

VENTILATION AND TRAFFIC STUDY FOR A PROPOSED DEEP GEOLOGICAL REPOSITORY IN CRYSTALLINE GEOSPHERE

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Abstract

The management of nuclear waste products in Canada is undertaken by the Nuclear Waste Management Organization (NWMO). 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. A conceptual adaptive layout design that can adapt to the structural anisotropy of the rock mass as expected in a hypothetical crystalline geosphere is being considered. This layout will incorporate significant flexibility in addressing geoscientific, safety and engineering aspects as details become available during progressive site specific study stages and construction.

This paper presents the conceptual design requirements, preliminary engineering analyses, and results for this adaptive layout. The overall layout configuration considers the functionality of the:

- Ventilation strategy.
- Establishment of flow-through ventilation.
- Traffic flow management.
- Underground central services area (CSA).
- Completion of the demonstration rooms during initial construction.
- Completion of the first panel of the placement rooms prior to operations.
- Worker safety and preliminary thoughts on emergency responsiveness.

The results of this study conclude that there is significant flexibility of the layout to adapt to the geosphere as it becomes progressively defined; the ventilation system and traffic flow can be configured for different scenarios through the DGR operations; and, potential worker exposure for defined emergency events is minimized with this adaptive layout.

1. Introduction

The NWMO is responsible for implementing APM, which is the approach selected by the Government of Canada for long-term management of Canada's used nuclear fuel. APM has,

at its endpoint, a deep geological repository in an informed and willing host community; of which, the current candidate sites are located in the province of Ontario.

The DGR will require approximately 100 km of placement rooms to dispose of the used nuclear fuel utilizing the Mark II used fuel container and storage room configuration depicted in Figure 1.

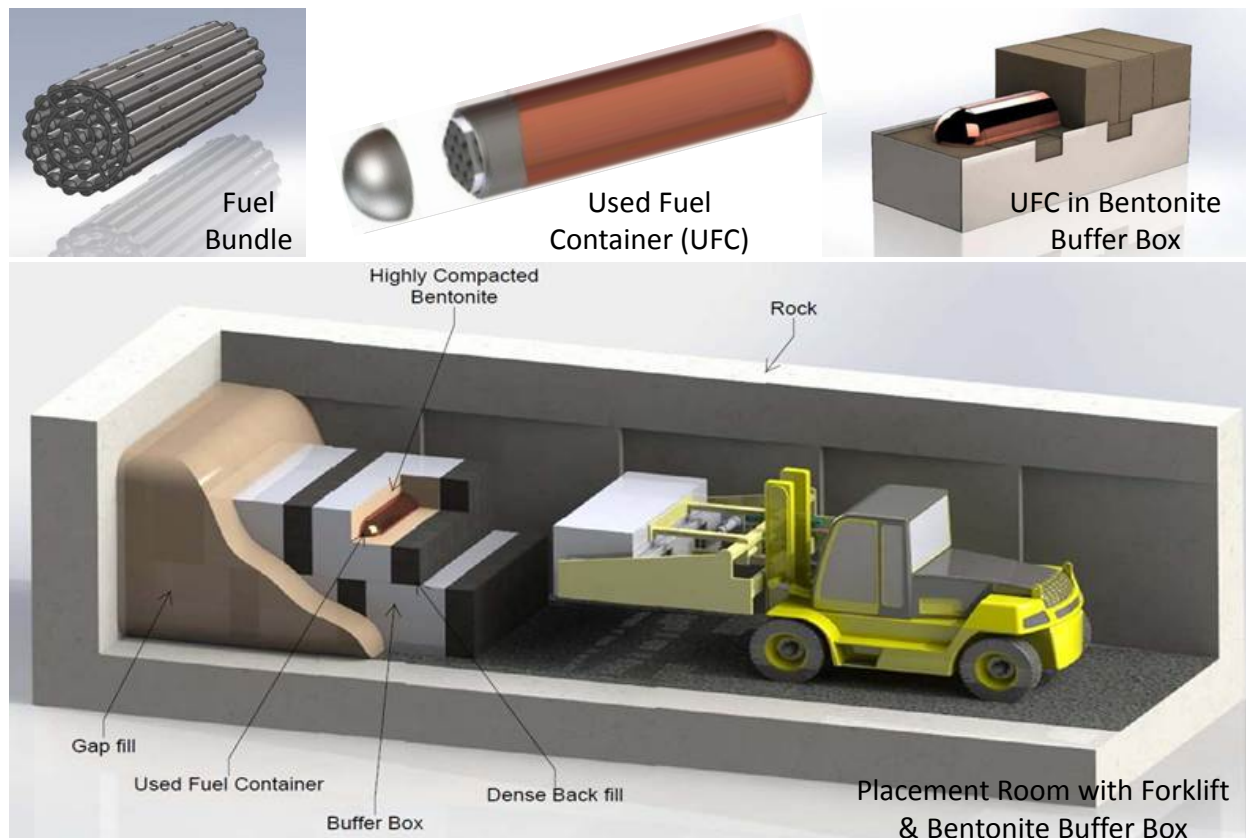


Figure 1: Canadian Mark II Container for DGR in Crystalline Rock

The Mark II used fuel container (UFC) consists of 48 spent CANDU reactor fuel bundles encased in a steel and copper coated container. This container is placed in a bentonite buffer box that is sized to provide the appropriate stacking dimensions in the placement rooms. These UFCs are placed in excavated placement rooms; of which some length at the entrance is reserved for a bentonite seal and concrete bulkhead. The gap surrounding the UFCs and buffer blocks is tight backfilled with bentonite pellets to balance heat dissipation and fluid transfer from and to the UFCs, respectively.

The DGR comprises a network of tunnels and placement rooms for UFCs. It will be constructed on a single elevation at a depth of 500 m below surface, depending on site specific rock characterization. A conceptual reference layout for a repository shown on the left side of Figure 2 would require an underground footprint of about 2 km by 3 km (about 600 ha) in an idealised “fractureless” rock domain. The actual underground footprint at any particular site

would depend on a number of factors, including the characteristics of the rock at the preferred site, the location of underground features in the rock, the final design of the repository and the total inventory of used fuel to be managed. A conceptual adaptive layout shown on the right side of Figure 2 addresses a set of factors in a different rock domain as discussed in the following section.

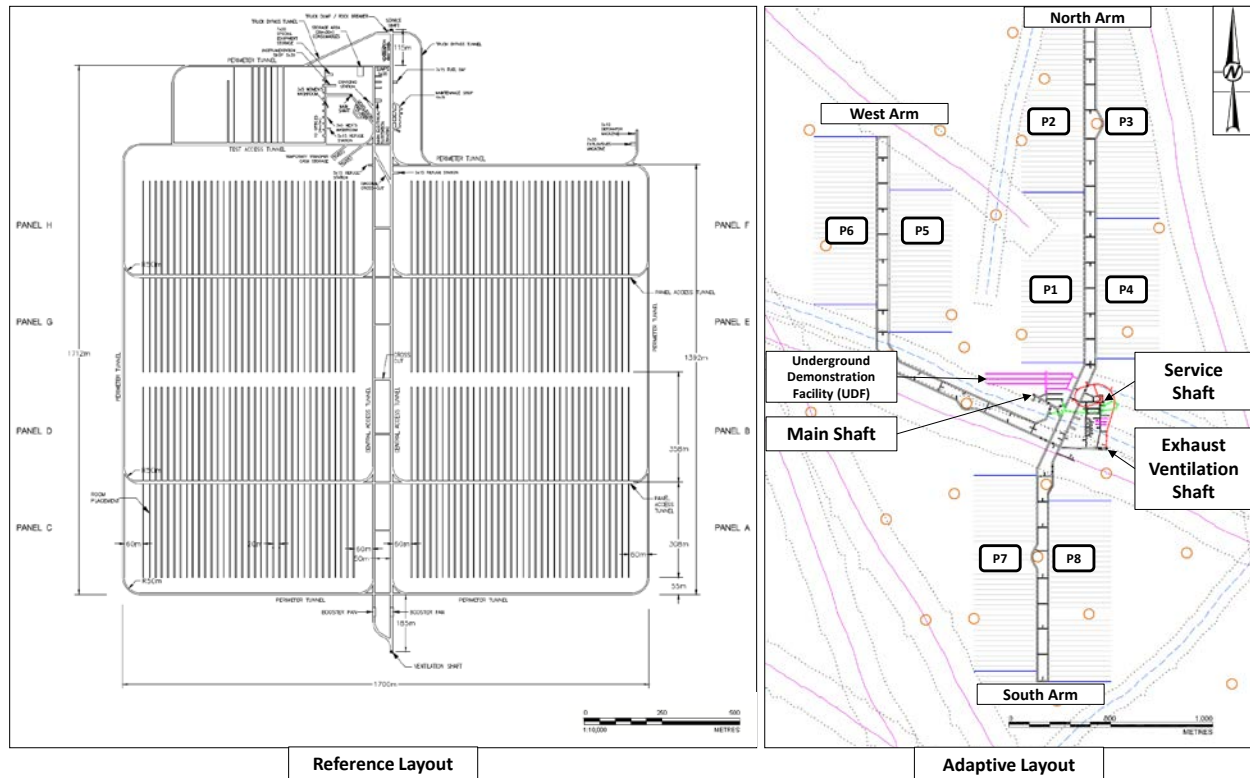


Figure 2: Conceptual reference and adaptive NWMO APM DGR layouts

2. Adaptive APM DGR Layout in Crystalline Geosphere

NWMO developed a hypothetical discrete fracture network (DFN) model. A map of the lineaments (faults and similar structural features) at a depth of 500 m was derived from the DFN, as shown in Figure 3. It is assumed once site specific data regarding the actual lineaments are available for: dip, strike and continuity at approximately 500 m below ground surface the constraints will be similar to this hypothetical map. Based on industry experience, the following lateral stand-off distances between placement rooms and the fracture zones were planned to avoid layout-limiting fracture zones based on the continuity, position uncertainty and curvatures:

- 100 m for fracture zones greater than 3 km in length.
- 50 m for fracture zones between 1 km and 3 km in length.
- 25 m for fracture zones between 0.5 km and 1 km in length.
- 25 m radius stand-off distance was established between boreholes and placement rooms.

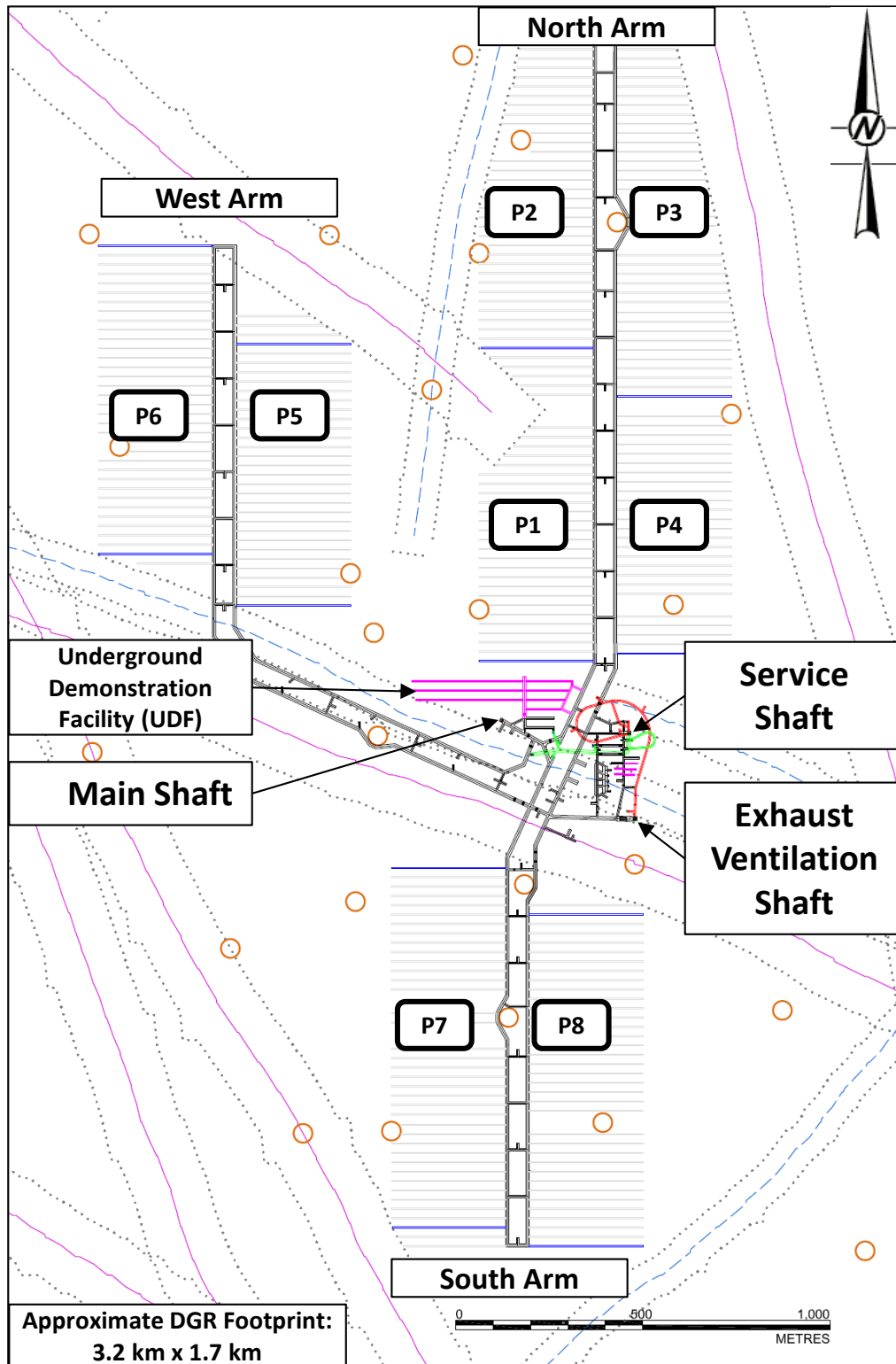


Figure 3: NWMO APM DGR adaptive layout in a hypothetical crystalline geosphere

The DGR layout shown in Figure 3 indicates a randomly distributed location of boreholes that will be drilled from surface to characterize the rock mass prior to sinking the shafts and developing the DGR. This layout demonstrates the flexibility of the general arrangements to be modified to accommodate the drill hole and hypothetical layout limiting fracture zones. For other DFNs, the three individual arms, panels and rooms, may change, but will remain as a central area with three arms branching out.

To house the UFC inventory projected for Canada's used nuclear fuel; approximately 100 km of placement rooms will be required. This will be divided into eight panels. In addition to the placement rooms, there is a requirement for a demonstration set of placement rooms (magenta in Figure 3) and a central service area (CSA); for isometric view, refer to Figure 4. Once the shafts have been sunk, the priority will be to develop the demonstration rooms, complete the CSA and develop the twined access tunnels in each of the three arms. Approval to place the used fuel will be based on the geosphere characterization and processes verified in the demonstration facilities. Since an adaptive layout is being considered, implications of its use for ventilation and traffic are described below.

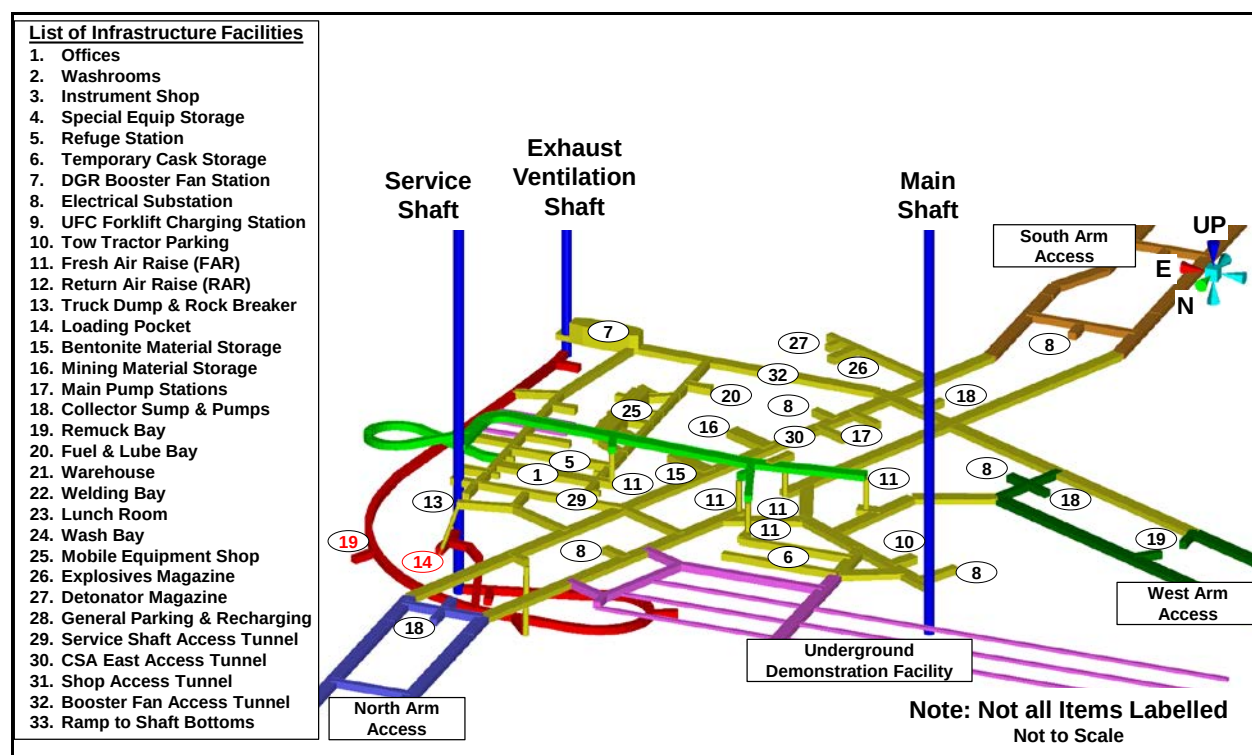


Figure 4: NWMO APM DGR adaptive layout - isometric view of central services area (CSA)

3. Ventilation – Conceptual Strategy

Ventilation systems for the adaptive facility layout must support ongoing development and placement activities occurring concurrently. A strategy of having separate air flow circuits for each of the arms (north, west and south) was developed. In addition to overall separation of ventilation circuits, the office area and mobile equipment maintenance shop areas of the CSA were located such that they would have their own independent ventilation circuits.

The key features and description of the layout are listed below:

- The service shaft will provide all the fresh air to the DGR. There is a fresh air distribution level located approximately 25 m above the DGR horizon with raises to connect to each independent circuit supplying north, west and south arms.
- The offices and laboratories area that service the geoscience and nuclear investigations are situated on an isolated access tunnel close to the shaft with the fresh air supply.
- The service garage and fuel station are located in proximity to the exhaust ventilation shaft with a dedicated exhaust air route. Fresh air is provided directly via the fresh air distribution level connector raise to the shop access tunnel.
- A large permanent refuge station is located in proximity to where workers will be located on a regular basis in the CSA; i.e. near the offices / lab area, service shaft and mobile equipment shop area.
- Additional permanent refuge stations are located in each arm for close access by development, construction and placement workers in those areas and in transit. Portable refuge stations will be used on an as needed basis during the initial development stage (prior to UFC placement) until the permanent refuge stations are constructed.
- The explosives storage is located centrally, while respecting the regulated stand-off distances from major infrastructure (e.g., 60 m from main access into the repository, key mechanical or electrical installations, refuge stations, where people may congregate, or where fuels or other combustibles are stored).

4. Conceptual Ventilation Design and Traffic Flow Requirements

Once the APM DGR is licensed for UFC placement, it will be governed by the Canadian Nuclear Safety Commission (CNSC) as a nuclear facility. The provisions of Canadian Standards Association (CSA) N393 2013, Fire Protection for Facilities that Process, Handle, or Store Nuclear Substances, will apply.

Based on conclusions made during the design progression of the Ontario Power Generation (OPG) low and intermediate level waste (L&ILW) DGR, it was determined that the use of

ducting systems was to be eliminated where possible in favour of flow-through ventilation systems. This was to:

- Mechanically simplify the system by reducing the quantity of ducting and auxiliary fans.
- Allow reduction in the size of tunnels (i.e. lower the overhead clearance required in underground openings).
- Improve the ability to monitor and take corrective action as needed regarding ground conditions along the roof of the tunnels without the ventilation ducting blocking the line of sight and access.

The ventilation air flow rates were determined by the O. Reg 854 at $0.06 \text{ m}^3/\text{s}$ per kW of diesel engine power, [1]. Generally, the minimum air flow velocity was established at 0.5 m/s with the recommended air velocity in placement rooms as non-entry areas set at 0.3 m/s during the placement activities to minimize dust and heat build-up.

It was assumed that air from the placement activities would be considered as fresh air and suitable to use in ventilation of the development – excavation areas.

5. Preliminary Engineering Analyses

The size of the main development headings are:

- Access tunnels 9 m wide x 4 m high as required to accommodate placement equipment; and,
- Cross-cuts and ramps 5 m wide x 5 m high (the extra 1 m height is for development ducting and door installations).

Based on these dimensions, the use of large scale development equipment was assumed; e.g. 17 t load-haul-dump (LHD) units, 50 t haulage trucks and comparable size of jumbo drills and support equipment. The placement rooms would require a separate fleet of excavation equipment of small-scale size; 5 t LHD and single-boom jumbo.

The equipment parameters and the conceptual layout were used for a preliminary estimate of the ventilating air flow rates. Overall this was determined to be approximately $400 \text{ m}^3/\text{s}$ during the maximum intensity of development and construction; the operational stage would require approximately $160 \text{ m}^3/\text{s}$ air flow. This air flow will be divided to the different operational areas on a controlled ventilation strategy; i.e. based on planned use of diesel equipment and minimum flow rates in each area.

There are two distinct stages of operation from a facility controls and monitoring perspective:

Stage 1

This stage covers the initial development and construction when there is no used nuclear fuel being transported or managed within the facilities. During this stage, connection between the first two shafts being developed is the first priority. The rock hoisting facilities would be constructed at this point combined with mobilizing the large development equipment. Construction of required infrastructure items; e.g. electrical sub-stations, temporary pumping system to surface and development auxiliary ventilation systems would be completed. The area between the shafts would be completed with off-shaft development; while the remaining portions would be considered independent workplaces with the development crew rotating between the different areas. Development would continue with the placement arm access tunnels, some placement rooms and completing the CSA.

By having the large number of available workplaces it is planned that testing and verification activities could be rotated between the workplaces with a reduced impact on the overall DGR development schedule. There are also a large number of short headings created that would allow for longer duration geoscientific activities while other development priorities are being advanced.

Stage 2

This is the operational stage when UFCs are being transported and placed in the placement rooms concurrent with placement room development activities. During this stage, the addition of defining the nuclear controlled areas places further thought or analysis on the design of the ventilation system and planned traffic flow. These controlled areas are where there is the potential for radiation exposure in proximity to the UFCs during transport; i.e. the UFC travel route. The objective is to minimize the potential exposure time and number of workers to any potential nuclear radiation exposure through designated controlled and uncontrolled areas daily operational processes, or in a rare emergency breach event. Consequently, the development activities are to be kept separate from a ventilation and traffic perspective.

6. Traffic Flow Management

A number of scenarios were reviewed, leading to a preferred one with a number of alternate workable arrangements. These included:

- Placement and development in the same arm at the same time.
- Development and placement in close continuous sequence.
- Panels spanning the access tunnels; the placement activities alternate sides with development in a separate arm.

The ability to demonstrate the operability in each of the scenarios indicates the flexibility of the general design concepts that can then be applied once the final site is selected. Furthermore, progressive flexibility and / or robustness in the design concepts was factored in the traffic management development to demonstrate how to minimize impacts of any changes during the DGR evolution, as governed by new geoscientific information when it becomes available.

In the preferred scenario, the development and placement activities follow the ventilation flow, starting with panel 1 in the north arm (Figure 3). They also alternate between arms; thus, not working in the same arm at the same time. As the steps are followed through, there is no overlap or conflicts with the ventilation and operational activities. Fresh air is provided to both the development crews, and the UFC room preparation, placement and sealing crews.

The rock breaker at the truck dump location is provided with an independent access, separated from the service shaft station access to allow separation of rock handling equipment and material handling equipment.

There would be a traffic flow interaction between the transportation of the bentonite materials and the waste rock haulage trucks in the CSA. This interaction would be limited to a short distance in the CSA east access tunnel. This small overlapping of non-nuclear traffic is considered acceptable.

7. Worker Safety and Emergency Responsiveness

The first step in considering worker safety is to differentiate between stages and locations that have the potential for a radioactive exposure to the workers. The distinction between the placement room development activities versus the UFC placement activities is within the operational stage.

In 2014 NWMO conducted a preliminary hazard identification process that identified one design basis accident (DBA). It was a fire on the placement vehicle while transporting a UFC with an undetected defect. A typical scenario for the north arm is described.

In the north arm during placement activities, workers in the downwind sections of the ventilation loop could be exposed. The workers located in the mobile equipment shop would have a direct fresh air supply to and through the respective workplaces. The refuge station is located close to the shop with a direct supply of fresh air; therefore, workers in this area have a clear path to the refuge station. Workers in the service shaft area would also have a clear path to this refuge station. Workers in the office/lab areas would have a fresh air supply and direct route to the same refuge station via the office / lab access tunnel.

Development workers, in the west arm while placement is taking place in the north arm would be in a fresh air section of the DGR. They would not be exposed to any smoke or potentially contaminated airflow from this event location or type. They would have a short distance access to the local refuge station.

For workers tramming materials or waste rock anywhere along the route, there would be exposure in the north arm only. The placement rooms would be ventilated with an exhaust vent duct and header system with the discharge being downwind of the workers installing the placement room seal and bulkhead. Therefore, these workers would not be exposed. Installing a portable refuge station near this location could mitigate smoke inhalation hazard. Depending on the exact event location, it might be possible for crews in transit to switch into the fresh air access tunnel via the closest cross-cut.

Many other credible and non-credible scenarios were reviewed and found acceptable from a worker safety perspective and some design mitigations have been proposed.

8. Closing Remarks

This conceptual level study of the ventilation and traffic flow has outlined:

- Robust adaptability in relation to layout flexibility as governed by geosphere constraints.
- Flexibility to control the ventilation flow as separate circuits to development and nuclear workers, with the exhaust flow directly to the exhaust ventilation shaft.
- That the potential worker exposure and ventilation for the defined DBA scenario is minimized versus the reference design.

For this stage of conceptual study, the layouts meet the requirements and provide a robust design basis for future design updates.

9. References

- [1] Occupational Health and Safety Act, R.R.O. 1990, REGULATION 854, MINES AND MINING PLANTS, Consolidation Period: From January 1, 2016 to the e-Laws currency date. Last amendment: O. Reg. 383/15.