Used Fuel Deep Geological Repository Shaft versus Ramp Trade-off Study

NWMO TR-2014-22 December 2014

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Nuclear Waste Management Organization

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ABSTRACT

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Abstract
The current reference design for the Adaptive Phase Management (APM) deep geological repository has assumed access via three shafts to the underground facilities with one shaft dedicated to the transfer of used fuel containers to the underground repository. A possible alternative access arrangement would be to replace one shaft with a ramp where the ramp would be used primarily for the transfer of used fuel containers.

The access concepts for proposed repositories for spent (used) nuclear fuel and other high level wastes in Finland, Sweden, Germany, Switzerland and France have been reviewed. The majority of the repository designs in these five countries include a ramp as a primary means of access and in most cases the ramp is used for delivery of spent nuclear fuel canisters into the underground repository. All repository designs with a ramp access also include shafts for personnel movement, transport of light-weight materials and ventilation.

A trade-off study was performed to compare shaft access with a ramp access option for the APM deep geological repository and to determine whether or not ramp access should be introduced into the APM deep geological repository design. Although ramp access has some advantages over shaft access, it was determined that these advantages were not considered sufficient to change to ramp access as the primary route for transfer of used fuel containers into the underground repository.

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1. INTRODUCTION

1.1 PURPOSE OF STUDY

The Nuclear Waste Management Organization (NWMO) is responsible for implementing Adaptive Phased Management (APM) which is 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 (DGR) in an informed and willing host community.

The current reference design for the deep geological repository for used fuel has assumed access via three shafts to the underground facilities with one shaft dedicated to the transfer of used fuel containers to the underground repository. A possible alternative access arrangement would be to replace one shaft with a ramp where the ramp would be used primarily for transfer of used fuel containers. A trade-off study has been performed to determine whether or not ramp access would have any significant advantages over shaft access for the transfer of used fuel containers into the underground repository.

1.2 SCOPE OF TRADE-OFF STUDY

This trade-off study compares the shaft and hoisting system option with ramp access option as the primary means for the transfer of used fuel containers into the underground repository. This study also explored whether or not the ramp would provide any advantages over shaft access with respect to personnel, equipment and materials movement into and/or out of the underground repository.

The trade-off study compares possible advantages and disadvantages of the two underground access alternatives during the construction, operational and decommissioning phases for the deep geological repository. This comparative evaluation took into consideration a variety of factors related to construction, site characterization needs, operations, maintenance, operational safety, long-term safety, cost and schedule. In general qualitative data and expert opinion about the two access options were used in the comparative evaluation process. Indicative cost and schedule estimates for the two access options were prepared and used in the trade-off study.

To provide background information, the access concepts for proposed repositories for spent (used) nuclear fuel and other high level wastes in Finland, Sweden, Germany, Switzerland and France were reviewed. The findings from this review were used, as appropriate, in this trade-off study.

2. ACCESS ARRANGEMENTS IN INTERNATIONAL REPOSITORIES

The access concepts for proposed repositories for spent (used) nuclear fuel and other high level wastes in Finland, Sweden, Germany, Switzerland and France are described. The repository designs in these countries are considered to be representative of a range of repository designs being considered in various countries around the world. The majority of the repository designs in these five countries include a ramp as a primary means of access and in most cases the ramp is used for delivery of spent nuclear fuel canisters into the underground repository. All repository designs with a ramp access also include shafts for personnel movement, transport of light-weight materials and ventilation.

2.1 FINLAND

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. Construction was started on an underground research lab (ONKALO) at the site in 2004, with excavation essentially completed in early 2012. This will eventually form part of the repository infrastructure.

Posiva is Finland's national agency responsible for the final disposal of spent nuclear fuel. In December 2012, Posiva filed the formal licence application to construct the repository with operation expected to start by 2022.

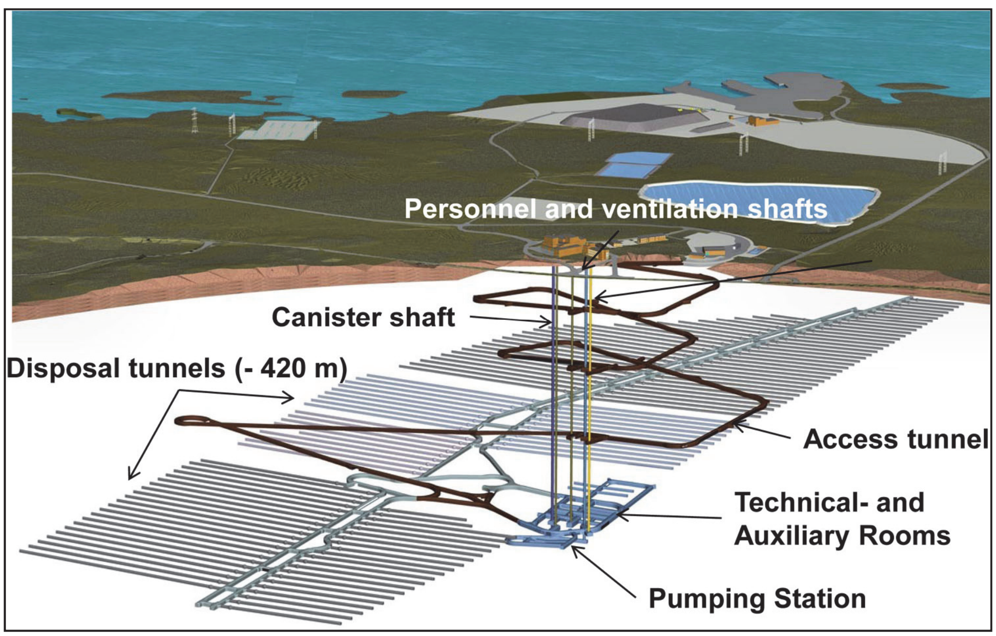

Figure 2.1: Posiva's Repository Design at the Olkiluoto Site

The repository design includes access by an arrangement of shafts and a ramp (Figure 2.1). The ramp has a 10% grade and is 5.5 m wide and 6.3 m high. It functions as a transport route for vehicle traffic between surface and the underground repository. Excavated rock is transported to ground level via the ramp. The ramp will not be used for the future transfer of canisters to the underground repository. Posiva plans to load their canisters into a shaft cage and then lower the cage by using a friction hoist system.

It is noteworthy that the canisters will be unshielded inside the shaft cage. The cage payload will be approximately 30 tonnes (Posiva, 2013).

The selection of a ramp as primary means of access into ONKALO was based on a thorough comparison of the alternatives, focusing on long-term safety, as well as the requirements related to research activities and technical implementation (Posiva, 2002). The access tunnel was chosen over the shaft type solution as it creates better opportunities to engage in the research activities during the construction period, and will also be a more flexible solution from the point of view of the final disposal facility. Transport functions (e.g. transport of equipment and the excavated rock) are also deemed easier to carry out in a tunnel than in a shaft. The ramp has facilitated the collection of the data needed for the application for the construction licence. The bedrock has been studied with methods from geology, hydrology and geochemistry. In addition to facilitating bedrock research, ONKALO also provides an opportunity to develop excavation techniques and final disposal techniques in realistic conditions.

By first constructing a ramp at the repository site, it was then possible to use a mechanical excavation method (i.e. raise boring method) to excavate the ventilation shaft. Future shafts will also be excavated using the mechanical excavation method. This approach allowed Posiva to avoid the use of drill-and-blast shaft sinking method which is typically not used in Finland for the excavation of shafts.

2.2 SWEDEN

SKB is Sweden's national agency responsible for the final disposal of spent nuclear fuel. In the spring of 2011, SKB filed a licence application with the Swedish regulatory authorities to construct the used fuel repository at the Forsmark site. Forsmark, in the municipality of Östhammar, is a volunteer host site. It is already home to a nuclear power plant and the SFR repository for short-lived L&ILW. For planning purposes, construction is assumed to start around 2017, with the repository in operation by 2025.

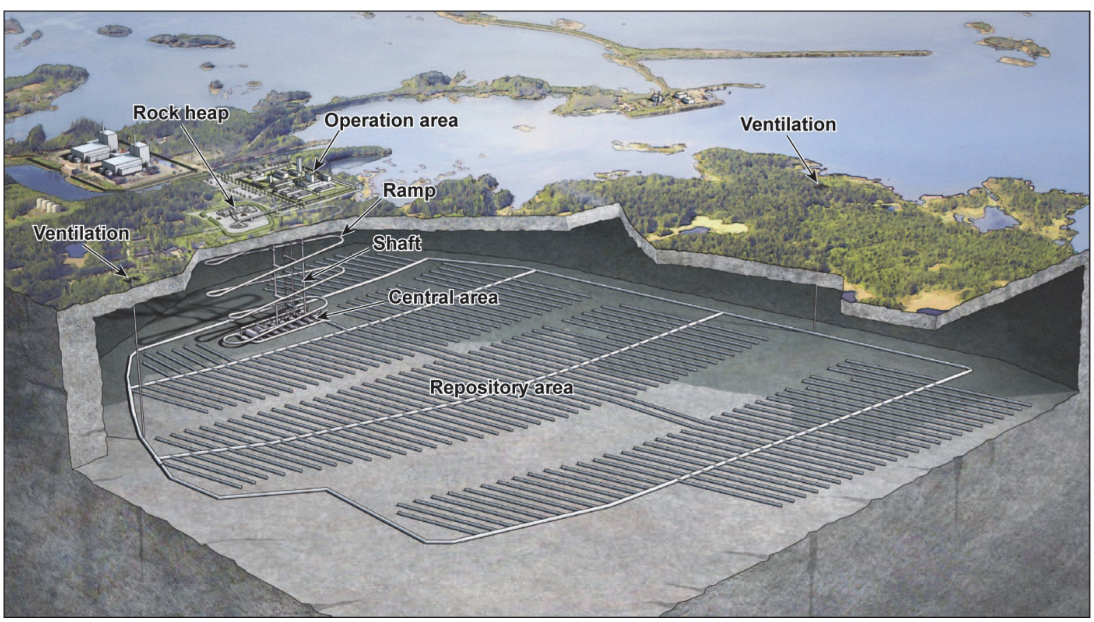

Figure 2.2: SKB's Final Repository for Spent Nuclear Fuel at Forsmark

SKB's repository access consists of a ramp and four shafts (skip[1] shaft, elevator shaft and two ventilation shafts). The 4.7-km-long ramp will have a 10% grade and will be 5.5 m wide and 6.0 m high. The function of the ramp is to provide a transport route between surface and the underground repository for vehicles carrying heavy and bulky materials. The ramp will be used by SKB's Ramp Vehicle for delivery shielded transport casks (loaded with canisters) down to the repository level. Figure 2.3 shows a prototype of the vehicle which has been designed for a 100 tonne payload (SKB, 2013). In addition, the ramp will function as a secondary egress route from the underground area as well as a secondary access route for rescue services. The ramp along with two shafts will be used for exhaust ventilation. The shafts will be used for personnel movement, transport of lightweight materials, removal of excavated rock via skipping, and for ventilation (SKB, 2009).

Figure 2.3: Prototype of SKB's Ramp Vehicle for Canister Transport Casks

The ramp will be excavated by the drill and blast method. It is anticipated that grouting of the rock to a depth of 200 m will be required to limit the amount of groundwater inflow to the ramp. SKB plans to carry out a systematic program of probe hole drilling and grouting during excavation of the ramp.

2.3 GERMANY

The proposed German repository for "heat generating waste" is located in a salt dome. Exploration and testing to a depth of 800 to 900 m was conducted between 1979 and 2000 at the Gorleben for its suitability to host a repository for high-level radioactive

[1] Skip is a mining term to describe a shaft conveyance mainly used for hoisting excavated rock from underground to surface.

waste. As a result of the phase-out of nuclear energy in 2000, exploration works discontinued between 1 October 2000 and 30 September 2010 (Gorleben Moratorium). The works were resumed in October 2010 but the exploration discontinued again in November 2012 and was terminated on 27 July 2013 when the Law on Site Selection became effective. The Gorleben mine will be kept open for as long as the Gorleben site is part of the site-selection procedure.

Access to the proposed Gorleben repository is provided by two shafts. The No.1 Shaft is 933 metres deep and is equipped with a Koepe friction hoist of 25 tonnes capacity, which will hoist a cage (for men, equipment and material) in one compartment, balanced by a rock skip on the other compartment to remove excavated salt rock. This shaft also acts as an emergency egress shaft in accordance with German mining law, which requires a minimum of two independent access routes out of an underground mine. The No.2 Shaft is 840 metres deep and is planned to be equipped with a large multi-rope Koepe hoist. This hoist will lower a cage having a payload capacity of 80 tonnes to suit the planned spent fuel or vitrified waste transfer canisters.

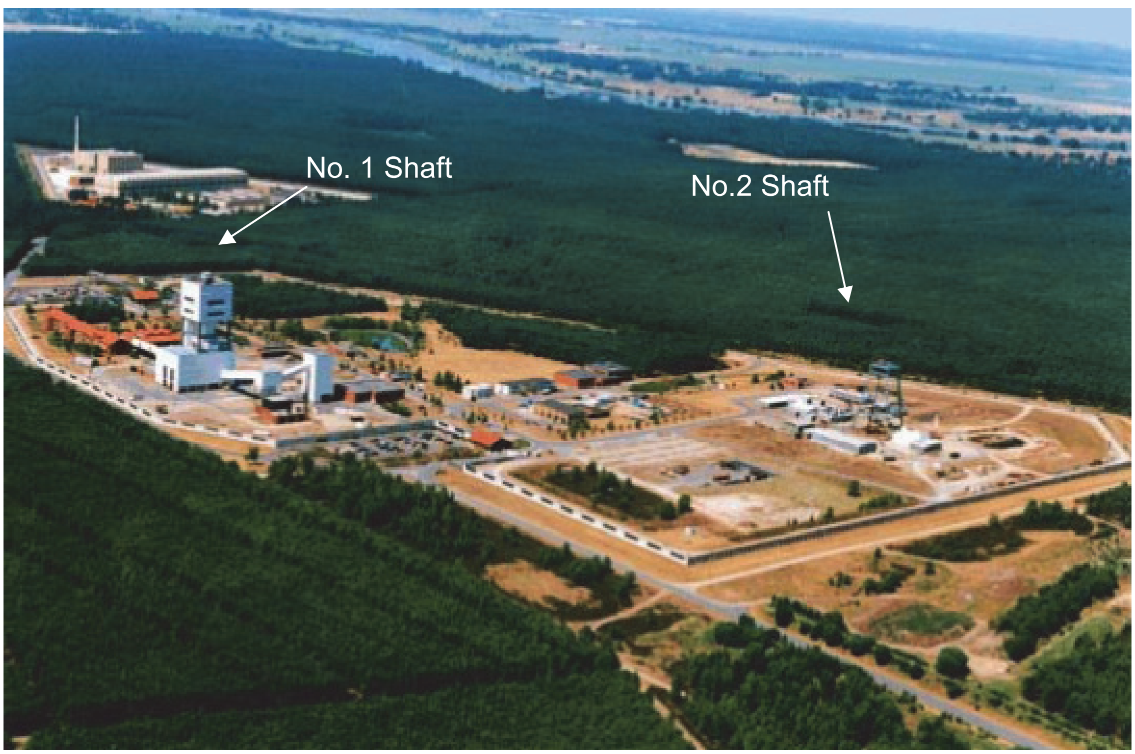

Figure 2.4: Surface Layout of the Gorleben Facility

2.4 SWITZERLAND

Long-term management of radioactive waste in Switzerland has been assigned to NAGRA ("National Cooperative for the Disposal of Radioactive Waste"), which was set up expressly for this purpose and is jointly owned by the Swiss state and the major waste producers (e.g. nuclear power plant owners and radioisotope companies). Spent fuel from the Swiss nuclear power plants and vitrified fission product solutions from reprocessing will be disposed of in a high-level waste repository. The high-level waste repository comprises disposal tunnels with a diameter of 2.5 metres for the placement of containers with spent fuel and vitrified high-level waste. The repository will also have tunnels for long-lived intermediate-level waste (ILW).

A ramp or a vertical shaft will be used to transfer canisters to the waste placement zone at a depth between 400 and 900 metres. The use of ramp access would allow the location of the surface facilities to be uncoupled from the underground repository location. Ramp is also deemed to have an advantage over shaft access with respect to transport of heavy goods. The ramp would have a maximum grade of 12.5%. NAGRA is considering the use of a rack-railway system in the ramp which requires curves with turning radii not exceeding 250 m. An alternative transport system using an electric-driven transfer vehicle on wheels could be used which would allow a spiral-like access ramp with significantly smaller curves (Fries, 2008).

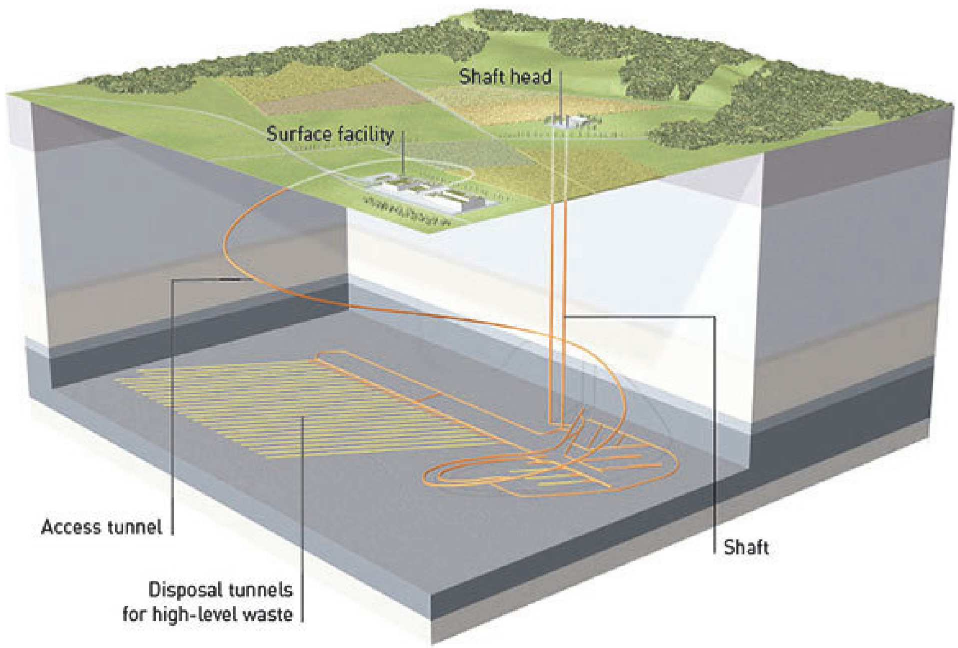

Figure 2.5: Switzerland (NAGRA) Repository Access Concept

2.5 FRANCE

Andra (Agence nationale pour la gestion des déchets radioactifs), a national public agency, has the responsibility for the long-term management of radioactive waste produced in France. Andra operates waste repositories, defines the acceptance criteria for waste packages in these repositories and controls the quality of their production. The agency is also in charge of designing, siting, and constructing new disposal facilities.

Andra is currently developing plans for the geologic disposal of long-lived wastes. The repository for HLW and long-lived L&ILW, otherwise known as Cigéo (based on the French acronym for “the Industrial Centre for Geological Disposal” - Centre industriel de stockage géologique) will include surface installations for controlling and conditioning waste packages, as well as underground installations for waste disposal purposes and connecting infrastructures between surface and underground. It is assumed that the repository would be constructed in the Callovo- Oxfordian argillaceous bedrock at a depth of approximately 500 m. The current siting process focuses on the region around the Bure area, which is the site of Andra's underground research laboratory.

The French repository concept currently incorporates two ramps and four shafts for conveying staff, transferring disposal containers and work-site machinery, as well as for ventilating the underground works. The use of ramp access allows uncoupling part of the surface installations from the underground repository by a distance of approximately 5 km. This gives more flexibility in the final siting process, in terms of local surface topography, availability of infrastructure (roads and rail access) and community acceptance/preference (Andra, 2014).

Andra has chosen a funicular system (an inclined railway) for the transfer of radioactive waste packages from surface to the underground repository. The deep funicular will be installed in a ramp and will extend over a distance of 4.2 kilometers. It will transport the waste packages down to a depth of 500m below surface at a speed of 2.5m/s on a 12% grade slope. The maximum load for the system is expected to be 130 tonnes.

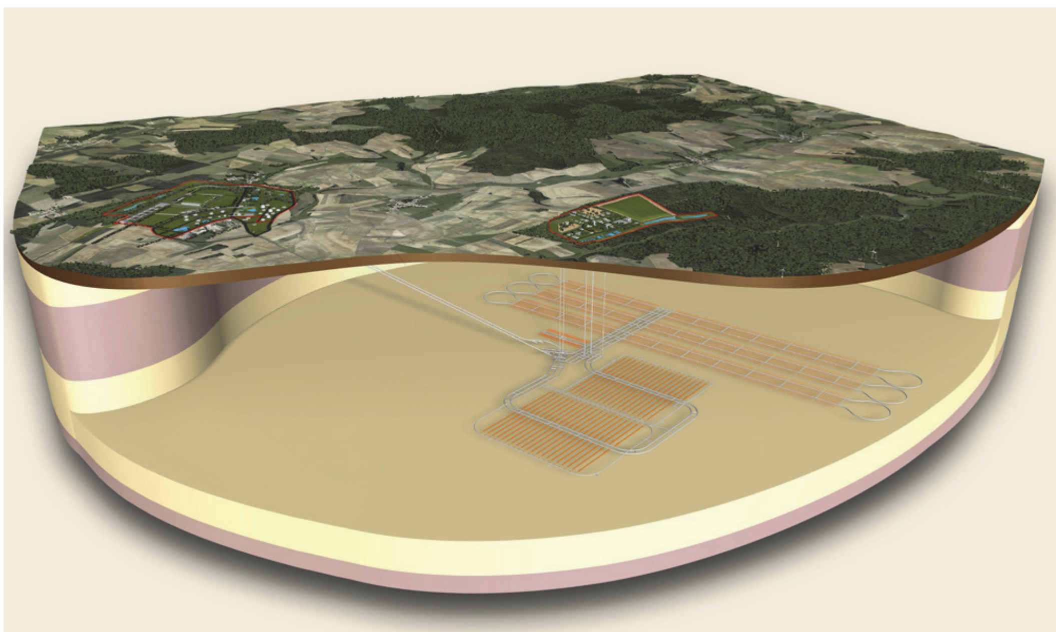

Figure 2.6: Andra's Repository Concept, Cigéo

3. APM DEEP GEOLOGICAL REPOSITORY CONCEPT

3.1 CONCEPT DESCRIPTION

The Adaptive Phased Management (APM) deep geological repository facility is a self-contained complex that includes an underground repository for the long-term management of Canada's used nuclear fuel and a number of surface facilities to support the siting, design, construction and operation of the repository. The deep geological repository will be constructed at a depth of approximately 500 metres, depending upon the specific geology and detailed characteristics of the site, and will consist of a network of placement rooms for the used fuel.

The reference design for the deep geological repository includes three shafts to enable the transfer of used fuel containers, rock, material, equipment and personnel between the surface facilities and the repository.

The containers will be transferred underground inside a transfer cask and then transported to one of many placement rooms via a network of underground access tunnels. The containers will be placed in vertical boreholes drilled in the floor along the axis of the placement room, or placed horizontally within the confines of the placement room, depending on the geological setting. The excavations will then be sealed using bentonite clay and other sealing materials. Monitoring systems will be installed to ensure the repository system is behaving as expected.

Example conceptual designs of a deep geological repository are shown in Figure 3.1.

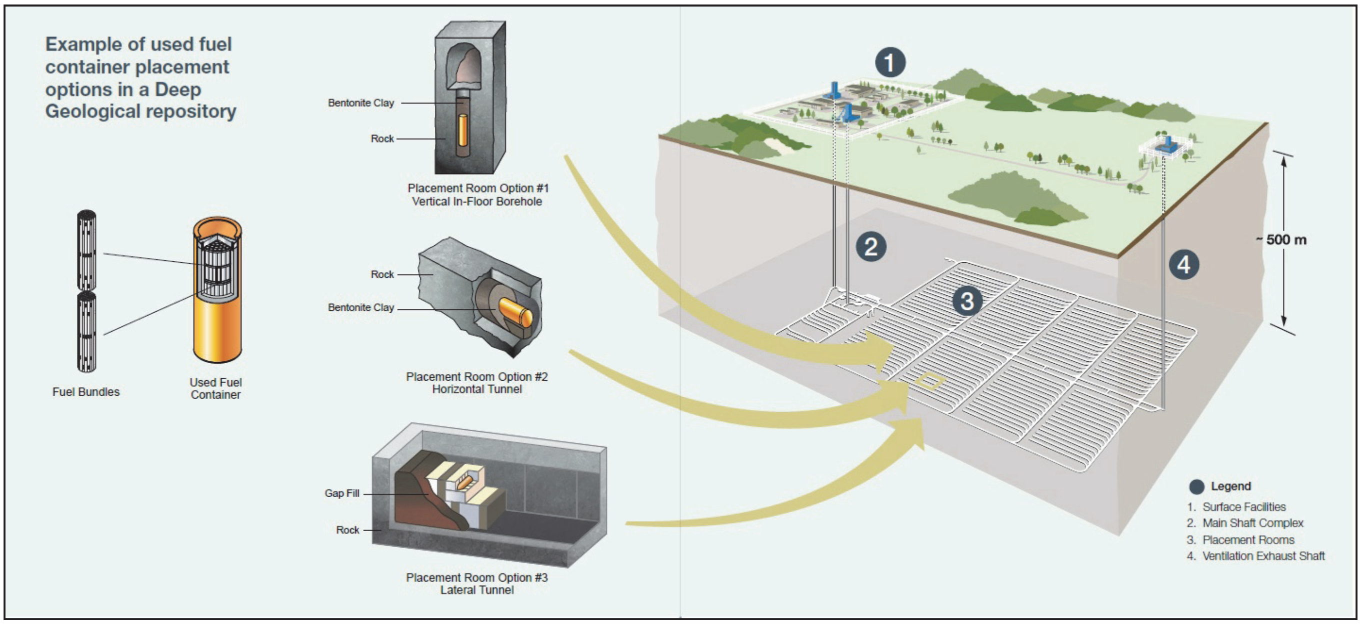

Figure 3.1: Used Fuel Container Placement Options in the Deep Geological Repository

3.2 USED FUEL CONTAINER DESIGNS AND THROUGHPUT

Two used fuel container (UFC) designs are currently being considered: Mark I UFC and Mark II UFC. Mark I UFC has a copper outer shell and carbon steel inner vessel design providing containment for 288 CANDU used fuel bundles. The Mark I used fuel containers would be placed either: a) inside vertical boreholes drilled into the floor of placement rooms where the underground repository is hosted in crystalline rock (Option #1 - vertical in-floor borehole concept in Figure 3.1), or b) horizontally along the length of placement rooms where the underground repository is hosted in sedimentary rock (Option #2- horizontal tunnel concept in Figure 3.1). Assuming that 120,000 bundles of use fuel bundles need to be transferred underground each year and 250 working days, then two Mark I containers would have to be delivered underground each day.

The Mark II UFC provides containment for 48 CANDU used fuel bundles. It incorporates an inner steel vessel for structural strength and an exterior 3-mm-thick layer of copper for corrosion resistance. Prior to transfer to the underground repository, the UFCs are housed within a rectangular-shaped buffer box filled with blocks of highly-compacted bentonite. While the buffer box will provide some shielding, an additional shielding overpack or transfer cask will still be required. The shielded UFC/buffer box assembly can be transferred in a hoisting arrangement similar to that proposed for underground transfer of Mark I UFCs. Buffer boxes would be stacked two-high along the length of placement rooms where the underground repository is hosted in either crystalline or sedimentary rock (Option #3 – lateral tunnel concept in Figure 3.1). At least 10 Mark II buffer boxes (holding used-fuel containers) would have to be delivered underground each day to achieve the throughput of 120,000 used fuel bundles per year.

3.3 SHAFT ACCESS

The reference repository design includes three shafts for the transfer of used fuel containers, rock, material, equipment and people between the surface facilities and the underground repository.

The three shafts and their functions are as follows:

- Main Shaft - This shaft will convey the used fuel containers within a shielded transfer cask. The main Shaft would deliver fresh air to the underground repository.
- Service Shaft - This shaft will convey personnel, equipment, waste rock, muck and sealing materials such as bentonite clay. The Service Shaft will exhaust a small portion of the underground ventilation air.
- Ventilation Shaft -This shaft will handle the majority of the repository exhaust to surface. In the event of an underground emergency the Ventilation Shaft would be able to support mine rescue or evacuation efforts.

Each shaft would be developed or “sunk” by a contractor with required specialized skills and equipment. The shaft excavation would advance at a rate of about 2 to 3 vertical metres per day (24 hours) and each shaft would take between 175 to 250 days to sink. If one assumes that only two shafts could be sunk at the same time, then the total time to sink three shafts would be in the range of 350 to 500 days. Duration could be longer if research activities are carried out during shaft sinking. All shafts would likely be concrete lined and divided into compartments to contain the hoisting equipment and various services that are required to support underground operations.

The concrete lining will be removed during decommissioning of the underground repository. During closure, the shafts will be sealed and all headframes and peripheral equipment will be removed.

3.4 RAMP ACCESS

A possible alternative access option would be comprised of a ramp and two shafts. The ramp would essentially replace the Main Shaft in the aforementioned shaft-only option. Whereas the Service Shaft and Ventilation Shaft would retain the majority of functions as described above in Section 3.3.

Most of the ramp would be 6 m by 6 m in cross-section, have a 10% grade, and an overall length of about 5000 m. Portions of the ramp would be 10 m wide to allow passing of vehicles. The ramp would be used to transport shielded used fuel containers on a vehicle that is similar to the vehicle shown in Figure 2.3. The ramp could also be used as an alternate route for transfer of excavated rock out of the underground repository, and for delivery of sealing materials and other materials into the repository.

It would not be cost effective to use the ramp as the primary means of delivering fresh air underground because the ramp would need to be significantly larger than the aforementioned dimensions to deliver the required airflow. Thus it is assumed that the ramp only delivers a small amount of fresh air to the underground repository with the Service Shaft delivering the majority of the fresh air. All exhaust air would be sent to surface via the Ventilation Shaft.

The ramp would be developed by conventional drill and blast methods. It is assumed that the ramp excavation could be advanced at a rate of about 5.5 m per day (24 hours) and would take about 900 days to excavate. Actual rate of advance may be slower due to research activities that would likely be carried out during ramp construction. A permanent rock support system comprised of rock bolts with wire mesh and shotcrete would be installed to ensure safe working conditions. It is assumed that the floor of the ramp would be paved with concrete to create a smooth driving surface for equipment travelling in ramp.

The concrete floor would be removed from the ramp and the concrete lining will be removed from the two shafts during decommissioning of the underground repository. During closure, the ramps and shafts will be sealed.

4. COMPARISON OF SHAFT AND RAMP ACCESS OPTIONS

4.1 METHODOLOGY

The Pugh Decision Matrix approach was used to comparatively evaluate the two access options for the underground repository. 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 generally is not available in the early stages of design when alternatives are being considered. Several concepts can be evaluated according to their strengths and weaknesses against a reference or base case concept. The base case is generally the current reference design and the Pugh Decision Matrix can be used to decide whether or not to move from the reference design and to implement an alternate design.

The following were the key steps followed in the comparative evaluation of the shaft and ramp access options using the Pugh Decision Matrix:

1. Confirm key aspects of the shaft access design which is the reference, or base case (see Section 3.3), and the ramp access design which is the alternative design (see Section 3.4).
2. Identify evaluation factors and assign a weighting to each factor based on a consensus opinion about the list of factors to be used and the relative importance of each factor.
3. Using Table 4.1 as a guide, assign a score to the ramp access design to indicate whether it is the same as, better than or poorer than the shaft access design with

respect to each evaluation factor. In the case of this study, scores were assigned based on consensus opinion at the trade-off meeting (see below). Note that in the Pugh Decision Matrix approach the base case design is always assigned a neutral score of 3 for each evaluation factor.

4. Multiply the assigned scores by the corresponding weightings and then sum the weighted scores to get total scores for the base case design and the alternative.

The trade-off meeting was held on 20 March 2014 with NWMO experts in the areas of geoscience, safety assessment and repository engineering design in attendance. Also present were experts from an engineering consulting firm.

Table 4.1: Pugh Decision Matrix Scoring Descriptions

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

4.2 RESULTS OF COMPARATIVE EVALUATION

The comparative evaluation of the shaft access and ramp access options shows that the shaft access option is still the preferred means for accessing the APM deep geological repository. Although ramp access has some advantages over the shaft access, the evaluation team determined that these advantages were not considered sufficient to change to a ramp as the primary means of underground access.

Table 4.2: Pugh Decision Matrix – Scoring Results

Evaluation Factor	Weighting	Score	
		Shaft Access	Ramp Access
Constructability	7	3	2
Excavated Rock / Water Management	7	3	2
Geoscientific Investigations during Construction	8	3	5
Ventilation	7	3	2
Ease of Waste Package Movement	8	3	2
Concurrent Placement and Lateral Development	5	3	3
Operational Flexibility	7	3	5
Maintainability over a +100 year Life	8	3	3
Worker Safety (Radiation/Fire/Emergency)	10	3	2
Preclosure Safety	10	3	3
Sealing of Access-way / Post Closure Safety	10	3	2
Capital Expense	6	3	2
Operating Expense	6	3	3
Schedule	5	3	1
Weighted Score		**312**	**277**

Table 4.2 provides a numerical summary of the comparative evaluation of the shaft and ramp access options for the Mark I deep geological repository concepts (i.e. Options 1 and 2 in Figure 3.1). The results of this comparative evaluation would also apply to the Mark II deep geological repository concept. The rationale for the scoring is presented below.

Constructability

The construction schedule for ramps is much longer relative to shaft excavation which would give more opportunity for accidents. The assessment of a ramp development advance rate of 5.5m / day was optimistic and thus the schedule impacts could be even more than assessed.

In the event a water-bearing zone is present, the construction of a ramp access through this zone would be more challenging. For a given thickness of water bearing zone, a ramp would expose more of the zone which, in turn, would lead to a larger amount of ground treatment (e.g. grouting) and dewatering work.

Excavated Rock / Water Management

Total volume of excavated rock to be managed from the excavation of the ramp is larger than the rock volume from the excavation of the shaft by a factor of 10.

During lateral development of the underground repository, it is assumed that excavated rock would be delivered to surface via skipping in both the shaft access and ramp access options. It would be more expensive to transfer excavated rock via ramp (on a truck) to ground surface.

Geoscientific Investigations during Construction

Ramp access will offer more opportunities than the shaft access option for geoscientific investigations, testing and experiments in rock overlying the repository during both construction and operations. By comparison, it will be more difficult to carry out geoscientific investigations within the shaft once the shaft liner and hoisting system are installed.

Ventilation

The ventilation system for the ramp access option requires additional ventilation fan horsepower relative to shaft-only access option.

Ease of Waste Package Movement

Delivery of used fuel containers from surface to the underground repository level would be slower via ramp relative to the shaft access option.

In the ramp, it is assumed that used fuel containers would be transferred underground using a vehicle similar to that shown in Figure 2.3. If one assumes a vehicle speed of 5 km/hr, it would take about one hour to travel the 5-km-long ramp one-way. Whereas it would take less than 10 minutes to transfer used fuel containers to a 500-m-deep underground repository via a hoisting system in a shaft.

The ramp transport vehicle is still under development and is untested under long-term service conditions.

Concurrent UFC Placement and Lateral Development

During operations excavation of new placement rooms would occur concurrently with placement of UFCs at another location that is remote from the excavation activities. Trucks carrying excavated rock and vehicles carrying used fuel containers would travel along different routes. The ramp access option does not offer any advantages over the shaft access option with respect to facilitating concurrent used fuel container and excavation activities. There are no major differences between the access options with respect to ventilation requirements, safety considerations, work area isolation and material handling considerations.

Operational Flexibility

Ramp access would allow location of primary access to underground repository to be distant from the repository. This offers the possibility of decoupling siting of surface facilities from the siting of underground repository.

Ramp access offers flexibility with respect to delivering large and heavy items into or out of the underground repository. For example, it would be relatively easy to bring mining equipment to surface for major maintenance or replacement, and new equipment underground. Should the design of the transfer cask change and become larger and/or heavier (due to shielding requirements or different type of used fuel from new reactor design), this design change could be more easily accommodated in the ramp access option.

Maintainability over a +100 year Life

Ramp access and shaft access are deemed to be similar with respect to maintenance over the expected 100 year operating life of the deep geological repository. The difference in estimated maintenance costs between the two access options is small. Factors affecting maintenance cost in the ramp access option are:

- Ramp will require road bed and rock support inspection and maintenance over its 5 km length. However ramp is a relatively simple facility to maintain;
- Repository location will determine portal[2] maintenance requirements. For example in cold weather locations ramp portals generally become icy in winter months and thus road surfaces would have to be heated to prevent ice build-up; and
- Operating heavy equipment on a 10%-grade ramp over a distance of 5 km will lead to higher equipment maintenance and replacement costs .

Factors affecting maintenance cost in the shaft access option are:

- A shaft and the associated hoisting system will require experienced, specially-trained personnel.
- Mine hoists and shafts are generally housed inside structures and protected from the weather (i.e. air is conditioned); and

[2] Portal is a mining term to describe the surface entrance to a ramp or tunnel.

- Hoisting equipment will not be heavily used (relative to a typical mining operation) and therefore maintenance and replacement costs will be relatively low.

Worker Safety (Radiation/Fire/Emergency)

From the perspective of worker safety, the ramp access option is considered to be less favourable than the shaft access option. The primary disadvantages of the ramp access option are as follows:

- In both shaft access and ramp access options the used fuel containers would be transferred in shielded transfer casks. However if a driver is present in the ramp transfer vehicle, then there is greater risk of exposure to radiation relative to the shaft access option. In the shaft access option, personnel will not be required to be present in the shaft cage during underground transfer of used fuel containers; and
- There would be a higher probability of worker injury due to a vehicle accident in the ramp scenario.

The aforementioned disadvantages outweigh the following potential advantages of the ramp access option:

- Compared to the shaft access option, ramp access would allow workers more flexibility to evacuate from the underground facility following an emergency event (i.e. can physically walk out of the repository); and
- Ramp does not require emergency electrical power to allow the escape of workers during an emergency event where the main electrical power source is lost. Whereas the shaft access option requires emergency electrical power to operate the hoisting system during an emergency event.

Preclosure Safety

Ramp access and shaft access are deemed to be similar with respect to preclosure or operational safety.

Worldwide, ramp haulage is widely used in the mining industry and international expertise exists for the design of ramps. Mine shafts and hoists are widely used in Canada and their use is highly regulated. There is a considerable amount of expertise and experience in the Canadian mining industry for design of shafts and hoisting systems.

Due to the relative long transport distance in the ramp, there is greater likelihood of an incident occurring during used fuel container transport (relative to the shaft access option). However the consequence of such an incident would likely be relatively small because used fuel containers would be heavily protected.

On the other hand the likelihood of hoist or cage failures leading to cage fall is considered to be very low. The last relevant Canadian hoisting accident occurred in 1982, and involved a fire in a headframe which, in turn, caused failure of hoist ropes and a cage fall (NWMO 2011). However if such a failure would occur when the cage is carrying a used fuel container, then the consequences would be relatively high.

If fractured and permeable rock conditions exist, say, in upper rock formations near ground surface, then grouting and concrete liner would be required to control groundwater inflow into either a shaft or ramp. Thus during operations there would be a risk of concrete liner failure and possible groundwater inflow for both the ramp and shaft access options. However for any given thickness of a permeable rock formation, the ramp excavation will intersect more permeable rock than the shaft excavation. Thus the ramp would have a higher risk of unexpected groundwater ingress due to concrete liner failure.

Sealing of Access-way / Post Closure Safety

The effectiveness of the shaft or ramp sealing system will be a key factor affecting the post closure safety of the deep geological repository. In preparation for placement of sealing materials, the concrete liner, shaft or ramp infrastructure, and the damaged rock will need to be removed. Sealing materials will then be placed so that a low permeability barrier is constructed inside the ramp or shaft excavation.

Sealing of the ramp is considered to be more difficult than in a shaft for the following reasons:

- The ramp is 10 times the length of the shaft and therefore preparation work and seal material placement work will require more effort;
- In the ramp option it may be difficult to create a complete seal at the back or roof of the underground opening; and
- Unlike the shaft access option, the ramp access option cannot take advantage of “self compaction” of sealing materials, due to the weight of overlying materials.

Capital Expense

Capital cost to construct and equip a 5-km-long ramp is estimated to be larger than the cost to sink a 500-m-deep shaft.

Operating Expense

Although the operating cost for the ramp is estimated to be larger than operating cost for a shaft, the cost difference is not considered to be significant. The ramp access option will have additional electrical demand for ventilation, and additional diesel and equipment maintenance costs required for the ramp transfer vehicles.

Schedule

The development of a ramp will take a significantly longer period of time than the shaft development.

5. DISCUSSION

The access concepts for proposed repositories for spent (used) nuclear fuel and other high level wastes in Finland, Sweden, Germany, Switzerland and France were reviewed. The repository designs in these countries are considered to be representative of a range of repository designs being considered in various countries around the world. The majority of the repository designs in these five countries include a ramp as a primary means of access and in most cases the ramp is used for delivery of spent nuclear fuel canisters into the underground repository. Thus, for this reason it was decided to explore whether or not there would be any significant advantages with the introduction of ramp access into the APM deep geological repository design.

Shaft transport systems are commonplace worldwide (for mining) and have an extensive knowledge base that can be applied to mitigate any risks that might be associated with shaft transport systems. The mining industry and regulatory bodies in Canada and elsewhere have refined the operation of shaft systems and are considered to be predictable, reliable and safe when operated and maintained within the confines of best practices. The shaft option further provides benefits related to constructability, excavated rock and water management, ventilation, worker safety, ease of waste package movement, sealing of access ways and postclosure safety, cost and schedule.

The two primary advantages of the ramp access option are related to geoscientific investigations during construction and operational flexibility. Ramp access will also offer more opportunities than the shaft access option for geoscientific investigations, testing and experiments in rock overlying the repository during construction and operations. Ramp access will offer more flexibility with respect to delivering large and heavy items into or out of the underground repository. However it was determined that these advantages were not considered sufficient to change to ramp access as the primary means of underground access into the APM deep geological repository.

6. CONCLUSION

A trade-off study was performed to compare the shaft access with the ramp access option for APM deep geological repository and to determine whether or not ramp access should be introduced into APM deep geological repository design. Although ramp access has some advantages over the shaft access, it was determined that these advantages were not considered sufficient to change to ramp access as the primary means of underground access.

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