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EVALUATION OF AN ADAPTIVE DEEP GEOLOGIC REPOSITORY LAYOUT IN CRYSTALLINE GEOSPHERE

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Abstract

The Nuclear Waste Management Organization (NWMO) is responsible for implementing Adaptive Phased Management (APM); the approach selected by the Government of Canada for long-term management of Canada's used nuclear fuel.

The Canadian program is in the conceptual stages and layouts have been advanced to facilitate communication about the disposal concept, but without the benefit of having a specific site identified as the host for the repository. The Canadian layouts to date have assumed that a large enough homogeneous and isotropic domain of rock will be available to host the repository; therefore the layouts tend to be of very regular geometries and compact. Other countries, such as Finland and Sweden, have identified their hosting locations which exhibit crystalline geosphere conditions. They started the development of adaptive (flexible) site-specific underground layouts capable of adjusting to encountered structural anisotropy. When viewed from this angle, it is possible that a number of Canadian candidate sites in crystalline geosphere would exhibit similar features. With this recognition, NWMO has started the development of adaptive layouts.

This paper presents the results of the first comparative study between the base case (regular and compact) and more adaptive layouts applied to a hypothetical Canadian crystalline geosphere. The Pugh Matrix (opportunity analysis) suitable for early design stages is used for comparative studies taking into consideration various factors including cost, schedule, site characterization requirements, constructability, operational flexibility, maintainability, operational safety and long-term safety, etc. It was concluded that the concepts represented in the adaptive layout offer advantages in relation to flexibility, schedule, post closure safety and thermal performance that may justify a deviation from the base case once a site has been selected.

Keywords: Deep Geological Repository (DGR), Adaptive Layout, Crystalline Geosphere, Pugh Matrix, Post Closure Safety

1. Introduction

The Nuclear Waste Management Organization (NWMO) is responsible for implementing Adaptive Phased Management (APM); the approach selected by the Government of Canada for long-term management of Canada's used nuclear fuel. APM has, as its endpoint, a deep geological repository in an informed and willing host community.

The current reference design for a repository in crystalline rock assumes it can be built with a series of contiguous panels laid out in a regular pattern. 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.

The reference DGR facility layout may not be suitable in a real crystalline geologic setting. It is possible that the various crystalline rock sites in Northern Ontario will have moderately to closely-spaced major geologic structures. Thus, the key objective for the development of an adaptive underground repository layout is the flexibility to adapt to these inferred structures through a strict application of respect distances, as governing criteria. These criteria will take into account engineering suitability and safety.

2. Description of the Canadian (NWMO) Reference Repository Layout

The current reference Canadian concept has a regular arrangement of eight panels of parallel rooms, accessed through central tunnels and panel access tunnels (see Figure 1). The current (reference) layout necessitates a total of three shafts. The main shaft and the service shaft will be located within the underground Central Services Area (CSA) at one end of the repository. The ventilation shaft is located at the opposite end of the repository. The central access tunnels and the perimeter tunnels will be excavated first, ahead of any room and panel development. Construction will initially focus on connecting the 3 shafts together and excavating the access, test rooms for the used fuel container (UFC) and ancillary facilities within the CSA.

As envisaged by NWMO, a two-stage approval process will be required by the regulator for the initial development and construction of the underground repository followed by the operational stage as per the following licensing requirements:

1. Stage 1 Approval: Construction of Site Development and Repository Access.
2. Stage 2 Approval: Construction of initial Placement Panels and Nuclear Facilities.

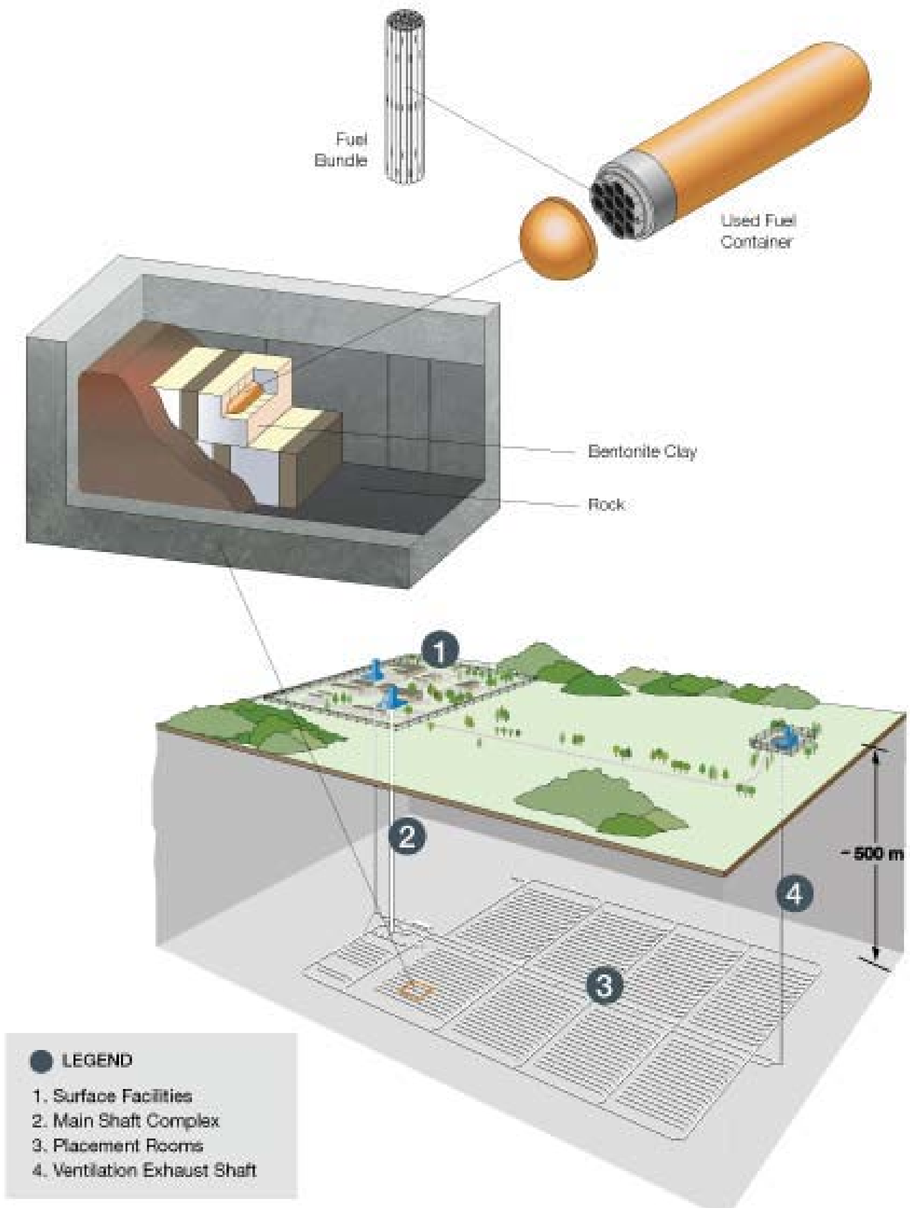

Figure 1 Reference repository layout in crystalline rock for the Mark II container.

2.1 Relevance of Finnish (Posiva) Repository Layout

Posiva is Finland's national agency responsible for the final disposal of spent nuclear fuel. Finland plans to dispose of its used nuclear fuel in a deep geologic repository at a nominal depth of 420 m in the bedrock of the Olkiluoto site (see Figure 2).

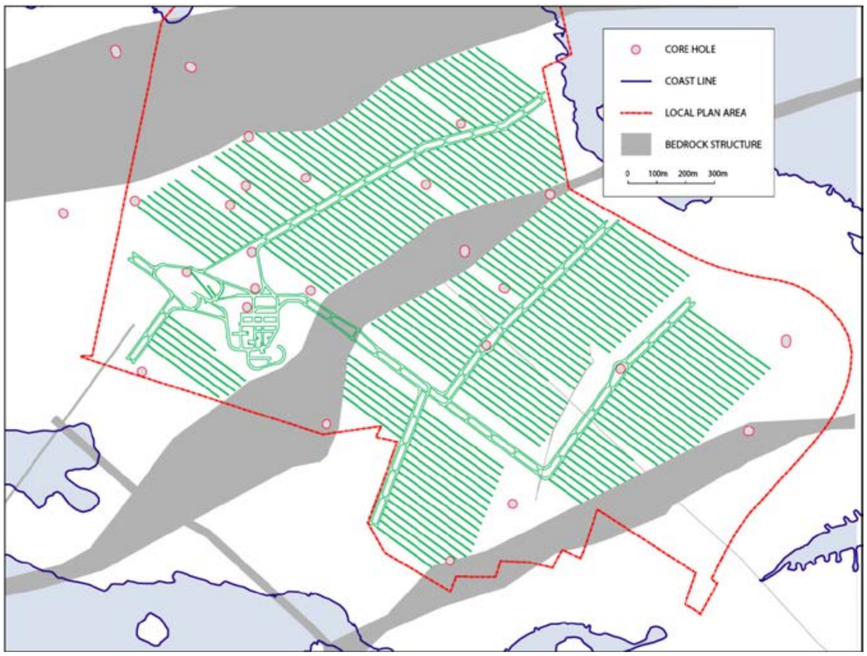

Figure 2 Posiva's layout for underground repository at Olkiluoto site [1].

Posiva's repository design comprises a main access through a ramp with a series of shafts in the service area for ventilation and involves UFC transportation to underground via the shaft. The Posiva layout approach uses a pair of central tunnels to facilitate division of controlled (placement) and uncontrolled (development) areas and further compartmentalization is achieved through series of perpendicular connecting tunnels spaced at approximately 100 m. This layout does not have perimeter tunnels.

The Posiva repository layout is relevant to the Canadian program in that it too has a two-stage licensing process and an underground facility was constructed in the first stage of the licensing. They have also received an approval for construction of the placement panels for the second stage. The Posiva repository is also being constructed in a crystalline bedrock environment with similar conditions to those in the Canadian shield.

2.2. Relevance of Swedish (SKB) Repository Layout

SKB is Sweden's national agency responsible for the final disposal of spent nuclear fuel.

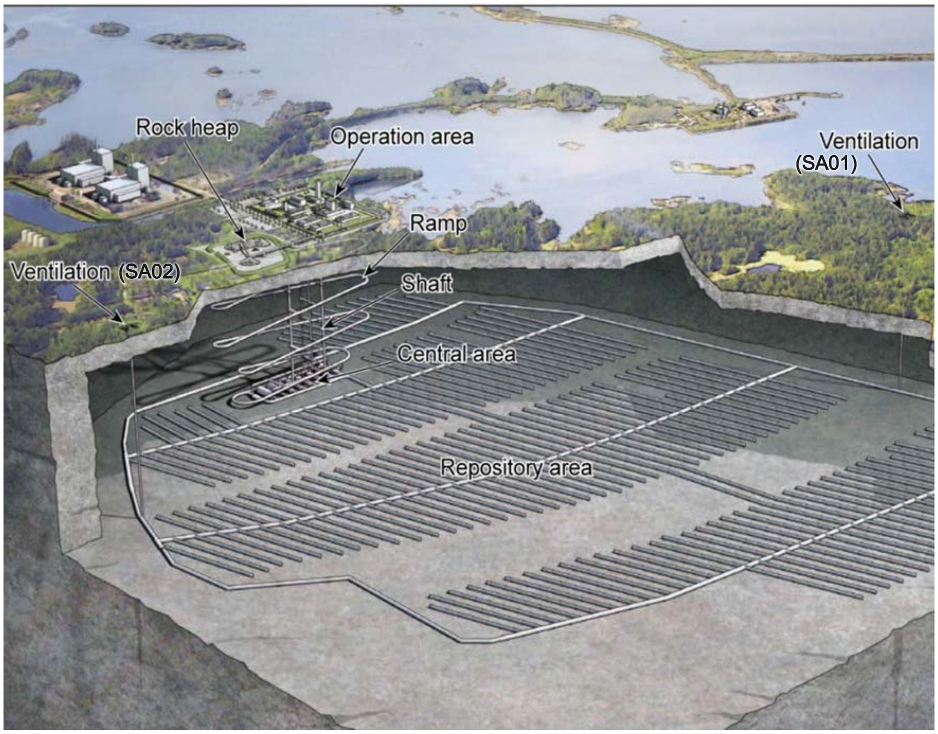

Figure 3 SKB's layout of underground repository at Forsmark Site [2].

SKB's concept uses a ramp as an access and delivery of UFCs. In addition to shafts in the service area, SKB envisions two additional (exhaust) shafts for ventilation. Exhaust shaft SA02 will be constructed first to support commencement of deposition. This shaft is located in the perimeter access tunnel in the vicinity of the central area, while SA01 will be constructed 20 years later. The panels of placement rooms will be developed out from the central area.

SKB's layout is relevant to the Canadian program in that it is also in a crystalline rock environment, which requires similar approaches in dealing with a fractured environment and requires the flexibility to adapt to the encountered conditions once underground. NWMO does not plan on a ramp access and adaptive layout can be accomplished with just access tunnels.

3. Description of an Adaptive Repository Layout

An example of an adaptive layout has three centrally located (within the CSA) shafts; the main shaft, service shaft and ventilation shaft. As depicted in Figure 4, two central access tunnels situated within three arms branching out from the CSA are used to separate development and placement activities. The UFCs will travel in a dedicated main shaft. The central tunnels are driven towards the first area to be developed up to the first cross-cut past the first panel. The placement room panels are developed in a direction away from the service area and the used fuel is placed from the furthest room in the panel towards the service area (see Figure 4).

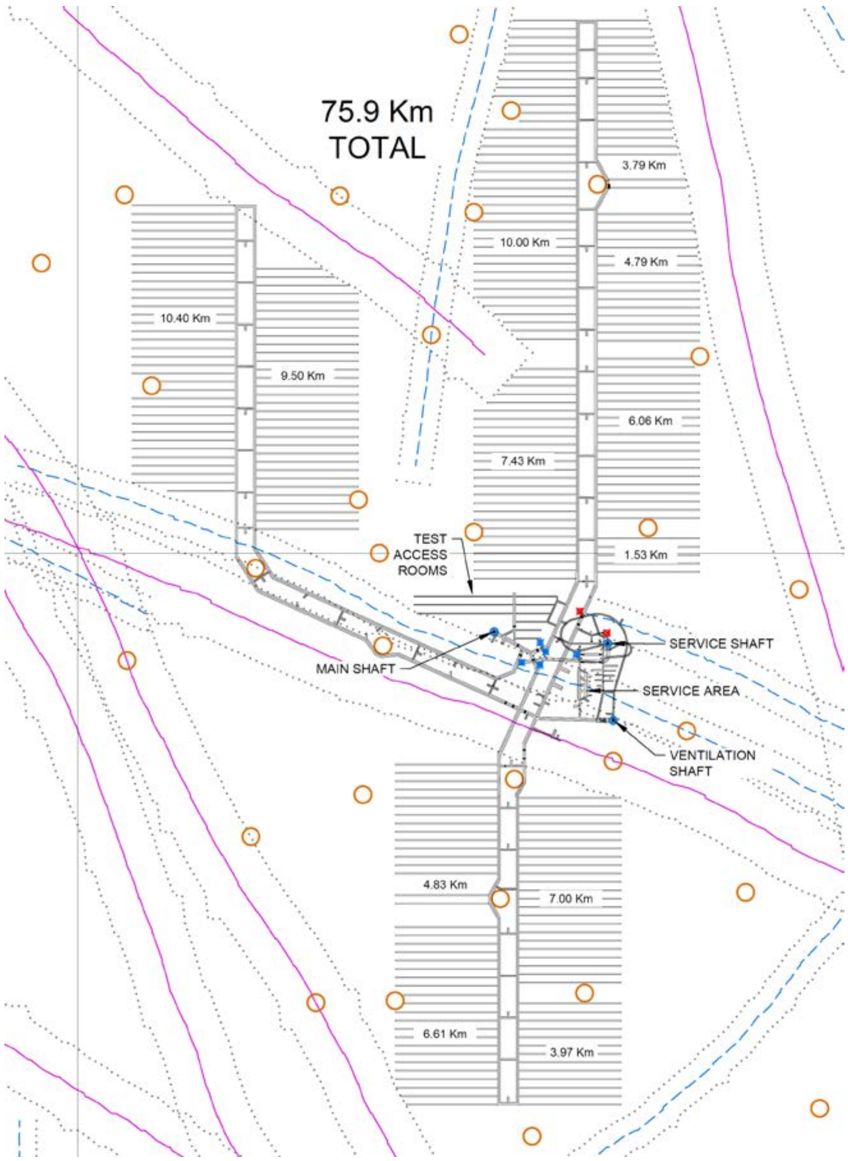

Figure 4 Adaptive Layout for Canadian underground repository

4. Comparison between Reference Layout and Adaptive Layout

The comparison between the reference layout (base case) and the adaptive layouts is in some respects difficult given that the reference layout assumes that a large volume (2 km × 2 km) of ground exists without major faulting and many of its characteristics were driven by that assumption. Nevertheless, the comparison is still a useful exercise to demonstrate that the reality of the ground conditions can still be addressed by layouts that have a certain degree of flexibility.

4.1 Methodology

The Pugh Decision Matrix approach is used to comparatively evaluate the adaptive layouts against the reference layout (base case). The Pugh Decision Matrix is a tool used to facilitate a disciplined, team-based process for concept generation and selection. This approach to decision-making is useful because it does not require a great amount of quantitative data on design concepts, which is generally not available in the early stages of design when other layouts are being considered. The base case is the current reference design and the Pugh Decision Matrix can be used to decide on the merits of the adaptive design. A discussion with NWMO experts in the areas of geoscience, safety assessment and repository engineering design, was conducted to define scoring descriptions (Table 1), evaluation factors, and their corresponding weightings (Table 2).

Table 1 Pugh Decision Matrix Scoring Descriptions

Score	Rationale
1	Significantly poorer than base case
2	Poorer than base case
3	Equal to base case
4	Better than base case
5	Significantly better than base case

4.2 Evaluation Factors

Table 2 shows the results of the decision-making exercise when the adaptive layout was compared against the reference layout.

Table 2 Pugh Decision Matrix and List of Evaluation Factors

Evaluation Factor	Weighting	Base Case	Adaptive
Constructability	7	3	4
Excavated Rock Management	7	3	3
Geoscientific Investigations during Construction	8	3	3
Ventilation	7	3	2

Evaluation Factor	Weighting	Base Case	Adaptive
Layout Flexibility	9	3	5
Concurrent UFC Placement and Lateral Development	5	3	4
Ease of Operations/Retrievability	7	3	3
Thermal Performance	7	3	4
Maintainability over a +100 year Life	8	3	3
Worker Safety (Radiation/Fire/Emergency Egress)	10	3	2
Pre-closure Safety	10	3	3
Post-closure Safety	10	3	4
Capital Expense	6	3	3
Operating Expense	6	3	3
Schedule	5	3	4
Weighted Score		336	371

The subsequent sections provide the rationale for the scores given per evaluation factor for each case.

4.2.1 Constructability

The construction methodology and techniques available to develop the adaptive layout are the same as those for the base case. The differences in favor of the adaptive layout lie on the order of operations and the amount of development required before placement of the used fuel can start. The development of the service area and the UDF is similar in both cases as it relates to excavation volume.

4.2.2 Excavated Rock

The reference layout has 2800 m of central access tunnels, 2800 m of perimeter tunnels and 3400 m of panel access tunnels for a total of 9000 m. The adaptive layout eliminates the panel access tunnels and the perimeter tunnels. However, it requires slightly longer development of central access tunnels. It was agreed that the adaptive layout may have less access tunnel development because of the elimination of the perimeter and panel access tunnels; however, the access tunnels are a small percentage of the total excavation volume.

The total length of access tunnels would vary based on arrangement of panels to suit geologic conditions. It should be noted that the base case layout would also have to be adjusted to suit geologic conditions (i.e. avoid geologic structures) and this would also lead to lengthening of tunnels.

4.2.3 Geoscientific Investigations During Construction

Opportunities for geoscientific investigations, testing and experiments in rock in the adaptive layout are considered equivalent to those in the base case. Moreover, there is no significant advantage for sub-surface site characterization in the reference design, in which a perimeter repository tunnel is first excavated, since it is not within the placement room rock and is replaced with characterizing access tunnels and placement panels.

4.2.4 Ventilation

The main factors to be taken into account are the requirement to keep “fresh air at the workers’ backs”, the requirement for additional fan horsepower versus an additional ventilation shaft and the need to maintain minimum air flow throughout the facility so that there is no stale air when entering an area that has not been active for a while. The adaptive layout has a return ventilation system design which required a more detailed supplementary evaluation of ventilation and traffic within the centrally located CSA. The results show that ventilation meets all criteria and provides an isolation benefit with the adaptive design.

4.2.5 Layout Flexibility

It was recognized by all participants that the reference layout is based on the premise that there will be a 2 km × 2 km block of rock without fractures, which will be difficult to find at crystalline rock sites. Therefore, the adaptive layout has more flexibility to deal with unexpected rock conditions. In the reference layout, the development and placement of the UFCs follows a more rigid sequence than in the adaptive layout. In the reference layout, the total footprint of the repository needs to be known a priori so that the perimeter tunnels can be developed.

In the adaptive layout, it is envisioned that three general areas for development of the placement rooms will be used. These areas have independent accesses which stem radially from the CSA. Placement would be ongoing in a different arm than the development and a third area is still available. In the adaptive layout, there is no need to develop the entire repository footprint ahead of time.

It was recognized that the adaptive layout (with 3 central shafts) will have advantages in dealing with isolation of the different repository areas, if necessary.

4.2.6 Concurrent UFC Placement and Lateral Development

In both the reference layout and the adaptive layout, excavation of new placement rooms would occur concurrently with placement of UFCs at another location away from the excavation activities during operations. Trucks carrying excavated rock and vehicles carrying UFCs would travel along different routes. The adaptive layout provides the opportunity for completing separate activities given that panel areas are developed radially from the CSA.

4.2.7 Ease of Operations/Retrievability

Ease of waste package movement should be identical in the base case and the adaptive case. The central tunnels in the reference layout are 7 m wide × 5 m high and the panel access tunnels are 9 m wide × 4 m high. In the adaptive layout the central tunnels have been changed to 9 m wide × 4 m high to meet the requirements imposed by the placement equipment. In the case of the adaptive layout, the placement rooms are now accessed via the central tunnels (no panel access tunnels). The adaptive layout can be susceptible to more traffic congestion in the service area since all traffic needs to move through the central tunnels.

Adaptive layout exhibits a slight advantage for operations with centralized security. Both layouts respect the access tunnel size requirements for operating the placement vehicles and the excavation equipment. Similarly, both layouts allow vehicles to bypass in the tunnels. Both layouts also allow retrievability of the UFCs as the entrances to the placement rooms are equally accessible.

4.2.8 Thermal Performance

The existing placement room spacing (pillar width) is governed by a design requirement that the UFC surface temperatures do not exceed 100°C. In the reference layout, the placement rooms are grouped in panels totaling about 10 km of lineal development each. These panels are arranged in a regular pattern with separating pillars of 50 m width. The adaptive layout is also arranged in panels with rooms totaling approximately 10 km of lineal development. However, in the adaptive layout, the panels are distributed in a more dispersed arrangement promoting better heat dissipation under actual versus modelled conditions. This could potentially result in reductions in pillar width (the current pillar widths are currently dictated by thermal constraints). It was noted however, that the current room spacing is based on the conservative assumption of an infinite repository.

4.2.9 Maintainability over a +100 year life

Maintainability of the reference layout and the adaptive layout should not be different. In the adaptive layout, because of the larger footprint and longer distance to reach the edges of the repository, ventilation requirements may be slightly higher. The length of access tunnels to be inspected and maintained is comparable, with the adaptive layout having potentially a smaller open area, should the geosphere conditions be favorable.

4.2.10 Worker Safety (Radiation/Fire/Emergency)

Both layouts maintain the philosophy of having “fresh air at the workers’ backs”. However, the reference layout has a once through air flow system from the service area to the ventilation shaft at the opposite end. The adaptive layout will have potentially three ventilation circuits. It may prove easier and beneficial in the adaptive layout to isolate panel areas in the case of an emergency. This was mentioned in the context of the Waste Isolation Power Plant (WIPP) incident discussion and how difficult or expensive it was to re-enter, inspect, and eventually clean the facility afterwards. It was identified that in the adaptive layout all the egresses are in the central service area; therefore, should an emergency occur at the far end of the adaptive layout, the distance and time to reach an egress could potentially be greater. This can be mitigated by suppression systems and refuge stations.

4.2.11 Pre-closure Safety

Discussions about pre-closure revolved around the “island” concept versus a shaft at a remote location. It was recognized that the spacing between the shafts in the “island” concept and the checking of no recirculation of emission air needs modelling, but the consensus was that it should not pose a problem. The need to manage security and public exposure at two locations, as compared to islanded shafts, is judged as overall neutral from the pre-closure safety perspective. Furthermore, the methods for transferring UFCs underground and to the placement rooms and access routes and tunnel sizes are the same in both layouts.

4.2.12 Post-closure Safety

The lack of perimeter tunnels in adaptive layout is overall neutral. The largest favorable factor in relation to the adaptive layout is in its greatest flexibility to maintain spacing to fractures in a realistic crystalline rock setting. Consequently, the adaptive layout is considered to be superior in relation to post-closure safety as compared with the reference design.

4.2.13 Capital and Operating Costs

Capital and operating expenses could be higher in the adaptive layout if the geosphere conditions force the layouts to extend far from the service area, but this could also be the case with the reference design. In case of operating cost, this could potentially have a small impact on the main fan power required. Maintenance of the facility was deemed to be similar, both during placement and up to closure.

4.2.14 Schedule

There are two schedule aspects to be considered for differences between the reference layout and the alternate layout. These are: the time to complete the Underground Demonstration Facility (UDF), and the time to complete the first panel. The completion of the UDF is slightly better in the alternate layout. Regarding the completion of the first panel for UFC placement, when taken from the start of underground lateral development (shaft sinking rates will be similar for reference and alternate layouts), the alternate layout shows an advantage to the completion of the first panel.

5. Conclusion

The current (reference) layout was evaluated against the adaptive layout which is adaptable to the ground conditions expected to be encountered in crystalline geosphere. As a result of the evaluation, it was concluded that the concepts represented in the adaptive layout offer advantages in relation to flexibility, schedule, post closure safety and thermal performance and consequently form a basis to deviate from the reference design layout for the DGR situated in a crystalline geosphere.

Knowing that the Canadian regulator will look at other jurisdictions, NWMO engaged Posiva for an independent review of the subject layout, and the related ongoing CSA ventilation and traffic study and the alternate design construction plan and schedule. The subject adaptive underground layout will be advanced based on results of Posiva's expert review and lessons learned presentation and discussion.

6. References

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