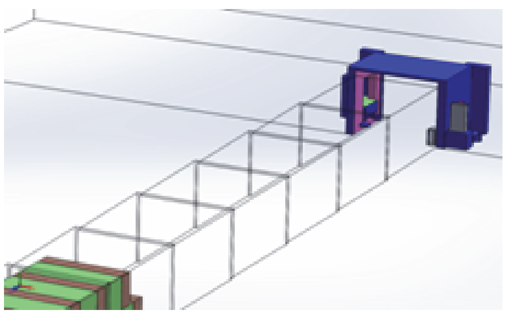
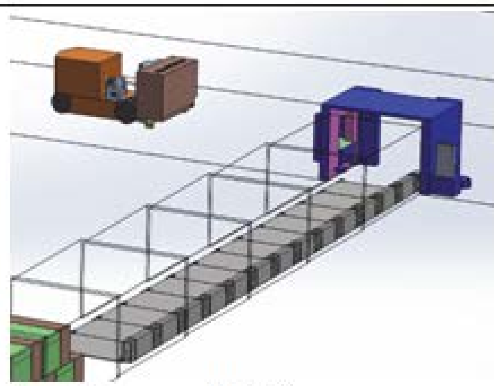
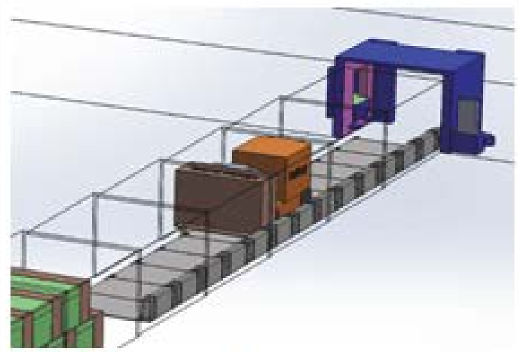
 Phase 7 Connect Shielding Canopy to ventilation and services	 Phase 8 Move Tow Vehicle with Shielding Canopy Trolley to Underground Storage
 Phase 9 Removal of the Bentonite Seal at the entrance of the Placement Room	

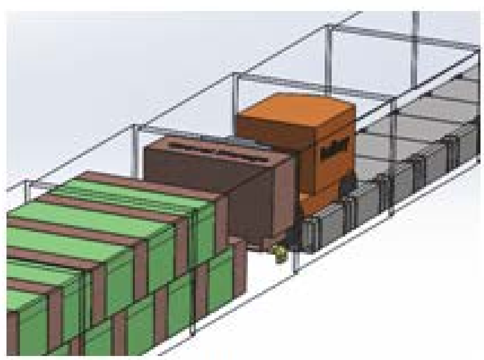
Figure 49: Gravel Placement & Leveling - Sequence of Operations



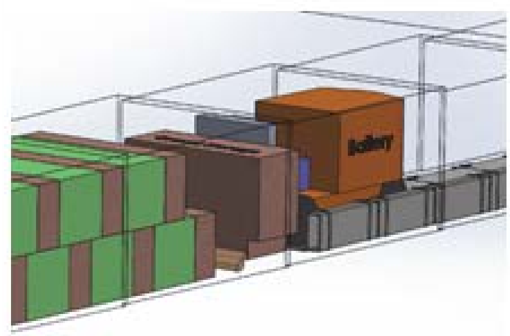
Phase 1
Move Gravel Placement
Vehicle to the Shielding Canopy



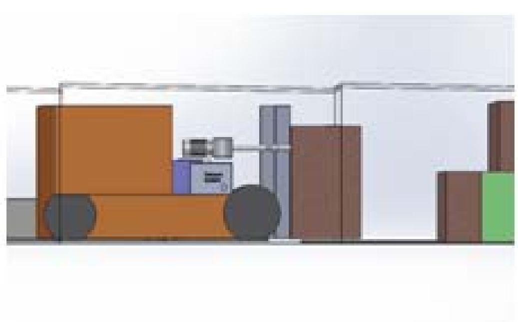
Phase 2
Move Gravel Placement Vehicle
remotely in front of the Bentonite backfill



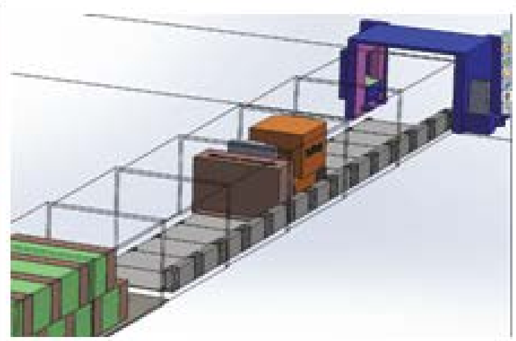
Phase 3
Removal of muck from
Placement Room Floor



Phase 4
Unload gravel onto Placement Room Floor



Phase 5
Level gravel on Placement Room Floor



Phase 6
Move Gravel Placement
Vehicle out of the Placement Room

Gravel Placement & Leveling - Sequence of Operations (continued)

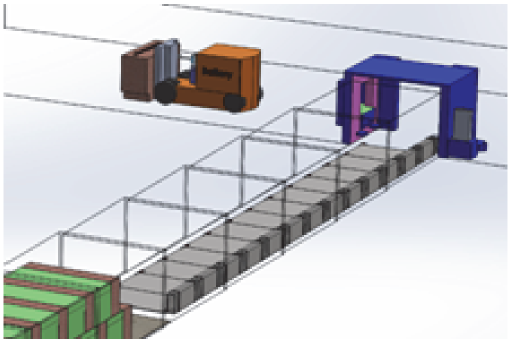
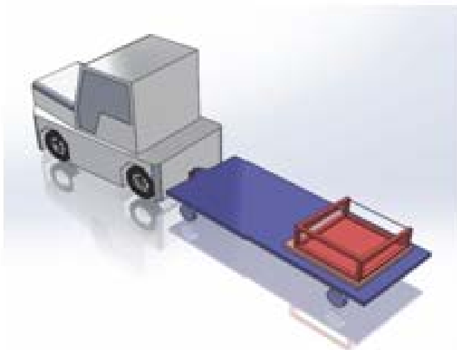
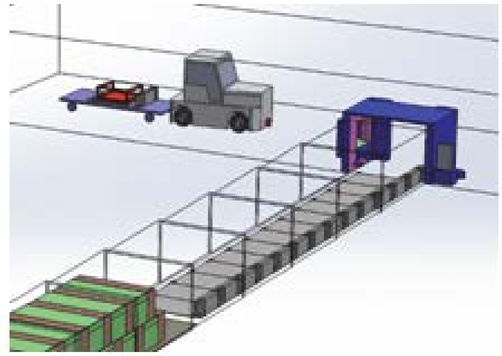
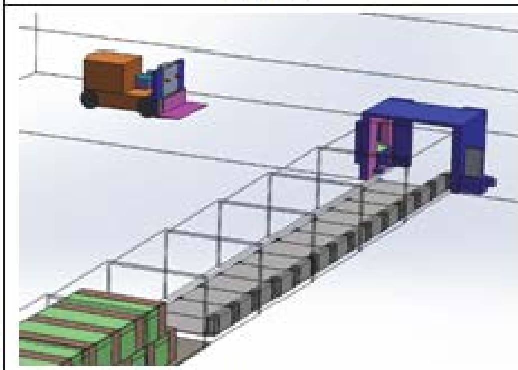
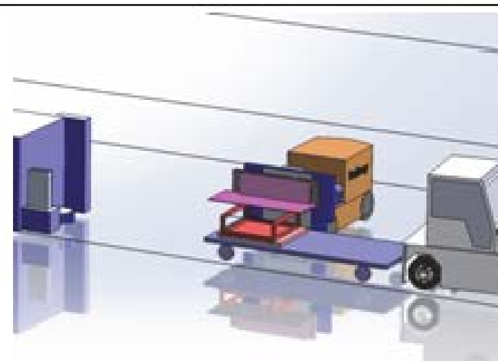
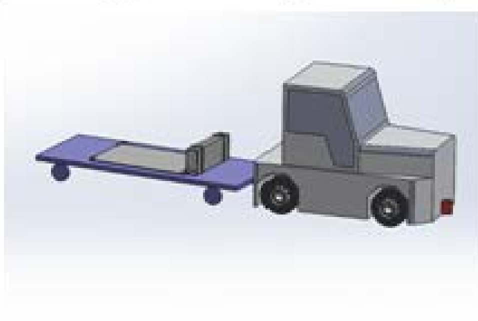
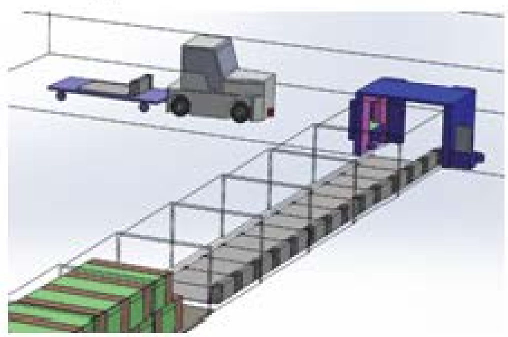
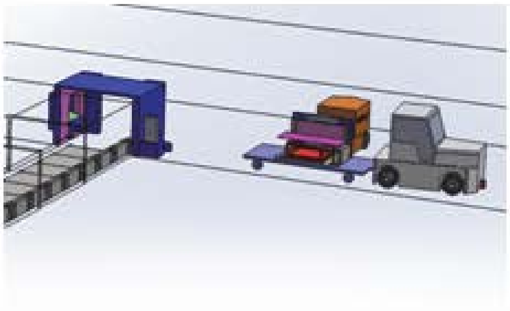
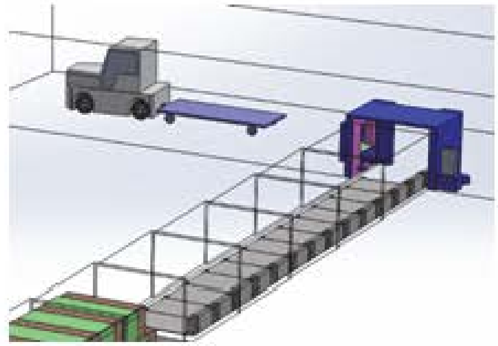
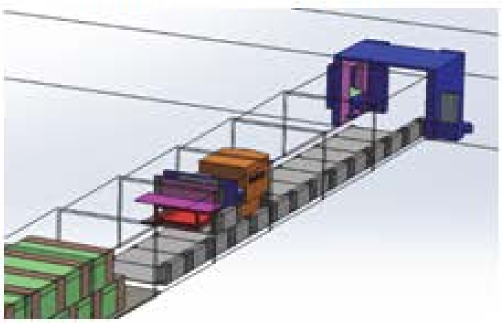
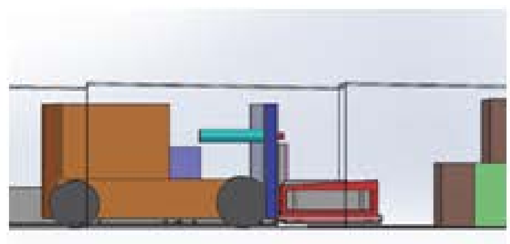
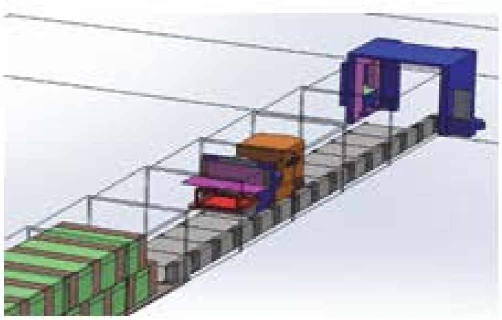
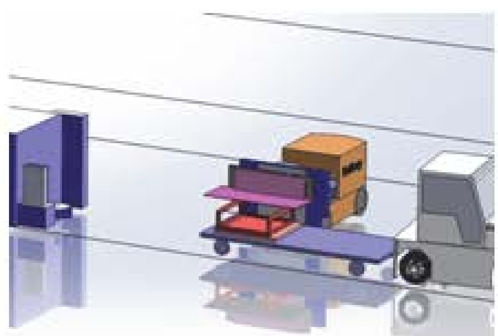
 Phase 7 Move Gravel Placement Vehicle to the Underground Storage	

Figure 50: Floor Plate / Ventilation Duct Placement - Sequence of Operations

 Phase 1 Connect Tow Vehicle to Trolley with Floor Plate Handling System at Underground Storage	 Phase 2 Move Trolley with Floor Plate Handling System to Shielding Canopy
 Phase 3 Move Placement Vehicle to Shielding Canopy from Underground Storage	 Phase 4 Attach Floor Plate Handling System to Placement Vehicle
 Phase 5 Connect Tow Vehicle to Trolley with Floor Plate at Underground Storage	 Phase 6 Move Trolley with Floor Plate to Shielding Canopy

Floor Plate / Ventilation Duct Placement - Sequence of Operations (continued)

 Phase 7 With Floor Plate Handling System Pick Up Floor Plate from Trolley	 Phase 8 Move Trolley to Underground Storage
 Phase 9 Move Placement Vehicle to the Floor Plate placement location remotely in the Placement Room	 Phase 10 Position and detach Floor Plate from Placement Vehicle
 Phase 11 Move Placement Vehicle out of the Placement Room	 Phase 12 Detach Floor Plate Handling System from Placement Vehicle

Floor Plate/Ventilation Duct Placement - Sequence of Operations (continued)

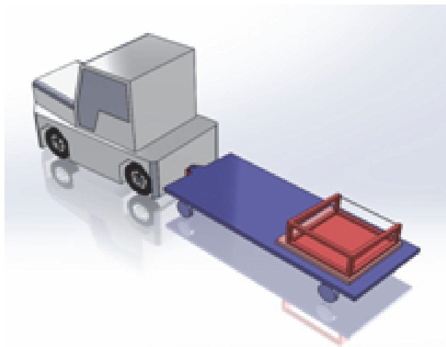
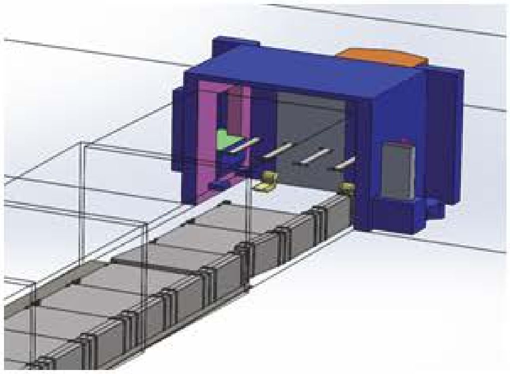
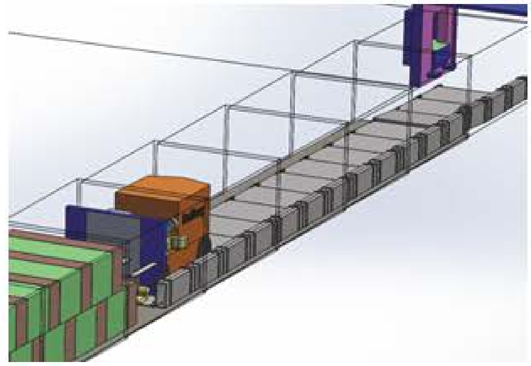
 Phase 13 Return Floor Plate System to Underground Storage	

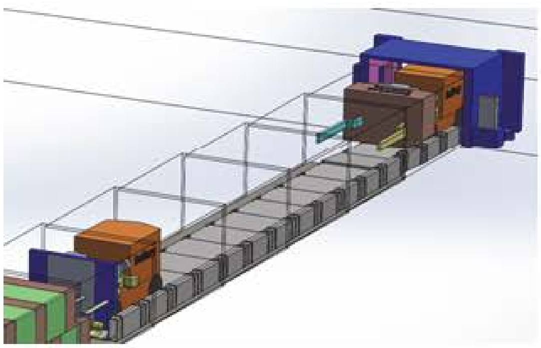
Figure 51: Container / Buffer Box Retrieval - Sequence of Operations



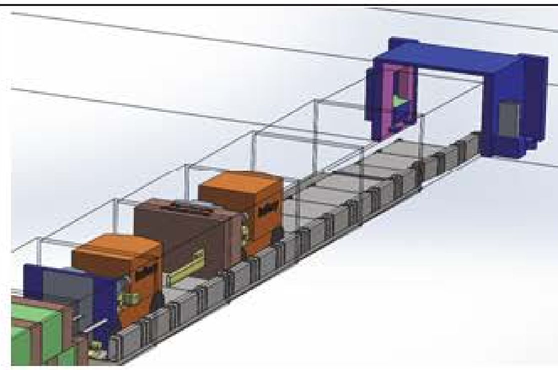
Phase 1
Move Retrieval Vehicle to Shielding Canopy



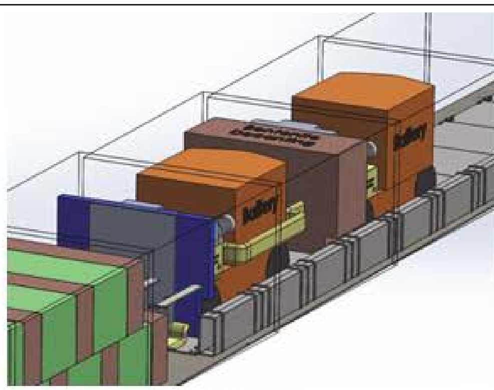
Phase 2
Move Retrieval Vehicle remotely to the last Floor Plate placement location in the Placement Room



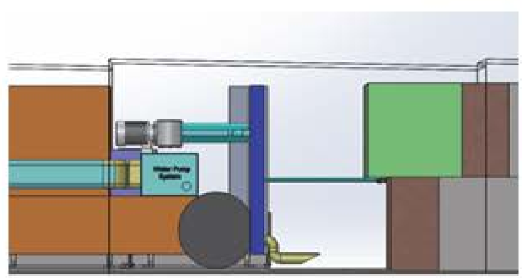
Phase 3
Move Bentonite Decanting Vehicle to Shielding Canopy



Phase 4
Move Bentonite Decanting Vehicle remotely in the Placement Room behind Retrieval Vehicle

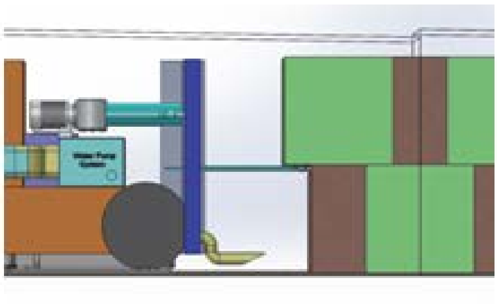


Phase 5
Remotely connect the Bentonite Decanting Vehicle to Retrieval Vehicle

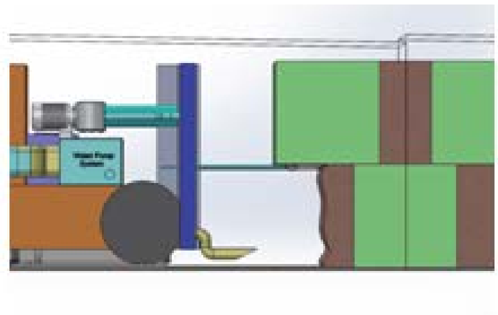


Phase 6
Position Retrieval Vehicle Forks to the elevation just below Buffer Box to be retrieved and Spray Nozzles against

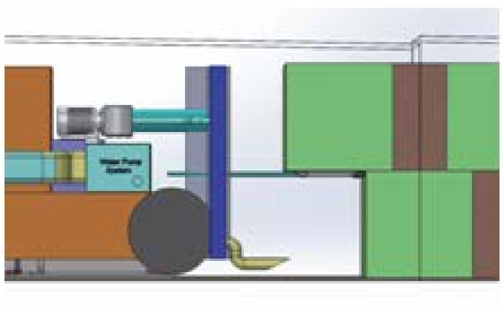
Container / Buffer Box Retrieval - Sequence of Operations (continued)



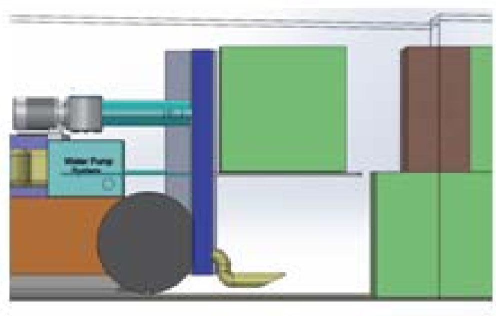
Phase 7
Start Bentonite Decanting and move Retrieval Vehicle forward to remove Bentonite Spacer Block



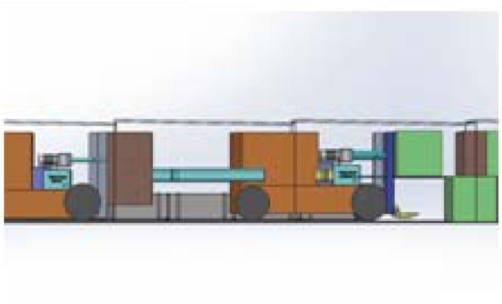
Phase 8
Continue the Decanting Operation and move Retrieval Vehicle forward while positioning the Spray Nozzles



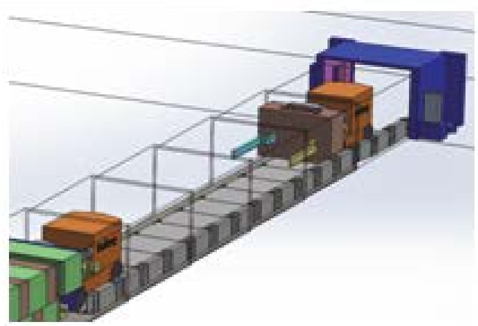
Phase 9
Stop Bentonite Decanting Operations and verify Bentonite has been removed under Buffer Box



Phase 10
Raise and level Retrieval Vehicle Forks supporting the Buffer Box for transport

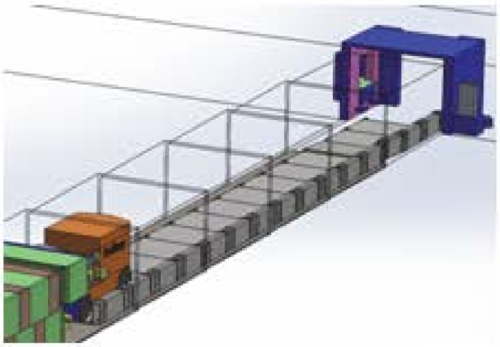


Phase 11
Disconnect the Bentonite Decanting Vehicle from Retrieval Vehicle

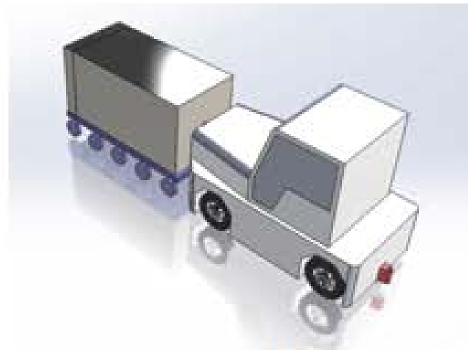


Phase 12
Move the Bentonite Decanting Vehicle remotely to the Shielding Canopy

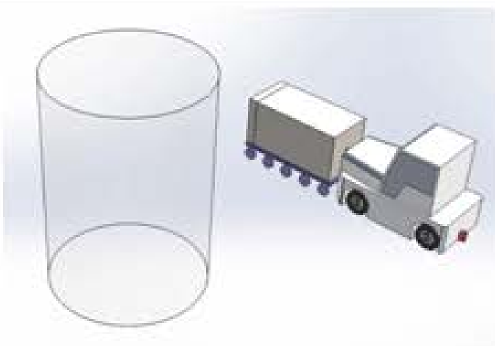
Container / Buffer Box Retrieval - Sequence of Operations (continued)



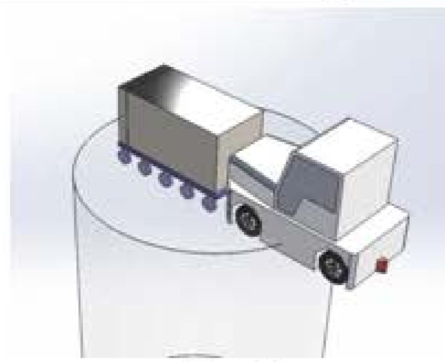
Phase 13
Close and secure Shielding Canopy Doors



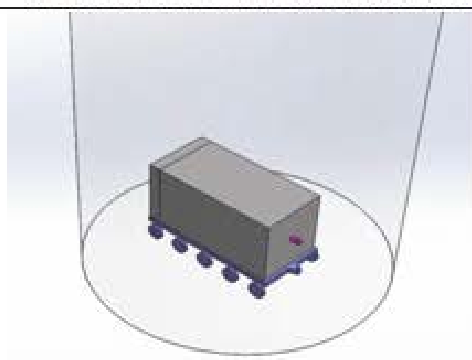
Phase 14
Connect Tow Vehicle with empty
UFC Transfer Cask & Trolley at UFPP



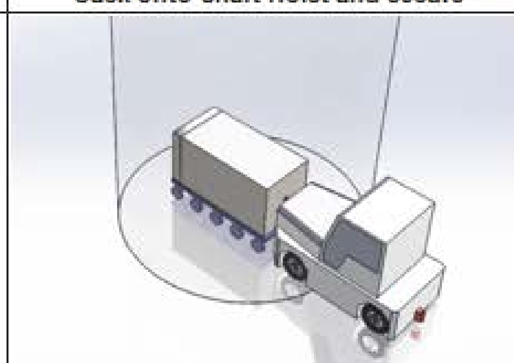
Phase 15
Move Trolley with UFC
Transfer Cask to Main Shaft Hoist Area



Phase 16
Move Trolley with UFC Transfer
Cask onto Shaft Hoist and secure

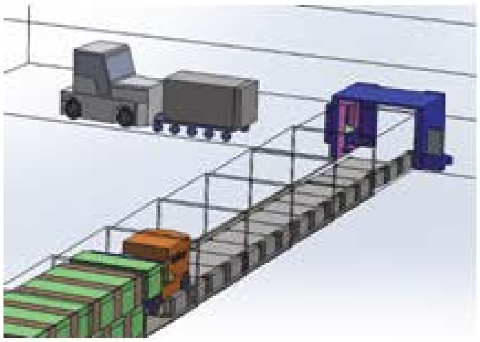


Phase 17
Trolley with UFC Transfer Cask
descent to Underground repository level

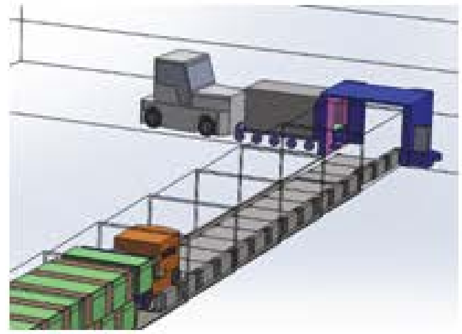


Phase 18
Unsecure and move Trolley with
UFC Transfer Cask off Shaft Hoist

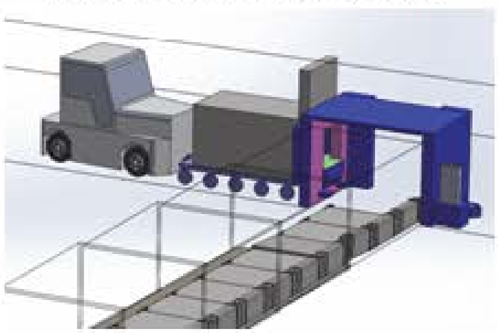
Container / Buffer Box Retrieval - Sequence of Operations (continued)



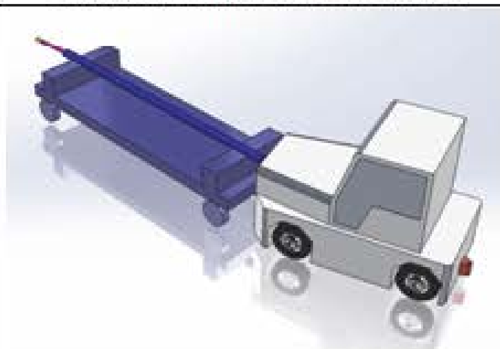
Phase 19
Move Trolley with UFC
Transfer Cask to Shielding Canopy



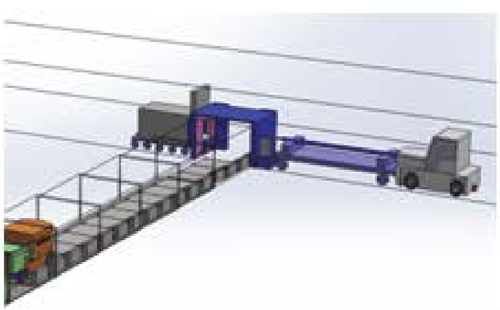
Phase 20
Secure UFC Transfer Cask to
Shielding Canopy Transfer Window



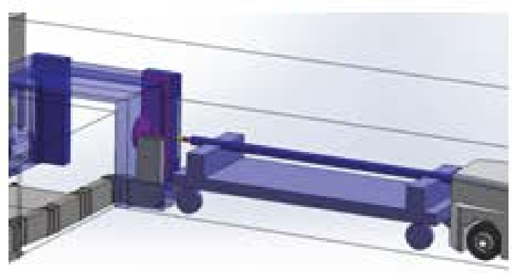
Phase 21
Open UFC Transfer Cask Shielding Door



Phase 22
Connect Tow Vehicle to Hydraulic
Cylinder Cart in Underground Storage

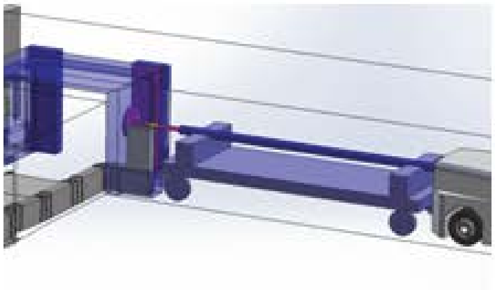
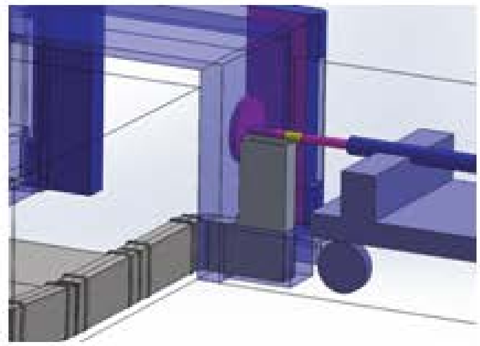
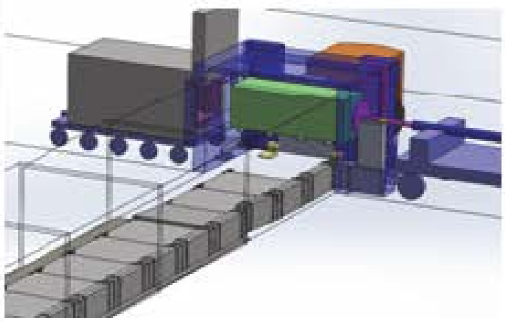
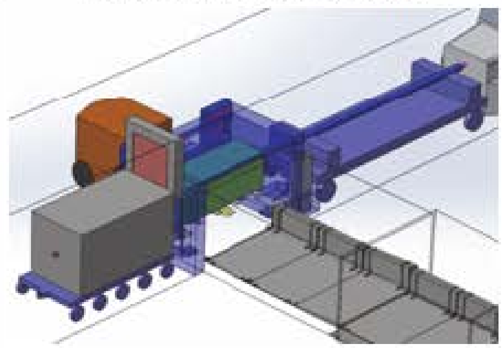
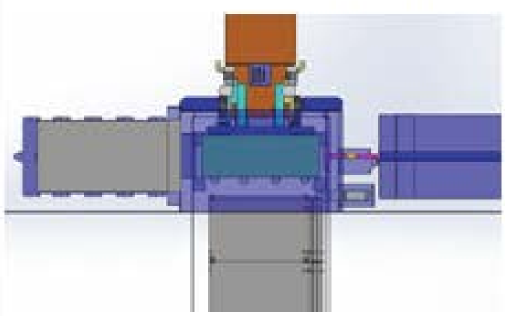
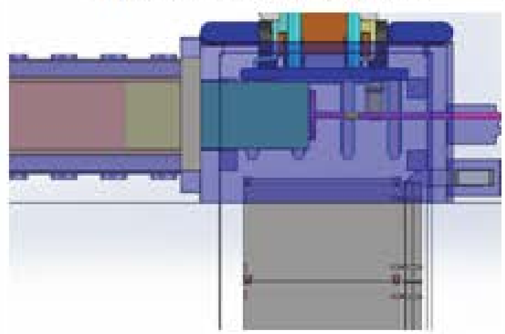


Phase 23
Move Hydraulic Cylinder
Cart to Shielding Canopy

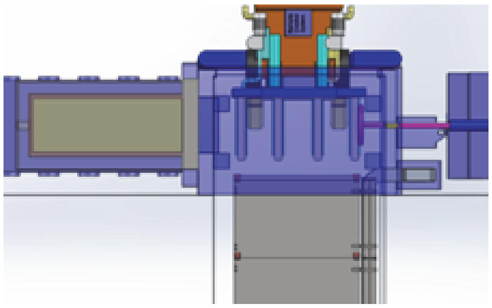
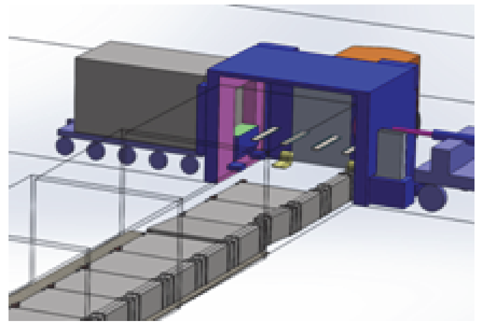
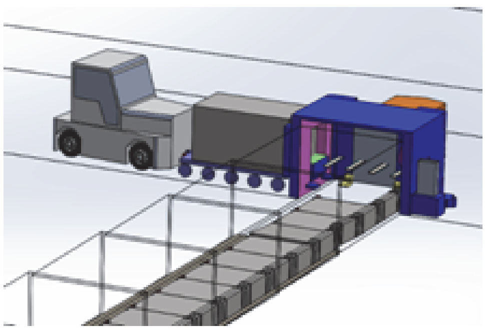
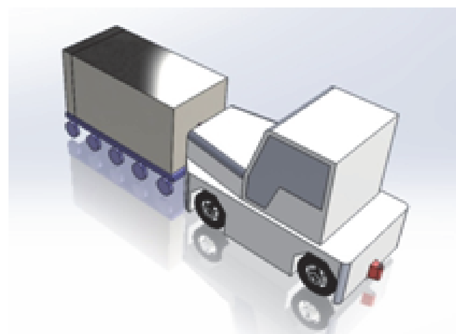


Phase 24
Connect Hydraulic Cylinder
Cart to Shielding Canopy

Container / Buffer Box Retrieval - Sequence of Operations (continued)

 Phase 25 Connect Hydraulic Cylinder Cart to Services	 Phase 26 Install Coupling between Cylinder and Ram on Shielding Canopy
 Phase 27 Move Retrieval Vehicle with the Buffer Box remotely to Shielding Canopy	 Phase 28 Extend Retrieval Vehicle Tray support under the Buffer Box
 Phase 29 Verify alignment of Buffer Box with UFC Transfer Cask and Shielding Canopy Ram	 Phase 30 Push Buffer Box into UFC Transfer Cask

Container / Buffer Box Retrieval - Sequence of Operations (continued)

 Phase 31 Retract Cylinder	 Phase 32 Close UFC Transfer Cask Shielding Door
 Phase 33 Connect Tow Vehicle with filled UFC Transfer Cask & Trolley	 Phase 34 Move Trolley with filled UFC Transfer Cask to Underground Storage

8. SITE SECURITY AND SAFEGUARDS

The DGR facility will employ security measures for physical protection of nuclear material and the nuclear facilities in order to prevent unauthorized removal and sabotage of nuclear material in use and in storage at the facility. The DGR facility will have safeguards measures which will provide credible assurance of non-diversion and the absence of undeclared safeguards relevant activities.

8.1 SITE SECURITY

The interior section of the surface facilities as well as that area around the Ventilation Shaft complex are considered Protected Areas per current Nuclear Security Regulations (SOR/2000-209). The Protected Area boundaries will consist of a physical protection system, with controlled personnel and vehicle access points. Furthermore, the entire surface facility will be surrounded by a fence in order to provide controlled access to vehicles and persons and to prevent intrusion of wildlife.

The Protected Areas physical protection systems will incorporate a perimeter barrier with unobstructed land of minimum 5 m clear distance on both sides of the barrier. In addition, a system of protective elements will be in place to provide multiple layers of delay, detection and assessment that are controlled through a central command post or security monitoring room. The assessment component will enable security personnel to evaluate detected threats and provide the appropriate response. All of these component layers will further be connected to a back-up uninterrupted power supply, located within the Protected Area.

Nuclear Security Regulation (SOR/2000-209) stipulates that the detection and assessment components must each feature two independent systems. The delay component must have additional capabilities to deny intruders using large vehicles from forcing entry. Consistent with these requirements, the systems established to secure the Protected Areas will include:

- A physical barrier to delay intruders for a sufficient period of time to enable effective interception by response personnel and provide sufficient time delay at all points around the perimeter of the facility;

- A detection system to identify intruders immediately and alert security and response personnel; and

- An assessment system, with a dedicated lighting network, to allow security personnel to clearly identify and quantify any possible intrusion.

The various aspects of the site security infrastructure, including those for the Protected Areas, are discussed in this section. For illustrative purposes, their individual locations in the DGR facility have been highlighted in the following Figure 52.

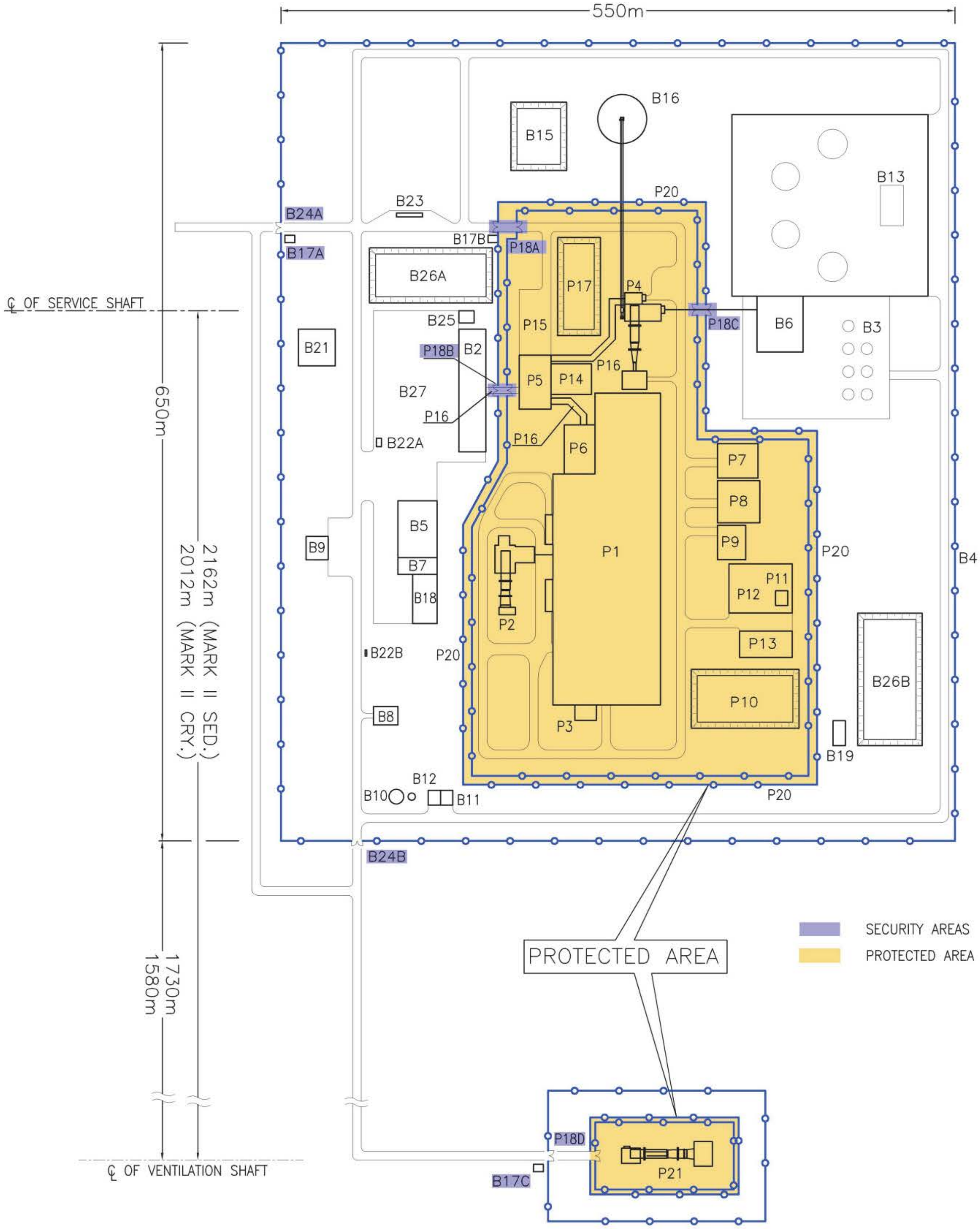


Figure 52: Site Security Components

8.1.1 Security Monitoring Room
Area B25

The main security monitoring room will house monitoring equipment including cameras and closed-circuit TV monitors, and will serve as the central command point for security works serving both the Protected Areas and the Balance of Site. The security room (Area B25), located adjacent to the Administration Building, will accommodate four on-duty personnel per shift. Remaining security team members will be on standby in the event of an emergency.

8.1.2 Physical Barrier Systems

There will be two security fence systems in place at the DGR facility. While a double fence (Area P20) will surround the Protected Areas, a separate perimeter fence (Area B4) will act to contain essentially all of the DGR's surface facilities, excluding the separately enclosed Ventilation Shaft Complex (Area P21).

8.1.2.1 Protected Area Security Fence
Area P20

A physical barrier system will be constructed to restrict unauthorized access by employees and visitors to the facilities in the Protected Areas. As illustrated on Figure 53, there will be two fences; one inner and one outer barrier each 3 m high above grade. The fences will be set 3 m apart with coils of barbed wire placed in between over a gravel surface. Lighting and monitoring will be in place as discussed below. The ground will be cleared to provide an unencumbered setback of 5 m on either side of the fence to permit visibility and provide moving room for patrol vehicles. Posted signs will identify the restricted access.

In addition, supplementary capabilities will be established to deny intruders using large vehicles access to the main Protected Area. While jersey barriers may typically be used for such purposes, a structure similar to that illustrated on Figure 54 will be installed at the vehicle access point. Two pairs of these movable gates will be established, separated by a space (sally port[2]) sufficiently large to accommodate any vehicle entering the Protected Area.

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[2] A sally port is an intermediate holding area for incoming vehicles. The vehicles are contained by two sets of gates for inspection and clearance.

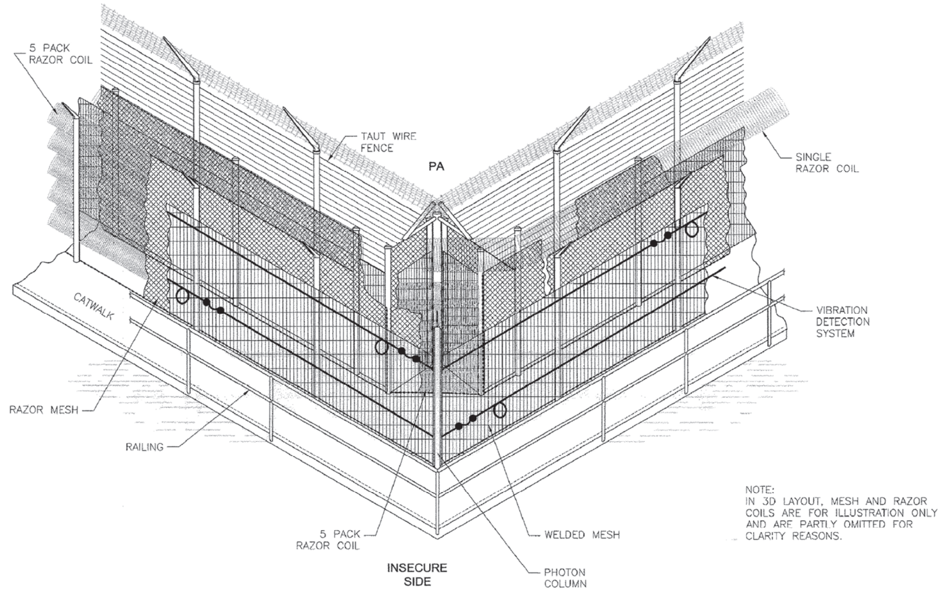

Figure 53: Protected Area Security Fence

Figure 54: Vehicle Entry Point

Protected Area Detection System

To detect intruders attempting to gain access into the Protected Areas the following sensor systems will be established:

- Photon sensors installed immediately outside the outer fence to detect and alert security personnel that an intruder is attempting to climb the fence;
- Shaker sensors installed on the outer fence to detect and alert personnel that an intruder is attempting to climb the fence; and
- A taut wire fence 3 m high and located 4 m away from the main fencing including a guy wire and detectors to alert security that an intruder is attempting to gain access.

Protected Area Assessment System

To assess alarm signals sent by the Protected Areas detection system sensors, the following will be in place:

- Each sector of the assessment system will have one dedicated CCTV camera installed on a pole. Every two sectors will have a camera with pan, tilt and zoom capabilities;
- Every two sectors will have one dedicated infrared camera to assist security personnel during poor weather and visibility conditions; and
- An auxiliary remote wireless surveillance camera mounted on the highest point of the facility will compensate for any deficiencies of the preceding equipment.

The installed cameras will be supported by lighting systems situated inside of the Protected Areas' boundaries that are capable of providing the required illumination levels. Additionally, secure mobile phones and satellite phones will permit secure lines of communication between security personnel.

The coordination of these security functions will be carried out through the security monitoring room (Section 8.1.1).

Protected Area Entry Control System

Personnel access to the facility's Protected Area will also be controlled by several integrated security features. These could include entry turnstiles controlled by hand geometry identifiers and exiting turnstiles controlled by a radiation portal monitor. Explosive detectors as well as metal detection devices for personnel and personal articles will additionally be installed. Figure 55 provides an illustrative example of such a system.

Figure 55: Example of Entry Control System

8.1.2.2 Balance of Site Perimeter Fence
Area B4

An additional fence will act as a site demarcation (perimeter) feature for the DGR facility while also providing a barrier / deterrent to intruders, including large animals. Entry through the fence will be by the facility access road from the incoming highway. While free access will be provided through this point, ‘cattle grates’ may also be incorporated to deter large animal entry. The ground will be cleared (minimum 5 m distance) to provide an unencumbered setback on either side of the fence to allow for unrestricted visibility and as a route for future maintenance. Signs will be posted on the fence indicating the purpose of the facility, and its restricted access.

The fence will consist of a 3m tall galvanized chain link wire, of heavy gauge construction. Access gates will be of the automatic sliding metal chain link type, with a secondary lift-up barrier. Gates will be controlled by security personnel at the guardhouses (Section 8.1.3.2), and be monitored by the main security monitoring room (Section 8.1.1).

8.1.3 Security Checkpoints and Guardhouses

Several access control points and guardhouses will be established at the DGR facility, as illustrated on Figure 52. These are discussed below.

8.1.3.1 Security Checkpoints
Areas P18A, P18B, P18C & P18D, B24A & B24B

Access to the Protected Areas will be strictly controlled, as discussed above. Regular staff will enter through controlled systems and all visitors, after registering with security staff, will be accompanied by authorized staff members when in the Protected Areas. The adopted system will be capable of tracking personnel into and out of the Protected Areas, and maintaining an electronic list of on-site personnel and their locations.

Four Protected Area access control points are to be established, two of which will allow for vehicular traffic. Identified as Areas P18A through P18D on Figure 52, the access control points are described below:

- Checkpoint P18A – will serve as the main vehicular access point to the Protected Area, and the gate through which the incoming used-fuel shipments will pass. This checkpoint will utilize a manned security booth for traffic control and inspections, and will provide barriers to deny intruder entry using large vehicles;

- Checkpoint P18B – will provide access to the Auxiliary Building (Area P5), and will be considered the primary access point for personnel. This checkpoint will utilize a manned security station, turnstiles and biometric identification systems for personnel control, with an auxiliary access gate for equipment;

- Checkpoint P18C – will allow access for materials from the Sealing Materials Compaction Plant (Area B6). A manned security booth will be in operation during active hours for the transport of materials to the Service Shaft complex (Area P4). Personnel access will not generally be through this checkpoint; and

- Checkpoint P18D – will allow as-required access to the Ventilation Shaft complex. Access will be by key and lock and will be overseen by the adjacent guardhouse (Area B17C).

Access control points for the Balance of Site will be provided for general security concerns only, such as theft, vandalism, animal intrusion, and general liability (safety). Personnel and vehicular access to the Balance of Site will be controlled through access gates. Two control points are provided and both will allow for vehicular traffic. Located as indicated on Figure 52, they include:

- Checkpoint B24A – will act as the main access point to the DGR facility. All facility traffic will pass through this point. While the gate will be able to be locked, its status will be controlled by the adjacent guardhouse (Area B17A); and

- Checkpoint B24B – will govern access to the roadway leading to the Ventilation Shaft complex (Area B1). Traffic through this area is expected to be minimal, therefore a manned security booth will not be required. Access will be by key and lock.

8.1.3.2 Guardhouses
Areas B17A, B17B & B17C

In addition to the checkpoints described above, three guardhouses will be provided for security personnel for the control, verification and authorization of vehicle and staff movements into and out of the DGR facilities.

The first guardhouse will be located at the main entrance to the Balance of Site (Area B17A on Figure 52). A second station will be situated at the entry control point for the Protected Area (Area B17B). Both guardhouses will accommodate a control room and security desk. A secure staging area for vehicles (a sally port) will be provided adjacent to the Area B17B station.

In addition to the above, a third (smaller) guardhouse will be located at the entrance to the Ventilation Shaft complex. This station is identified as Area B17C on Figure 52. This guardhouse would normally not be occupied unless there is work activity in the area. The surface area will be routinely monitored by cameras and motion detection equipment that would alarm in the security monitoring room (B25).

8.2 SAFEGUARDS

The purpose of safeguards measures is to provide credible assurance of non-diversion and the absence of undeclared safeguards relevant activities as prescribed by the IAEA. In the DGR facility, this would be accomplished through nuclear material accounting techniques (to maintain knowledge of the contents of each package) and a containment and surveillance system (to verify the continued integrity and movements of the spent fuel packages to maintain the continuity of knowledge on them). An important aspect of the safeguard system is the security measures (see Section 8.1). The security measures will provide physical protection of nuclear material and nuclear facilities in order to prevent unauthorized removal and sabotage of nuclear material in storage. Security measures include technical means and procedures of access control, detection of unauthorized intrusion and response to unauthorized intrusion.

9. OPERATIONAL SAFETY AND MONITORING

The following section addresses operational safety and monitoring initiatives that will be enacted at the DGR facility. The described initiatives have been identified both from a best practice perspective, as well as to meet the objectives set out in domestic and international regulatory and guidance documents (e.g., Canadian Nuclear Safety Commission, International Atomic Energy Agency, etc).

Conceptual-level design details are provided herein for radiation detection and monitoring systems, fire detection and suppression, facility environmental and performance monitoring, and emergency response procedures.

9.1 OPERATIONAL SAFETY

An occupational health and safety program will be in place and implemented for all periods in the evolution of the DGR when there are workers actively involved. As the project's components involve underground construction and operation as well as the handling of used nuclear fuel, there are significant industrial and radiological components to the program.

9.1.1 Radiological Detection and Zoning

Radiological detection and monitoring will be addressed with regard to achieving, among other things, As Low As Reasonably Achievable (ALARA) objectives while also maintaining information to support health physics programs. Radiological zoning considers the movement of staff and material, required maintenance activities, regulatory requirements etc. Three radiation hazard zones have been assigned to various areas of the facility, as noted below.

ZONE 1

Zone 1 is considered a "clean" zone. The dose received by an individual from external radiation sources during continuous occupancy of a Zone 1 area is not to exceed the recommended annual limit to the public in one year. Apart from natural background levels of radioactivity no other radioactive contamination would be present in this zone.

Zone 1 space typically includes offices, access corridors, lunch / coffee rooms, site lands and roadways. In terms of the DGR facility, the identified 'Balance of Site' (that is, all locations outside of the Protected Areas) would be considered as Zone 1.

ZONE 2

This zone is normally free from contamination and radiation fields. However, contamination and temporary radiation fields may exist. If contamination is found, it will be cleaned up as soon as detected. Chronic recurrences of contamination in Zone 2 will not be tolerated. Continued occupancy of Zone 2 operations will be restricted to those who have been designated Nuclear Energy Workers, as specified in the Radiation Protection Regulations (SOR/2000-203).

Generally, all operations within the surface Protected Areas will be considered as Zone 2 and all underground repository will also be considered Zone 2. The underground repository is considered to be Zone 2 because the integrity of the UFCs and associated administrative controls will prevent the release of radioactivity.

ZONE 3

Zone 3 is for medium-term occupancy by personnel classified as Nuclear Energy Workers with such occupancy subject to continuous management review. The nature of the work would be expected to result in contamination and, therefore, its presence would be managed until a work assignment was completed, when the contamination would be cleaned up as required. Based on radiation fields, in order to maintain the doses ALARA, the worker exposure times would require monitoring and the radioactive work would require proper planning. Worker protection in the form of protective clothing would usually be a prerequisite, and respirator protection might also be required.

Depending upon the final design details, the only Zone 3 areas associated with the DGR facility will be within the UFPP. It is currently expected that the radiation hazard zones for this building will be a mixture of Zone 2 and Zone 3 designations. A Zone 4 area to control the hot cells in the UFPP might also be considered.

9.1.2 Monitoring for Radioactive Releases

A system will be established to detect, monitor and record any airborne or waterborne releases of radioactivity leaving the site. The system will be implemented with the goal to keep the amount of exposure to ALARA. Prior to start of operations, environmental programs will establish baseline conditions at the site for naturally occurring radioactivity (e.g. for naturally occurring radon and uranium) to help differentiate the radiological impact caused by the facility. Monitoring will continue through operations.

A licensed dosimetry service will be used to measure and monitor releases, environmental samples and dosimetry for personnel who have a reasonable probability of receiving a recordable effective dose due to work at the facility.

The radiation monitoring system will employ multiple measuring devices and continuously analyze for potential concerns, alerting personnel if required. An uninterrupted power supply will be provided for all devices required by the detection and assessment systems (in addition to any associated alarm annunciations).

9.1.3 Radiation Protection on Site

In conjunction with the radiation monitoring program, a protection and control system will also be instituted. This system will incorporate the following features:

- Use of personal dosimeters for all staff or visitors within the Protected Areas;
- For personnel leaving a higher level radiation defined zone to a lower defined zone (e.g., going from a Zone 3 to a Zone 2 area) or at each radiation zone transition point, use of hand and foot monitors or whole body monitors is expected;

- A whole body counter for personnel to use annually or quarterly;
- Fixed area gamma monitors located throughout the facility to gauge local dose rates at places routinely occupied by operating personnel;
- Air radiation monitors located throughout the facility, including the exhausts for ventilation systems; and
- Radiation vehicle monitors (portable and fixed) at entry or unloading areas.

9.1.4 Fire Detection and Suppression

The following discussion focuses on the underground systems to be put in place as related to fire detection and fire safety. An optimum suppression concept that balances worker and nuclear safety will be established.

The underground portion of the DGR facility will have the following fire protection features:

- Suitable fixed fire suppression systems and portable fire extinguishing equipment in any fire hazard area;
- Fire extinguishing equipment in the mine entrance and at shaft stations; and
- Permanent and portable refuge stations for workers during emergencies. These stations will have breathing equipment, emergency air systems and communication devices.

In addition, fire detection systems incorporating heat, smoke and carbon monoxide detectors at key points in the facility will also be set up. Key locations for fire detection equipment will include all underground infrastructure rooms, the exhaust ventilation air ducts exiting each placement room, the intake duct for the Main Shaft, and at the main exhaust ducts of the upcast Ventilation Shaft. Audible and visual alarms will be activated on detection by any instruments required to do so. A stench gas system will also be used to notify underground workers in the event of an emergency.

All underground vehicles will also be fitted with fire detection and suppression equipment. In total, fire suppression will be achieved through the use of a number of systems both for the equipment and the underground environment. Systems will include the following:

- Hand-held foam based fire extinguishers mounted throughout the facility;
- Automatic, foam-based fire suppression systems mounted on all diesel equipment;
- An inert gas generator and a portable foam generator for extinguishing any fires that develop in the placement rooms;
- Normal sprinkler and/or fire hose systems for areas where appropriate;
- A water spray deluge system for hazardous environments where fires may spread very quickly or where valuable materials need to be cooled; and
- A water mist system for areas where appropriate.

Breathing air requirements as prescribed by regulatory guidelines and worker health and safety protocols (as applied to firefighting, non-nuclear air contamination, etc.) will be followed.

9.1.5 Emergency Response

Procedures for emergency response planning, the notification of releases and incident reporting will meet CNSC requirements and include the utilization of incident command systems to meet the needs of any kind or complexity of situation. For severe incident management (e.g., extreme or violent weather, chemical spills, etc.), various emergency related resources will be available. These will include:

- Pre-planned response procedures (including shutdown protocols);
- Pre-established post-emergency procedures including those for resuming operations;
- Off-site and on-site communications and management protocols, including regulatory notifications and public interaction;
- The services of an Emergency Response Team (ERT); and
- Pre-trained staff that have undergone regular training on emergency response issues.

The primary personnel involved in handling any emergency will reside within an ERT. These resources would also be supported by on and off-site firemen and first aid attendants as well as the DGR's various superintendents and shift managers. Communications staff will be available to coordinate and assist in the required incident communications activities.

9.2 ENVIRONMENTAL MONITORING PROGRAMS

Prior to the start of construction, the environmental monitoring program will collect data to establish baseline conditions. Thereafter, the program will monitor for any changes that may be imposed on the environment due to construction activities and ultimately the operation of the DGR facility. Monitoring requirements for the postclosure period will need to be re-examined as part of the final plan for decommissioning and closing the site.

The environmental monitoring program will be comprised of the following components:

- Radiological monitoring;
- Groundwater quality and levels monitoring;
- Monitoring of surface water and stormwater;
- Air quality monitoring; and
- Meteorological monitoring.

The following sections address each of the program components. The final elements will be developed as part of the formal licensing process for the DGR. The expectation is that the program will provide reliable, accurate and timely data in a fashion that is easily audited.

9.2.1 Radiological Monitoring

As a nuclear facility, radiological environmental monitoring will be established around the site as required to support compliance with the licensing conditions, which may include the Canadian Standards Association (CSA) Standard N288.4, Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills.

9.2.2 Groundwater Monitoring

Baseline hydrogeological studies will establish a conceptual groundwater system model that will describe site-specific properties, hydrostratigraphy and system behaviour. From the groundwater system model, features will be identified that should be monitored during the construction and operation of the DGR facility. Such features will encompass the groundwater regime at the DGR site, as well as any nearby community or individual water supply wells.

Potential groundwater impacts arising from operation of the DGR could include localized influence to near-surface groundwater flow patterns and/or the potential for non-radiologic contamination from, for example, chemical or fuel oil spills. Monitoring well locations will include those installed to characterize and establish baseline site conditions and those installed during the construction phase. In total, the monitoring well network is anticipated to be in the order of 100 wells. The wells will be positioned within key sub-surface pathways both up- and down-gradient of potential on-site contaminant source areas (e.g., the excavated rock storage areas and on-site ponds) to allow reliable monitoring and detection of potential groundwater impacts, if any.

Representative water supply wells for any proximate community, as well as strategically positioned points between these and the DGR site, will also be included in the program.

Groundwater parameters monitored will include those related to groundwater flow (i.e., hydraulic head) and quality (i.e., non-radiologic; radiologic). Groundwater samples will be collected and analyzed on a quarterly basis. Assessment of groundwater quality impacts would be performed annually with 5-year reviews conducted to assess monitoring program adequacy and effectiveness.

9.2.3 Stormwater / Surface Water Monitoring

Stormwater runoff from the developed site (roads, parking areas and rooftops) can lead to increased flows and downstream erosion. Stormwater management ponds are designed to attenuate the variations in flow conditions while also being designed to detain and settle out sediments associated with runoff. They will also provide detention to allow sampling to confirm effluent limits are met prior to discharge and accommodate some emergency storage in the event effluent limits are exceeded and discharge is not allowed.

The monitoring program will be focused on the measurement of flows and water quality at the pond discharge points to confirm that water quality meets limits set in permits for the ponds. In the remote event that pond discharge water quality is found to exceed the limits then corrective actions will be taken to ensure the maintenance of regulatory compliance.

Pond water samples will be analyzed for a full suite of conventional parameters including anions and cations, metals, oil and grease and nutrient compounds. Sediment samples will additionally be collected from each pond and analyzed for trace metals, PCBs, PAHs, organochlorine pesticides, total organic carbon, nutrients, and oil and grease.

Grab samples from the inlet and outlet of each pond will be examined for the identified parameters on a regular basis and as required by the permit for these facilities. Sediment samples will be assessed on an annual basis.

The monitoring program will also encompass surface watercourses and bodies outside the DGR site footprint and at nearby communities. Sampling locations will be selected to characterize water quality and flows both upstream and downstream of the DGR site in the local watersheds. Gauging locations will further be established to measure surface water elevations and flows. Water quality and hydrologic conditions will be monitored using both automatic and manual sampling techniques.

9.2.4 Conventional Air Quality Monitoring

For the above-ground environment, ambient air quality monitoring locations will be established both in the predominant downwind direction of the facility (including one at the nearest community) as well as upwind of the site. The underground ventilation system will be exhausting into the atmosphere and thus it will be necessary to monitor potential discharge impacts on the local air shed.

The primary contaminants expected to be emitted include the products of combustion of diesel fuel from the operation of mobile equipment. The pollutants of concern to be addressed by the monitoring program, therefore, are anticipated to include particulate matter, nitrogen oxides, sulphur oxides, carbon monoxide, carbon dioxide and total organic compounds.

The air quality in the underground repository will be monitored, the underground air monitoring equipment will include hand held instruments (see Figure 56) as well as in-situ continuous emission monitoring devices.

Figure 56: Manual Air Quality Monitoring

9.2.5 Meteorological Monitoring

A weather monitoring station will be installed and operational at the DGR site. Using tower-mounted instrumentation, the station will provide site-specific and continuous meteorological data to assist in the ongoing operations of the facility. Real-time measured parameters will include:

- Ambient temperature;
- Relative humidity;
- Dew point;
- Barometric pressure;
- Wind speed;
- Wind direction;
- Rainfall;
- Solar conditions; and
- Radioactivity in air and water.

9.3 SEISMIC AND VIBRATION MONITORING

Earthquake ground motions could occur during the operating life of the DGR facility. To provide adequate protection for workers, the public and the environment, the DGR facility will be designed to withstand the effects of a potential strong earthquake ground shaking at the site.

A regional seismic monitoring network will be established prior to start of construction to collect seismic data. These data combined with historic seismic data will be used to assess the seismic hazard at the proposed DGR site and will provide data for the seismic design of the DGR facility. The seismic monitoring will continue to operate during the operating life of the DGR facility for the purpose of confirming that risk of unacceptable earthquake ground shaking event are still low.

Ground vibration or movement is a commonly examined characteristic at underground mines. Ground vibration may occur due to blasting or due to failure within rock mass as result of stress redistribution around rock excavations. Significant ground vibration events are not anticipated at the DGR site because site selection criteria are favouring sites that have large masses of competent rock. In any event, a series of geophones will be installed to create an underground vibration monitoring system. This system will be used to confirm any vibrations that are sensed are well below acceptable levels at key underground locations (e.g. placement rooms receiving UFCs). A series of geophones will be grouted into short boreholes drilled into the roof and floor of the underground openings at repository level and into the shaft sidewalls at various elevations. A typical geophone is shown in Figure 57.

Figure 57: Geophone

9.4 GEOTECHNICAL MONITORING

Geotechnical monitoring will be performed during the construction of the underground repository openings to measure and confirm in-situ rock behaviour. Rock movement and changes in rock stress will be monitored at selected locations as follows:

- **Rock Movement Monitors**: extensometers will be installed within short boreholes in the shaft walls and the roofs of underground rock openings to monitor for rock movement; and

- **Stress Cells**: stress cells will be installed within the concrete shaft liner and at the rock / concrete shaft liner interface. Stress cells will be installed in the roofs of underground rock openings to measure any changes in rock stress as a result of excavation work and/or heating of rock due to heat loading by the UFCs.

9.5 QUALITY ASSURANCE / QUALITY CONTROL FOR MONITORING

Quality assurance / quality control procedures will be implemented throughout the monitoring programs to ensure thoroughness and accuracy of the data. In this regard, the programs will include the following measures (among others) to ensure a high degree of confidence in the collected information:

- Strict adherence to standard protocols for the collection, preservation, storage, handling and shipping of samples and for in-situ sampling;
- A field quality control program, including the submission of travel and field blanks and duplicate samples;
- Implementation of a quality control program for the laboratory analyses; and
- Timely review of analytical results to identify areas of concern (including potential impacts).

Annual and quarterly status reports will be prepared to summarize the activities as related to the environmental monitoring program. The results of the ongoing QA/QC activities will be incorporated in these reports.

9.6 CENTRAL TAGGING SYSTEM

A central tagging system will be put in place at the DGR facility to monitor the movements and quickly locate all facility personnel, equipment and tools (including radiation-impacted objects). The system will be coordinated out of a central control area which will receive wireless signals from transmitting / receiving devices assigned to on-duty personnel and installed on each facility vehicle or asset. Conceptually, the tagging system will operate as follows:

- A wireless tag will be provided to a person and/or attached to a piece of equipment when entering the DGR facility check-in point;
- As the person / equipment moves through the DGR facility, the associated tag is read by other multiple wireless readers positioned in various locations in the facility;
- In terms of hard assets, once the item reaches its destination, a tag reader will allow a cross-check to be made to confirm that it is supposed to be at that location;

- Items incorrectly received will be flagged for removal and re-routed; and
- When an item or person leaves the facility the associated wireless tags are read at the exit point.

This tracking system will assist operational personnel and increase worker safety. It will also allow for the remote-management of all assets by identifying their exact location.

In the underground environment, the collected data will be transmitted using a leaky co-axial and fibre optic system, which will relay information from the source instrument or electronic device to the surface control room. As illustrated on Figure 58, such a system consists of cables running along the tunnels and in shafts which emit and receive digital transmissions. The digital information is transmitted by fibre optic cable.

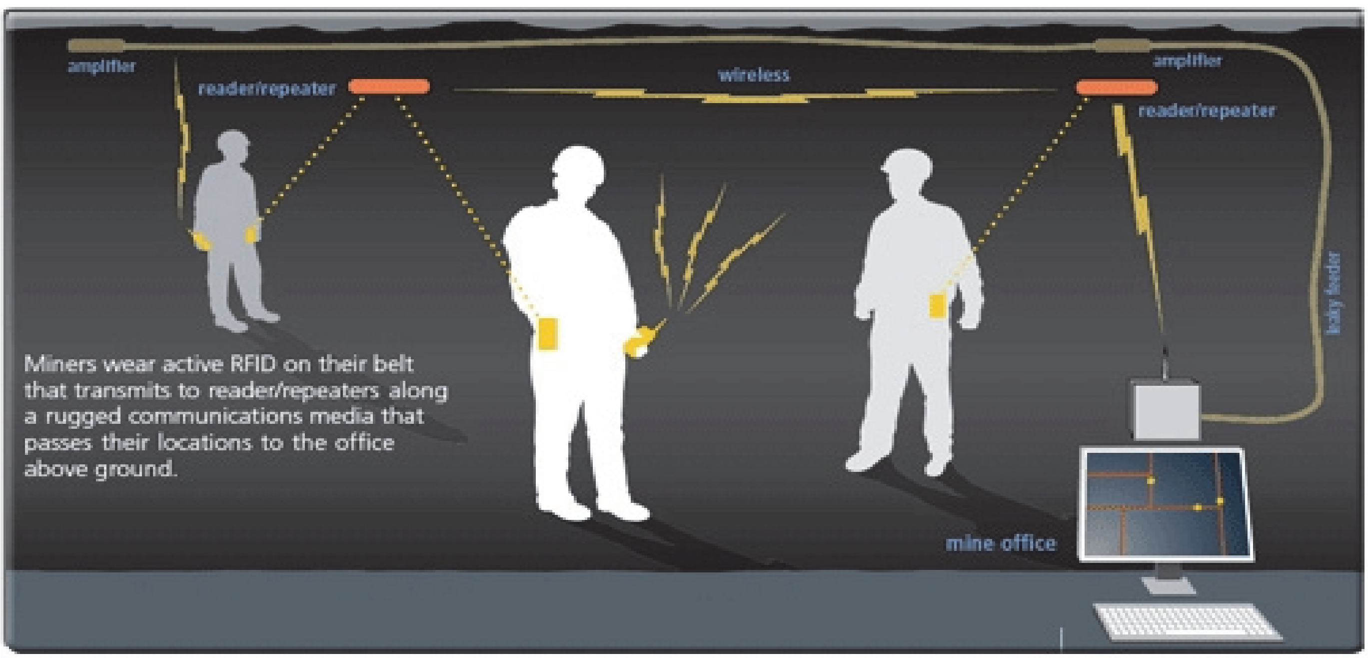

Figure 58: Typical Wireless System for Underground Mining Operation

10. DECOMMISSIONING AND CLOSURE

Subsequent to the cessation of used-fuel placement activities and the 70-year extended monitoring period, the following series of actions will take place:

- 10-year decommissioning period;
- 15-year closure period; and
- Postclosure period.

These activities are the subject of this section, following a brief discussion of certain key issues that will impact upon the decommissioning and closure (D&C) work and the staged, progressive development of D&C planning. As discussed below, such planning will commence with the preparation of a Preliminary Decommissioning Plan structured to meet the requirements of CNSC Regulatory Guide G-219, Decommissioning Planning for Licensed Activities, and CSA Standard N294-09, Decommissioning of Facilities Containing Nuclear Substances.

10.1 KEY ISSUES

Several issues have the potential for a material impact to D&C planning and implementation. Such issues include the final site selection, the status of container retrieval initiatives, the potential for advancements in associated technologies, and the direction received from regulatory bodies. These factors are outlined below.

Site Selection

Actions undertaken during the D&C period will be designed to return the selected site and related facilities to the desired end-state. Given this, the ultimately chosen location for the DGR will have a material influence over the required D&C activities.

Container Retrieval

The possibility for future container retrieval has a potential major impact on the implementation and staging of D&C activities. For example a decision following completion of placement activities to forego the possible retrieval of buffer boxes (with UFCs) would allow a number of surface facilities to be decommissioned near the start of the extended monitoring period. On the other hand, under the approach that the potential for retrieval must remain open during the 70-year extended monitoring period, then surface and underground facilities will need to be inspected and maintained over the full 70-year period (or until a decision has been taken that the ability to retrieve buffer boxes is no longer required).

Advancements in Associated Technologies

The described initiatives within this section have been identified from, in part, a current best-of-practice perspective and feasibility perspective. Decommissioning and closure activities will occur in the future (in excess of 100 years from now) and it is likely that new technical solutions will be available at that time. These new solutions would be considered and, if appropriate, used to decommission and close the DGR facility.

10.2 PLANNING FOR DECOMMISSIONING AND CLOSURE

Major decommissioning and closure activities include the following:

- Initial preparation of the Preliminary Decommissioning Plan near the start of preliminary design at the preferred site. Progressive updates over the course of the preliminary and detailed design stages of work, as well as for the period of used-fuel placement. The maintained and updated plan will support periodic licence renewals throughout the DGR operations based on current codes, regulations and standards and incorporate relevant advances in technology. The plan will evolve throughout this period to continually represent the current as-built status of the facility, and operational and maintenance experience gained during placement;

- Following operations and at the commencement of the 70-year extended monitoring period, a material revision to the Preliminary Decommissioning Plan will be made. The plan will be subject to a special detailed review in order to finalize requirements for the extended monitoring period. As a significant portion of the effort spent during the extended monitoring will be focused on the design of facilities needed to support decommissioning and closure, this review will assist in providing directions and recommendations for this work. Several key parameters that may be monitored for an extended period are rock temperature, rock stress / displacement (response to thermal loading), water ingress, emplacement room seal performance, ground water quality, ground water radioactivity, humidity and acoustic emissions. This revision will be progressively updated over the course of the extended monitoring phase. Any updates would consider experience gained, as well as regulatory or technology updates. The evolving D&C plans will also provide updated directions and recommendations for facility maintenance or even early removal and disposal of component operations, where appropriate;

- Another material revision to the plan will be made prior to the commencement of the 10-year decommissioning period, using information collected during extended monitoring. The resulting Detailed Decommissioning Plan will support the application for regulatory approval to start decommissioning and closure work. The plan will be based on a fully defined methodology and procedures for implementation. It will form the basis for contracting and managing the implementation activities. Progress reports would be published over the course of the decommissioning stage;

- Assembly of the final material revision to the plan at the start of the 15-year closure period, based on information collected to that point in time and documenting the results of the decommissioning work. Progress reports would also be produced during the closure period; and

- Preparation of a postclosure report documenting the results of decommissioning and closure activities.

Regular maintenance of the evolving D&C plans will help ensure that the site programs and designs remain consistent with up-to-date and relevant internal / external decommissioning experience. It will also act to ensure that licensing and other regulatory requirements are continually met with regards to site safety, security and access control needs.

The D&C plans will all be designed, prepared and maintained to achieve the return of the site and related facilities to the desired end-state.

10.3 DECOMMISSIONING AND CLOSURE OF UNDERGROUND FACILITIES

Following the receipt of regulatory approval and the licence to decommission and close the DGR facility, underground facilities are expected to be removed first, in parallel with those surface facilities not required to support the remaining underground decommissioning and closure activities.

Decommissioning of underground facilities involves the removal of operational systems and furnishings, the interim installation of temporary services and furnishings, and the repair and preparation of exposed rock surfaces for sealing. As currently envisaged, the decommissioning and closure activities will be carried out in several stages and will include activities related to removal of ground support and material handling systems, the sealing of underground horizontal openings, and the sealing of shafts and boreholes.

10.3.1 Support Systems and Material Handling Systems

During decommissioning, when it is safe to do so, ground support systems including bolting and shotcrete will be removed and taken to the surface for disposal. The removal of ground support systems will be sequenced with the sealing of underground horizontal openings to minimize the time span of unsupported ground.

10.3.2 Sealing of Underground Horizontal Openings

The sealing of underground horizontal openings consists of closing off panel access tunnels and ancillary facilities. Such activities would commence with the removal of instruments from boreholes (and sealing the boreholes) followed by the preparation of exposed rock surfaces and removing loose rock before backfilling and sealing. The central access tunnels would then be backfilled, with sealing bulkheads installed at strategic locations where conditions dictate.

The key functional requirements for various components of sealing system will be as follows:

- Fill the entire excavated volume of each area being sealed;
- Resist physical and chemical deterioration by the local environment, which includes the preclosure and postclosure geochemical conditions; and
- Limit the rate of groundwater flow to and from the sealed placement rooms; and
- Limit rate of potential radionuclide migration from placement room and, if released from rooms, radionuclide migration along various underground tunnels and within the shafts.

Sealing of the underground openings will be achieved by using materials and methodologies similar to that used within the placement rooms. The clay-based fill material would occupy most of the underground tunnel space. At strategic locations seals comprised of highly compacted bentonite blocks would be constructed which would be complemented by a concrete bulkhead These bentonite seals and concrete bulkheads would be installed near access tunnel intersections and also near intersections with significant zones (as appropriate).

The key functional requirements for the concrete bulkheads will be to provide mechanical restraint against the forces exerted by swelling clays or pressures from other repository sealing systems, the surrounding rock mass or other sources. The bulkheads will further act to keep the sealing materials isolated in their intended locations and protected from any adverse conditions that may exist in adjacent unsealed excavations.

The sealing of the access tunnels will be carried out ensuring that the required tunnels are maintained open to provide ventilation to working areas. Therefore, the sequence for tunnel closures will consist of sealing all tunnels in a retreating manner from the Ventilation Shaft to the Service Shaft. Local ventilation systems using portable exhaust fans and duct tubing will be exhausted into the flow-through ventilation system. Periodic crossovers between the tunnels will be used to provide flow through ventilation and to draw air from the work areas.

10.3.3 Sealing of Shafts

Sealing of the shafts is the last step in the closure of the DGR. This activity starts when the sealing of underground openings and ancillary areas is complete. At that time, the following activities are envisioned:

- Removal of shaft services including compressed air lines, water lines, power supply and lighting cables, and communication cables;
- Removal of instruments from any impacted boreholes and sealing of each borehole;
- Removal of furnishings including all of the shaft guides and sets, steel support brackets, brattice and lower crash beam assemblies from bottom to top while backfilling; and
- Reaming of the shafts (as required) to remove the concrete linings and any highly damaged wall rock. Thereafter, each shaft will be re-equipped with services and staging, and backfilling will commence with sealing bulkheads installed at strategic locations.

Table 18: Proposed Sealing System for Shafts

Depth from Surface	Material
0 – 20 m	Low heat high performance concrete (LHHPC) – concrete cap at surface
20 – 150 m	70/30 bentonite / sand shaft seal compacted in situ
150 – 170 m	LHHPC for concrete bulkhead keyed into rock / overburden to a distance of 0.5 times the original radius of the shaft
170 – 330 m	70/30 bentonite / sand shaft seal compacted in situ
330 – 380 m	Asphalt seal

Depth from Surface	Material
380 – 480 m	70/30 bentonite / sand shaft seal compacted in situ
480 – 500 m	Concrete monolith – LHHPC

The reference concept for a shaft seal system is summarized in Table 18. The design of the shaft seal system will be updated to suit site-specific geologic conditions.

The shaft sealing system presented in Table 18 is based on the assumption that all shafts will intersect low permeability rock over the full depth of the shafts. However it is possible that the DGR shafts will intersect relatively permeable rock near ground surface. If so, then engineered fill material based on rock excavated during shaft sinking or some other suitable material will be used in the upper portion of each shaft. This engineered fill would likely be placed from surface to a depth where low permeability rock is first encountered.

The shaft seal design concept in Table 18 has focused on the use of simple, relatively well understood and durable materials, and use of proven methodologies for placement. Concrete, bentonite/sand mixture and asphalt will be the sealing materials used in each shaft. Additional information about each major component of the shaft seal system is presented below.

Concrete monolith will be placed at the base of the seal system. Concrete will provide a stable foundation for the overlying seal materials. The monolith will be constructed in stages beneath each shaft. Each monolith will form a contiguous mass concrete structure with no structural reinforcement within the concrete. All services and utilities will be stripped out of the excavations to be filled by the monolith.

Bentonite/Sand Seal: The column of sealing materials in each shaft is largely composed of a compacted bentonite/sand mixture. Once saturated, the compacted bentonite / sand materials will act as a low permeability barrier to retard the movement of radionuclides out of the repository and minimize the potential for groundwater flow down into the repository. Compacted clays or clay/sand mixtures are the most commonly proposed sealing materials for nuclear waste repositories. Sand will be added to the bentonite to act as a filler without compromising the hydraulic conductivity and swelling potential of the bentonite dominant material. The use of sand will improve workability during placement, ease compaction and dust control. 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 against the shaft wall and provide a confining pressure to the rock surface.

Asphalt Seal: An asphalt column will be placed above the lowermost bentonite / sand column. Asphalt has been selected because it has the ability to flow and make good contact with host rock. Immediately upon emplacement, the asphalt will create an effective barrier to water flow. 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.

Concrete Bulkhead: The primary function of the concrete bulkhead will be to provide structural support in the column of sealing materials. In the short-term the concrete will act as an additional seal and over the long-term the ability to act as a seal will diminish as concrete degrades. As with the monolith, concrete for the bulkhead will be placed in mass and with no reinforcing steel, and using measures to control heat build-up. Contact / seal grouting will be applied around the bulkheads to minimize the potential impacts of shrinkage at the interface with the host rock formation. Concrete will be poured directly onto the bentonite / sand columns located below each bulkhead.

Concrete Cap: A surficial concrete cap will be installed on each shaft to minimize risk of human intrusion into the underground repository via shafts. The cap will be constructed using concrete. Air entrainment within the concrete is required to minimize adverse effects of freeze/thaw action on the concrete cap.

10.3.4 Sealing of Boreholes

The purpose of sealing a borehole (e.g., monitoring boreholes) is to inhibit groundwater movement and contaminant transport along the borehole and in the near-field rock parallel to the borehole axis. Cement-based sealing materials will be installed where required to isolate fractured and highly permeable zones because of their low hydraulic conductivities and their groundwater resistance. Clay-based materials with low permeability and a high swelling potential will be installed in adjacent zones.

Sealing of boreholes is commonly practiced in the construction and resource industries to decommission water and monitoring wells. As the geological features intercepted by each borehole will not be identical, a thorough review will be conducted on all available core and borehole logs and down-hole test results to ascertain the preferred sealing approach for each location.

Investigation boreholes will generally be located outside the footprint area occupied by the underground repository. Exceptions would be investigation boreholes at each shaft locations.

10.4 DECOMMISSIONING OF SURFACE FACILITIES

During the 10-year decommissioning period, some supporting surface facilities will be dismantled and removed from the site. The surface facilities and related services will be evaluated and classified in the D&C planning instruments to identify if they are required to support underground decommissioning and closure activities. The sequencing described in this section, and suggested in Table 19, is based on an initial evaluation in this respect which resulted in the placement of each component or service in a comparative position on the decommissioning time queue.

In general, and as illustrated in Table 19, the majority of surface facilities will not be decommissioned until the underground operations have been dismantled and removed, with the access tunnels and shafts sealed as planned. These activities will be the primary focus for concrete and special sealing materials which require an operating surface facility and an underground hoisting operation.

Table 19: Surface Facility Classification for Decommissioning

Area	Protected Area	Primary Function	Comments
P1	Used Fuel Packing Plant (UFPP)	UFC processing	Decommissioned with underground (U/G) facilities. Once no UFC retrieval is contemplated the UFPP can be demolished.
P2	Main Shaft Complex	Provide U/G access	Can be decommissioned as last step of U/G D&C.
P3	Stack	Related to UFPP	Will be decommissioned with the UFPP.
P4	Service Shaft Complex	Provide U/G access	Can be decommissioned as last step of U/G D&C.
P5	Auxiliary Building	Related to U/G access	Can be decommissioned as last step of U/G D&C.
P6	Active Solid Waste Handling Facility	Related to operation and decontamination	Will be decommissioned as part of Protected Area facilities.
P7	Waste Management Area	Related to operation and decontamination	Will be decommissioned as part of Protected Area facilities.
P8	Active Liquid Waste Treatment Building	Related to operation and decontamination	Will be decommissioned as part of Protected Area facilities.
P9	Low-Level Liquid Waste Storage	Related to operation and decontamination	Will be decommissioned as part of Protected Area facilities.
P10	Stormwater Management Pond	Related to total project	Will be part of closure activity.
P11	Switchyard	Related to total project	Will be part of closure activity.
P12	Transformer Area	Related to total project	Will be part of closure activity.
P13	Emergency Generators	Related to total project	Will be part of closure activity.
P14	QC Offices and Laboratory	Related to total project	Will be part of closure activity.
P15	Parking Area	Related to total project	Will be part of closure activity.
P16	Covered Corridor / Pedestrian Routes	Related to total project	Will be decommissioned consistent with connected structures.
P17	Mine Dewatering Settling Pond	Related to decommissioning of U/G	Cannot be decommissioned until U/G decommissioning is complete.
P18	Security Checkpoints	Related to total project	Will be part of closure activity.
P20	Double Security Fence	Related to decommissioning of U/G	Cannot be decommissioned until U/G decommissioning is complete.
P21	Ventilation Shaft Complex	Related to U/G access	Can be decommissioned as last step of U/G D&C.

Area	Balance of Site	Primary Function	Comments
B1	Excavated Rock Management Area	Related to total project	Will be part of closure activity.
B2	Admin. Building, Firehall, Cafeteria	Related to total project	Will be reconfigured as part of closure activity.
B3	Sealing Material Storage Bins	Related to decommissioning of U/G	Cannot be decommissioned until U/G decommissioning is complete.
B4	Perimeter Fence	Related to total project	Will be part of closure activity, possibly reconfigured.
B5	Garage	Related to total project	Will be part of closure activity.
B6	Sealing Materials Compaction Plant	Related to decommissioning of U/G	Cannot be decommissioned until shaft sealing is complete.
B7	Warehouse and Hazardous Mat'ls	Related to operation and decontamination	Will be decommissioned with Protected Area facilities.
B8	Air Compressor Building	Related to total project	Will be part of closure activity.
B9	Fuel Storage Tanks	Related to total project	Will be part of closure activity.
B10	Water Tanks	Related to total project	Will be part of closure activity.
B11	Water Treatment Plant	Related to total project	Will be part of closure activity.
B12	Pump House	Related to total project	Will be part of closure activity.
B13	Concrete Batch Plant	Related to decommissioning of U/G	Cannot be decommissioned until shaft sealing is complete.
B15	Process Water Settling Pond	Related to decommissioning of U/G	Cannot be decommissioned until shaft sealing is complete.
B16	Excavated Rock Stockpile (working)	Related to total project	Will be part of closure activity.
B17	Guard Houses	Related to total project	Will be part of closure activity.
B18	Storage Yard	Related to total project	Will be part of closure activity.
B19	Sewage Treatment Plant	Related to total project	Will be part of closure activity.
B20	WRMA Storm Pond	Related to total project	Will be part of closure activity.
B21	Helicopter Pad	Related to total project	Will be decommissioned at end of decommissioning period.
B22	Bus Shelters	Related to operation until start of D&C	Will be decommissioned at end of decommissioning period.
B23	Weigh Scale	Related to total project	Will be decommissioned at end of decommissioning period.
B24	Security Checkpoints	Related to total project	Will be part of closure activity.
B25	Security Monitoring	Related to total project	Will be part of closure activity.
B26	Stormwater Management Ponds	Related to total project	Will be part of closure activity.
B27	Parking Area	Related to total project	Will be part of closure activity.

Once the shafts have been sealed, the surface facility decommissioning will proceed generally in the following sequence:

- The UFPP, hoisting systems, and all other facilities in the (formerly) Protected Areas will be dismantled, removed, and sent off-site for disposal or recycling;

- Approval will be obtained to remove the Protected Areas' fencing and security systems, and they will also be subject to disposal or recycling;

- All surface facilities not required for the maintenance of site administration and staff-related purposes (the administration-focused systems) will be dismantled and removed (e.g., process water settling pond, hazardous material storage, etc.);

- At this point the site status will be an Administration Building supported by electrical utilities, water and sewage treatment, parking, and the perimeter fence; and

- Reconfiguration of the remaining administration facilities and utility services into a suitable package to support the postclosure period. The balance of site will be rehabilitated to greenfield conditions.

10.4.1 Decontamination

The issue of decontamination during decommissioning is expected to be of potential significance solely from the perspective of radiological matters. After placement operations are complete, operations staff will decontaminate the UFPP and other surface facilities except for fixed contamination in the concrete surfaces or equipment which will be addressed during decommissioning. It is expected that proper practices during the DGR's operational period will have effectively eliminated any residual concerns with other forms of hazardous materials.

The strategy adopted for decontamination, therefore, is based on the facility being free of loose surface contamination, with design elements intended to minimize the amount of fixed or exposure-based radioactive waste.

Although the radiological facilities will have been surveyed and loose contamination removed following the end of operations, the first step will be to re-survey and confirm the loose contamination-free status and the current exposure rate levels where fixed contamination or material sources exist. Following the removal, packaging and disposal of any contaminated material or removable equipment found (including any additional wastes generated in addressing concrete surfaces), the initial radiation survey would be repeated to confirm the absence of contamination.

The survey and clean-up activities will be carried out for all appropriate facilities including, as needed, the underground facilities.

10.5 CLOSURE AND POSTCLOSURE

The minimized administration area will be maintained during the closure period in order to support the post-decommissioning monitoring systems. If at that time it is felt that permanent facilities are no longer required, the monitoring systems could be supported by small enclosures for the electrical equipment, and all other remaining facilities would be removed and the site essentially fully returned to its intended end-state.

The facility's environmental monitoring carried out during the operational and extended monitoring periods, as well as throughout the decommissioning stage will further be continued into the closure and postclosure periods. While the level of monitoring will be reduced, it is expected that the program will still address (at a minimum) groundwater and surface water quality issues, to ensure compliance with regulatory requirements.

In addition, safeguards containment / surveillance monitoring (e.g., an acoustic emissions or micro-seismic network) will be considered on the surface in the rock above and around the DGR to detect any noise that might be associated with an attempt to excavate into the repository. In all respects, inspections and containment / surveillance measures will continue for as long as necessary to ensure the full safeguarding of the sealed DGR.

As the closure period nears its end, the final approval to release the site for public surface use (with underground access excluded) will establish any final postclosure long-term monitoring needs. At that point, the monitoring would be finally configured, fenced and signed as required, and the site released in accordance with the obtained approvals.

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APPENDIX A: USED FUEL CONTAINER AND BUFFER BOX DESIGN

The primary engineered barriers are the used fuel container and the bentonite buffer.

The role of the used fuel container (UFC) is to provide containment for used CANDU (CANada Deuterium Uranium) fuel, non-standard fuel, and any other fuel deemed acceptable for the repository.

The role of the buffer is to:

- Inhibit microbiologically influenced corrosion;
- Fill the excavated volumes and support the surrounding rock;
- Inhibit flow and act as a sorption agent;
- Support the container; and
- Transfer heat to the surrounding rock.

The UFC uses standard available materials and modularization of the used fuel container / bentonite assembly to:

- Simplify development activities;
- Simplify operations of the facility;
- Provide greater certainty of container placement state;
- Efficiently use raw materials (e.g. copper); and
- Improve system performance during the post closure evolution of the repository.

The UFC is designed to use readily available, pre-qualified ASTM/ASME pipe and plate (to form the hemi-spherical head) for the steel core. The corrosion barrier is a copper coating that is bonded directly to the external surface of the steel core. Copper coating eliminates creep performance concerns, avoids the need for micro-alloying, and requires significantly less copper than having a separate outer copper shell.

The smaller and significantly lighter used fuel container provides an opportunity to pre-pack the highly compacted bentonite around the UFC at surface. This eliminates the need to perform tight tolerance work in a radiological environment that has poor lighting and limited visibility. Once packaged, used fuel container placement is simplified by using commercially available vehicles with modified handling attachments to place the container below ground.

A.1 Design Requirements

Although there are many requirements, below are the primary postclosure design requirements that must be met. These apply to the container and the bentonite buffer.

A.1.1 Used Fuel Container

1. Core material property - The steel core materials must meet the minimum strength and impact toughness requirements of the ASME Boiler and Pressure Vessel code for the service conditions intended by the design.

2. Container design - Container designed to withstand the emplaced loads and meet the intent of the ASME Boiler and Pressure Vessel code.

   Emplaced loads include:
   a. Uniform buffer swelling load - Buffer swelling assuming complete saturation;
   b. Non-uniform buffer swelling - Buffer swelling assuming non-uniform saturation;
   c. Rock load - Rock load as transmitted through the buffer; and
   d. Hydrostatic load - Hydrostatic load that would be associated with a water column from repository depth to the surface.

3. Glacial load - Container designed to withstand the hydrostatic load that would be associated with a water column from repository depth to the surface of a glacier without rupture of the container (through thickness stresses less than ultimate).

4. Container sealing - No leakage path between the inside of the container and the placement room under any of the above loads.

5. Corrosion allowance - The design has the following considerations:

   a. an allowance for corrosion attributable to all of the oxygen trapped in the repository;
   b. an allowance for all of the chloride that may be present or flow through the repository;
   c. an allowance for sulphide that might be present in the buffer and any sulphide produced by sulphate reducing bacteria;
   d. an allowance for sulphide that might be present or produced in the rock that is capable of migrating to the container;
   e. an allowance for microbially induced corrosion and/or corrosion events that combine trapped oxygen, water and radiation to damage the inside of the container; and
   f. an allowance for flaw size detection limit.

A.1.2 Bentonite Buffer

1. Dry density – The weighted average dry density of the emplaced buffer must be ≥1.6 g/cm^3 to:

   a. Suppress microbial growth – Microbes are suppressed at Water Activity < 0.96 which is achieved with the dry densities above; and
   b. Provide interface contact pressure – The dry densities specified above generate 100 kPa of interface contact pressure to ensure voids are filled in the room and to provide support to the container and excavated damage zone.

2. Heat Transfer – Bentonite geometry and container spacing must be selected to sufficiently transfer heat to keep the container surface temperature below 100°C.

A.2 Used Fuel Container (UFC)

A.2.1 Used Fuel Container Description

The engineered barrier closest to the fuel is the used fuel container. Its safety function is containment and isolation. It fulfills the safety function by incorporating the corrosion barrier and the structural vessel to meet performance requirements. The Used Fuel Container is a mid-sized capacity (12 bundle/layer x 4 layers= 48 bundle) vessel which incorporates a steel core for structural strength and a 3 mm exterior copper coating for corrosion resistance. The weight of the container loaded with fuel is approximately 2,805 kg.

The selection of the 48 bundle vessel is based on the results of the used fuel container sizing study which identified this design as the optimal mid-sized container in terms of vessel manufacturability. This vessel design permits the use of readily available, standard pipe size and formed heads from flat plate, instead of a custom forged product. This container size also better facilitates automated production in component fabrication, encapsulation plant operations, and buffer pre-assembly.

Some unique features of the UFC (Figure A-1) are:

a. Geometry (hemi-spherical heads) for optimization of stress distributions;
b. Hybrid Laser Arc Weld (HLAW) weld technology to seal the container; and
c. Corrosion barrier product form (copper coating) which permits the corrosion allowance to dictate the thickness of copper instead of manufacturing limitations. Copper coating avoids creep ductility and the need for stabilizing chemical additives.

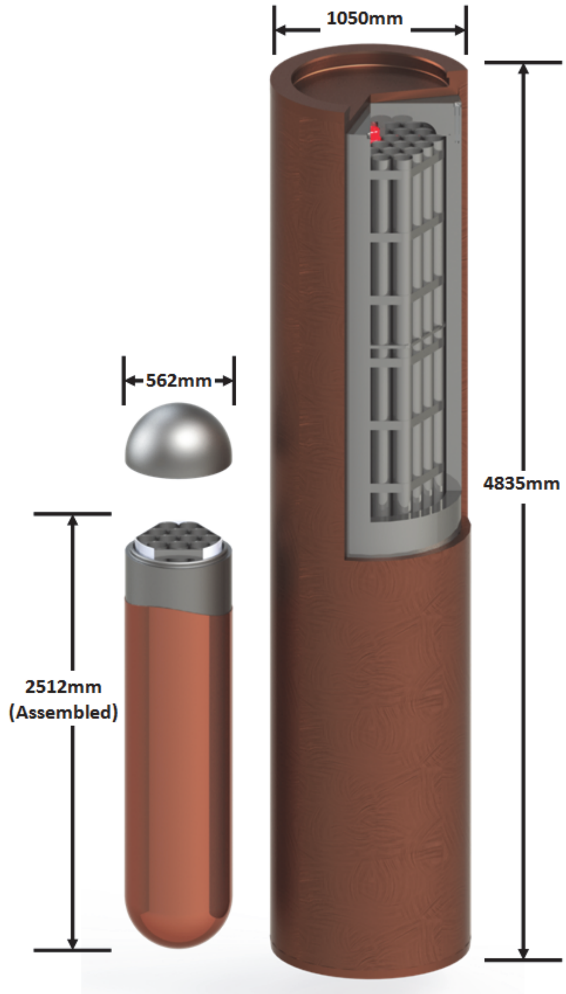

Figure A-1: 48-bundle container (Left) vs. 288-bundle container (Right)

A.2.2 Used Fuel Container Closure Weld

The used fuel container is sealed with a closure weld instead of a mechanical seal like the one used in the 288 bundle container. This weld is also structural and has been designed to meet the worst case loading scenario. Since the 45 MPa load is an external pressure, the stresses in the container are compressive and only require a nominal 8 mm partial penetration weld.

The used fuel container closure welding operation is critical and presents various process challenges due to the radioactive nature of the container load. The closure welding process must be suitable for remote welding operation using an automated or remotely controlled system in a radioactive environment.

NWMO has conducted feasibility programs into the evaluation of several welding technologies as part of the manufacturing assessment of this design. Based on the findings of the closure weld development program, the single pass Hybrid-Laser-Arc-Weld process has been selected as the reference weld technology for the Used Fuel Container.

A.2.3 Copper Coating

The corrosion barrier of the Used Fuel Container is a fully dense 3 mm copper coating applied to the exterior. The external surface of the used fuel container must not have any gaps or crevices like those associated with a bolted lid design for the coating to perform as required. From a design perspective, the use of a fully bonded copper coating eliminates potential concerns regarding creep ductility associated with the copper outer shell and the accompanying need for micro-alloyed chemistry (e.g., phosphorus doped copper). The specified thickness of 3 mm gives an additional 130% margin over the 1 million year corrosion allowance of 1.3 mm and well within the capability of modern coating technologies.

All external core surfaces of the used fuel container, with the exception of a narrow band adjacent to the closure weld location, will be copper coated prior to delivery to the encapsulation plant. Based on the findings of the copper coating optimization work, electrodeposition is the preferred technique for coating the factory supplied components.

A.3 Buffer Box

Prior to transfer to the repository, the used fuel container is pre-packaged into a rectangular shaped buffer box. The Buffer Box (Figure A-2) is a 2 piece assembly made from highly-compacted bentonite blocks with a machined cavity to house the used fuel container. The dimensions of the Buffer Box are 1 m x 1 m x 2.8 m and the loaded mass is approximately 7,125 kg.

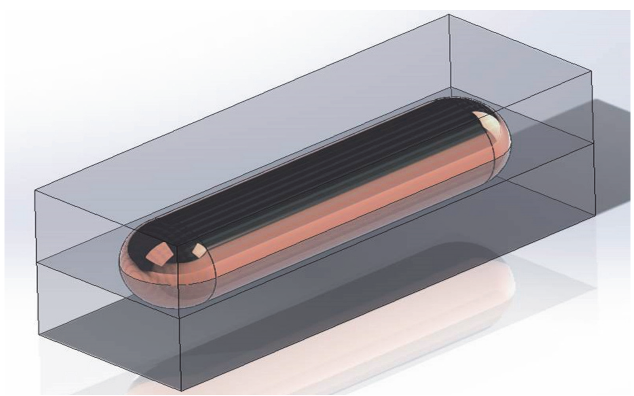

Figure A-2: 48-Bundle Used Fuel Container Buffer Box

The buffer box permits assembly of the highly compacted bentonite to tight tolerances ensuring material voiding is minimized. The standard buffer box shape permits stacking and relatively simple placement within the placement room. Any water inflow will be managed during operations to ensure bentonite erosion does not occur. The buffer box provides an added level of protection to the material within the container by providing buffer protection. This is not expected to occur until after the facility has been decommissioned.

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APPENDIX B: RADIATION SHIELDING

Radiation shielding is to be consistent with the ALARA principle for normal operations. In order to ensure that the design is in accordance with this principle, radiation dose rates were calculated for a variety of different scenarios for normal operations. These estimates have provided a basis for shielding designs in the DGR concepts. Contributions from gamma, neutron, and neutron-induced gamma radiations were assessed.

The UFC is designed to hold 48 used fuel bundles (with an outside diameter of 565 mm, an overall length of 2515 mm, and a loaded weight of approximately 2,805 kg). Prior to transfer underground, the UFCs are pre-packaged into a rectangular shaped buffer box in the UFPP. The Buffer Box consists of an outer shell, filled with blocks of highly-compacted bentonite. A cavity is machined out to house the UFC. The dimensions of the Buffer Box are 1 m x 1 m x 2.8 m and the loaded mass is approximately 7,125 kg.

Neutron and gamma dose rates as reported in the current analyses were obtained using either MCNP or SCALE MAVRIC calculations. The SCALE MAVRIC code was employed for the deep penetration problems instead of MCNP. Examples of deep penetration problems are the shielding calculations for the underground placement configurations.

B.1 Dose Rate Constraints

The following dose rate constraints were adopted for this work:

a. Permanent and temporary radiation shielding shall be designed to provide protection from both gamma and neutron sources so that:
   - The effective dose rate on the accessible face of any shielded structure is less than 1 mSv/h near contact with the outer surface;
   - The effective dose in normally occupied areas (or 1 m from the shielding surface) is less than 10 μSv/h;
b. During normal operation, an individual worker must not receive a radiation dose exceeding 10 mSv/a. This constraint is for ALARA and was not directly imposed on the shielding design calculations; and
c. Permanent and temporary radiation shielding systems shall be designed to ensure that doses are maintained ALARA during normal operations.

B.2 Analyzed Shielding Scenarios

Completed shielding scenarios included the following:

- Bare UFC (for 10 and 30 year fuel decay times) and produced radiation field;
- UFC inside bentonite box (for 10 and 30 year fuel decay times);
- For the above, sensitivity of dose rate to moisture content and bentonite block gaps;
- For a shielded UFC without the buffer box, the minimum thickness of concrete, carbon steel or lead to meet dose constraints (for 10 and 30 year fuel decay times);
- For a shielded UFC inside the buffer box, the minimum thickness of concrete, carbon steel or lead to meet dose constraints (for 10 and 30 year fuel decay times);
- Radiation fields inside placement room;
- Thickness of movable steel shielding wall inside the placement room with no gap present between the steel and room rock wall / ceiling; and
- Radiation field during placement of 4 m HCB wall in placement room.

B.3 Input Data for Shielding Assessments

Input data used as the basis for performing the neutron and gamma transport calculations are identified below.

B.3.1 Geometry and Dimensions

The UFC shielding calculations considered the geometries of the fuel bundles, UFC, buffer box, shielding materials, the underground placement room, and the sealing materials.

The modeled fuel bundles were the standard 37-element configurations. While fuel elements and their claddings were modeled explicitly, endcaps / plates and fuel appendages were not modeled (does not impact the calculated results). The basket fuel bundle tubes as well as the UFC's steel shell and copper coating were also modeled explicitly.

In the underground placement room the UFCs / buffer boxes are stacked two-high, with spacer blocks inserted between them and with gap fill being used to fill any remaining surrounding voids (see Section 6).

B.3.2 Material Compositions

Materials relevant to the shielding assessments included the fuel material and cladding, the UFC's steel and copper, bentonite in the buffer box, potential concrete / steel/lead / polyethylene shielding materials, the repository host rock, and dense backfill. Related assumptions included:

- Uniform material compositions for all 37 elements inside a fuel bundle;
- Fuel cladding for each of the 37 fuel elements were explicitly modeled;
- The fuel tube is composed of carbon steel material and its copper coating was assumed to be pure copper;
- Concrete shielding, when considered, was composed of ordinary concrete;
- Lead shielding, when considered, was assumed to be composed of pure lead;
- Low density polyethylene was used for neutron shielding where necessary;

- Underground placement room walls were assumed to be granite;
- DBF is used in the underground placement room comprised 500 mm thick blocks with a composition of 70% granite, 25% clay and 5% bentonite;
- Buffer boxes were modeled as one piece of solid bentonite with a 14% moisture content. Its metallic cover was not credited in the dose rate calculations; and
- HCB used as backfill material in the underground placement room had a 15% moisture content.

B.3.3 Source Terms

The characteristics of the reference source term fuel bundle were as follows:

- Type of fuel: CANDU standard 37-element fuel bundle;
- Initial uranium loading: 19.25 kgU;
- Burnup: 280 MWh/kgU; and
- Decay time: 10 years.

Variations of the reference source terms were also considered. Such variations included a 30 year decay time for the fuel assessments. Sensitivity studies were done on moisture content in the bentonite blocks and gaps between blocks in the buffer box.

B.3.4 Dose Conversion Coefficients

The main results from the shielding calculations are the gamma and neutron fluxes. In order to convert the flux values into dose rates, appropriate conversion coefficients were needed. Gamma photon and neutron dose conversion factors used were extracted from ICRP Publication 74. The effective dose conversion coefficients for the antero-posterior (AP) geometry were applied (these values are higher as compared to that of the postero-anterior, lateral, rotational, or isotropic geometries).

B.4 Results and Discussions

This section describes the radiation field assessments and shielding requirements from the modelled scenarios.

B.4.1 Radiation Field around Bare UFC

The dose rate profiles for both gamma and neutron from near contact to 10 m away from the axial mid-plane of the UFC are presented in Figure B-1. As illustrated, gamma radiation dominates the radiation field outside of the bare UFC with gamma dose rates being four orders of magnitude higher than the neutron dose rates for all observation points. Due to the high radiation field around the filled UFC, shielding must be provided to allow personnel to handle the filled UFCs.

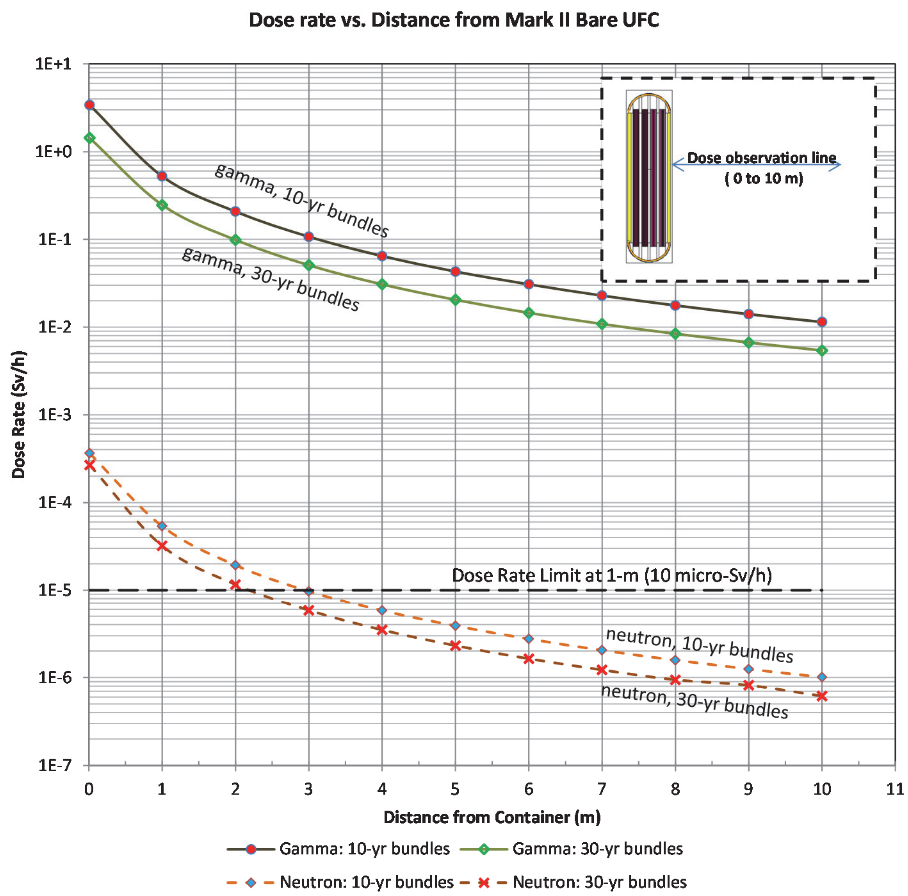

Figure B-1: Dose Rate Profile as a Function of Distance from UFC

B.4.2 UFC Inside Buffer Box

For this shielding configuration, the buffer box containing one filled UFC was placed on the concrete ground on its side. Dose rates were then tabulated in three-dimensional mesh tallies around the box. The maximum dose rates as a function of distance from the buffer box are listed in Table B-1. Both the near contact and 1 m dose rates exceed the dose rate constraints. Shielding is, therefore, required when handling the UFC / buffer box assembly.

Table B-1: Dose Rates outside of Buffer Box

	Gamma Dose Rate							
	TOP				SIDE			
	10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU		10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU	
Distance (m)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)
0.2	1.35E-1	0.7%	6.18E-2	0.7%	1.18E-1	0.5%	5.07E-2	0.5%
1	2.23E-2	0.5%	1.01E-2	0.5%	4.10E-2	0.3%	1.76E-2	0.3%
2	7.35E-3	0.5%	3.32E-3	0.5%	1.76E-2	0.3%	7.56E-3	0.3%
4	2.11E-3	0.5%	9.49E-4	0.5%	5.78E-3	0.3%	2.48E-3	0.2%
6	9.64E-4	0.5%	4.33E-4	0.5%	2.73E-3	0.2%	1.18E-3	0.3%
8	5.44E-4	0.5%	2.43E-4	0.5%	1.56E-3	0.3%	6.71E-4	0.3%
10	3.41E-4	0.5%	1.53E-4	0.5%	9.99E-4	0.3%	4.28E-4	0.3%
	Neutron Dose Rate							
	TOP				SIDE			
	10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU		10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU	
Distance (m)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)
0.2	4.91E-6	1.6%	2.91E-6	1.6%	8.92E-6	0.9%	5.35E-6	0.8%
1	7.85E-7	1.3%	4.64E-7	1.3%	2.70E-6	0.5%	1.62E-6	0.5%
2	2.64E-7	1.2%	1.56E-7	1.2%	1.07E-6	0.5%	6.42E-7	0.5%
4	7.85E-8	1.2%	4.62E-8	1.2%	3.28E-7	0.5%	1.97E-7	0.5%
6	3.66E-8	1.2%	2.16E-8	1.1%	1.51E-7	0.5%	9.11E-8	0.5%
8	2.06E-8	1.2%	1.22E-8	1.1%	8.57E-8	0.6%	5.12E-8	0.5%
10	1.29E-8	1.1%	7.63E-9	1.1%	5.37E-8	0.5%	3.23E-8	0.5%
	Gamma + Neutron Dose Rate							
	TOP				SIDE			
	10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU		10-yr, 280 MWh/kgU		30-yr, 280 MWh/kgU	
Distance (m)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)	Sv/h	Uncertainty (%)
0.2	1.35E-1	0.6%	6.18E-2	0.6%	1.18E-1	0.5%	5.07E-2	0.5%
1	2.23E-2	0.5%	1.01E-2	0.5%	4.10E-2	0.3%	1.76E-2	0.3%
2	7.35E-3	0.5%	3.32E-3	0.5%	1.76E-2	0.3%	7.56E-3	0.2%
4	2.11E-3	0.5%	9.49E-4	0.5%	5.78E-3	0.3%	2.48E-3	0.2%
6	9.64E-4	0.5%	4.33E-4	0.5%	2.73E-3	0.2%	1.18E-3	0.3%
8	5.44E-4	0.5%	2.43E-4	0.5%	1.56E-3	0.3%	6.71E-4	0.3%
10	3.41E-4	0.5%	1.53E-4	0.5%	9.99E-4	0.3%	4.28E-4	0.3%

B.4.3 Shielding Thicknesses to Meet Dose Rate Constraints (Bare UFC and UFC within Buffer Box)

Three commonly used gamma shielding materials were examined to reduce the radiation field from a UFC (either bare or held within a buffer box) to within the identified dose rate constraints. These included ordinary concrete, carbon steel and lead. For neutron shielding, a low-density polyethylene was considered. The polyethylene was placed outside of the gamma (concrete, carbon steel, or lead) shielding.

Shielding thicknesses required to meet the dose constraints are listed in Table B-2 for a bare UFC. Table B-4 provides similar information for a UFC contained within a buffer box. In both cases, the 1 m dose rate constraint was found to be more limiting than that of the near contact one. The associated dose rates at a 1 m separation from a bare UFC are given in Table B-3. For a UFC within a buffer box, the comparable values are provided in Table B-5.

It should be noted that the estimated shielding thicknesses are valid only when shielding is provided all around the bare UFC (i.e. no pathways for streaming or shining). The estimated shielding thickness was also obtained without crediting for any distance between the source and the shield. Since radiation exposure decreases with distance, a lower amount of shielding is required if there is distance between the source and the shield, provided that the same shielding strength is provided all around the source.

Table B-2: Shielding Thickness for Bare UFC (mm)

	Concrete	Polyethylene	Carbon Steel	Polyethylene	Lead	Polyethylene
10 years bundles						
Top	730	0	235	60	130	75
Side	780	0	250	75	140	105
30 years bundles						
Top	650	0	205	60	105	60
Side	700	0	220	60	115	90

Table B-3: Dose Rates associated with Shielding Thicknesses for Bare UFC

		Concrete + Polyethylene	Carbon Steel + Polyethylene	Lead + Polyethylene
10 years bundles				
Top	Gamma	7.17	5.61	6.27
	Neutron	0.00	0.39	0.77
	Gamma from n-capture	0.03	0.15	0.12
	Total	**7.20**	**6.15**	**7.16**
Side	Gamma	8.56	5.29	5.92
	Neutron	0.00	0.74	1.25
	Gamma from n-capture	0.06	0.39	0.30
	Total	**8.62**	**6.42**	**7.47**
30 years bundles				
Top	Gamma	7.00	5.58	5.92
	Neutron	0.00	0.31	0.89
	Gamma from n-capture	0.01	0.09	0.07
	Total	**7.01**	**5.98**	**6.88**
Side	Gamma	7.24	5.31	4.81
	Neutron	0.00	1.03	1.33
	Gamma from n-capture	0.01	0.24	0.19
	Total	**7.25**	**6.57**	**6.33**

Note: The above table lists 1 m dose rates (μSv/hr) with shielding thicknesses as per Table B-2.

Table B-4: Shielding Thickness for UFC in Buffer Box (mm)

	Concrete	Polyethylene	Carbon Steel	Polyethylene	Lead	Polyethylene
10 years bundles						
Top	540	0	180	0	100	0
Side	600	0	190	0	110	0
30 years bundles						
Top	470	0	150	0	75	0
Side	520	0	160	0	80	0

Table B-5: Dose Rates associated with Shielding Thicknesses for UFC in Buffer Box

		Concrete + Polyethylene	Carbon Steel + Polyethylene	Lead + Polyethylene
10 years bundles				
Top	Gamma	8.61	7.38	6.46
	Neutron	0.00	0.13	0.38
	Gamma from n-capture	0.00	0.00	0.01
	Total	8.61	7.51	6.85
Side	Gamma	7.30	7.75	5.78
	Neutron	0.00	0.48	1.27
	Gamma from n-capture	0.01	0.01	0.01
	Total	7.31	8.24	7.06
30 years bundles				
Top	Gamma	7.37	7.61	6.67
	Neutron	0.00	0.10	0.26
	Gamma from n-capture	0.00	0.00	0.01
	Total	7.37	7.71	6.94
Side	Gamma	5.89	7.06	6.69
	Neutron	0.00	0.34	0.93
	Gamma from n-capture	0.01	0.01	0.01
	Total	5.90	7.41	7.63

Note: The above table lists 1 m dose rates (μSv/hr) with shielding thicknesses as per Table B-4.

B.4.4 Radiation Fields in Placement Room

While personnel are not expected to be inside the placement room during UFC / buffer box placement, the radiation field inside the room during operations (open room) was calculated. Results indicate that the radiation field inside the placement room is mainly due to the two front-most (or last-placed) UFCs / buffer boxes. The contribution from the front two buffer boxes at a 1 m separation is 99.99% of the total dose rate.

The maximum doses rates as a function of location inside the placement room are shown in Figure B-2. As illustrated, the overall dose rate is dominated by gamma radiation. The contribution of neutrons to the overall dose rate is around 0.01%. Further, the total dose rates drop by a factor of ~100 when the two front-most spacer blocks were credited (see Figure B-6).

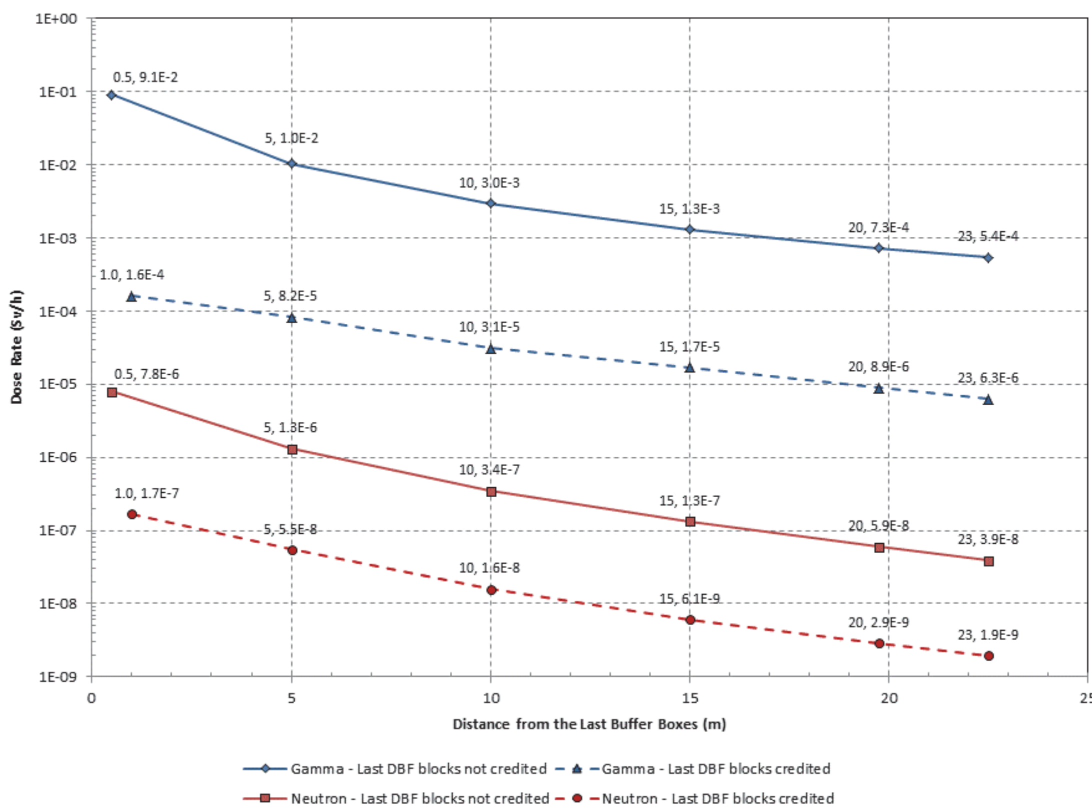

Figure B-2: Maximum Dose Rate in Placement Room (Open Room)

During UFC / buffer box placement, personnel may be present in the access tunnel area. As described in Section 6, a movable carbon steel shielding canopy is provided to reduce the radiation field outside of the shielding panel (in the access tunnel) to within the dose rate constraints. For the shielding canopy, the required thickness of its steel wall was assessed to be 210 mm. This thickness can cater for 10-year old fuel bundles inside the UFCs.

B.4.5 Sensitivity to Bentonite Block Moisture Content

As the expected tolerance on moisture content in manufactured bentonite blocks is presently unknown, a sensitivity study was carried out for the worst case scenario wherein the bentonite blocks would contain no moisture. Since the effectiveness of neutron shielding depends heavily on the hydrogen content, the absence of moisture will increase the neutron dose rate. However, since gamma dose rates outside of the buffer box are still the dominant contributor, the overall dose rate increase is more influenced by how much the gamma rate increases. Table B-6 illustrates the sensitivity study results.

Table B-6: Impact of Bentonite Block Moisture Content on Dose Rate

Moisture content (% of total bentonite weight)	Maximum dose Rate (Sv/h) at 1 metre away from the buffer box			
	Gamma	Neutron	Neutron-induced gamma	Total
14% (reference)	4.10E-02	2.68E-06	3.08E-07	4.10E-02
0%	6.16E-02	1.51E-05	1.23E-07	6.16E-02

B.4.6 Sensitivity to Gap Sizes between Bentonite Blocks

In the buffer box, any gaps between the bentonite blocks have the potential to result in increased dose rates from streaming radiation. A sensitivity study was performed to assess the impact of different gap sizes (10, 20, 30, and 40 mm) on dose rates 1 m away from the side of the buffer box. The results are tabulated in Table B-7. As expected, the dose rate increases as the gap size is increased.

For the same gap size, the increase in dose rate is less when the buffer box is assumed to be made of two layers of bentonite blocks in a staggered arrangement. One example of the beneficial impact of a staggered block arrangement is provided on the last row of Table B-7.

Table B-7: Impact of Bentonite Block Gap Size on Dose Rate

Gap size (mm)	Maximum dose rate 1 m from buffer box
0 (reference)	4.10E-02 Sv/h
10	4.56E-02 Sv/h
20	5.09E-02 Sv/h
30	5.67E-02 Sv/h
40	6.36E-02 Sv/h
20, staggered arrangement	4.76E-02 Sv/h

B.4.7 Sealing of Placement Rooms

After the placement room is filled to capacity, a 4 m HCB wall is put in place, followed by the construction of a 10 m concrete bulkhead. The radiation field during the establishment of the HCB wall was calculated, with radiation field profiles determined with 1, 2, 3, or 4 m of the HCB wall in place. The results are shown on Figure B-3. As illustrated, after 1 m of the HCB wall is in place, the dose rate outside of the wall will always be lower than 10 µ Sv/h.

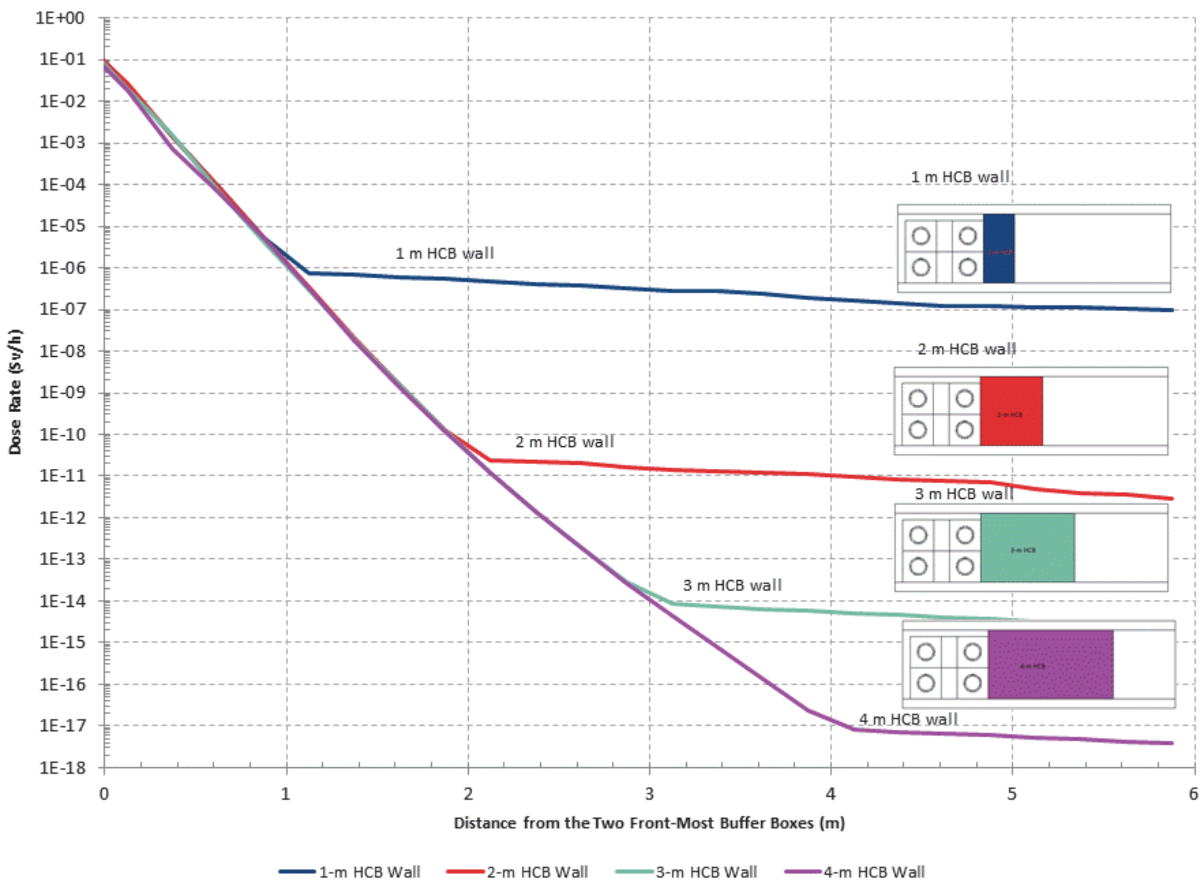

Figure B-3: Radiation Field inside Placement Room for Different Stages of HCB Wall Placement

The dose rates shown in Figure B-3 were calculated using the nominal moisture content (15%). When the moisture content in the HCB wall is removed (i.e. the wall is made of dry bentonite), the neutron field becomes the dominant contributor to the outside radiation field. However, even in this situation, the dose rate outside of the HCB wall will remain low (~10^{-7} micro-Sv/h with 4 m dry HCB wall in place).