Used Fuel Container Retrieval from a Deep Geological Repository in Crystalline Rock

Vertical Borehole Configuration

NWMO TR-2012-03 February 2012

J.E. Villagran

Nuclear Waste Management Organization

nwmo

NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Nuclear Waste Management Organization
22 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

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ABSTRACT

Title: **Used Fuel Container Retrieval from a Deep Geological Repository in Crystalline Rock Vertical Borehole Configuration**
Report No.: **NWMO TR-2012-03**
Author(s): J.E. Villagran
Company: Nuclear Waste Management Organization
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Abstract

This report describes a conceptual design for a used fuel container retrieval system and the container retrieval operation for a deep geological repository in crystalline rock. In the context of this report retrieval is the concrete action of removing used fuel containers from the repository. Retrievability is the ability in principle to recover used fuel containers once they have been placed in the repository, and implies making specific provisions in the repository design in order to make retrieval feasible should it be judged necessary.

The conceptual design for the repository consists of a network of shafts and tunnels that provide access to several panels of placement rooms where the used fuel containers are placed and sealed inside vertical boreholes drilled in the room floor.

The container retrieval system described in this report provides a conceptual description of the means to retrieve a used fuel container from its location in a repository placement room and to transfer it to the repository surface facilities. It makes use of the equipment used for the container placement operation and of mining equipment used for construction of the repository. The retrieval operation is essentially based on reversing the container placement operation, using the container transfer cask for subsequent transport of the retrieved container to the repository surface facilities. It also includes methods for removal of the concrete bulkheads and the engineered barrier materials surrounding the container.

Safety is a key consideration for the used fuel container retrieval operation. The conceptual design of the retrieval system equipment provides the required radiation shielding to allow unrestricted movement of personnel during operations. Monitoring of radiation fields and sampling of the underground environment can be conducted to ensure safety throughout the entire container retrieval operation.

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1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management (APM), Canada's plan for long-term management of used nuclear fuel. APM includes long-term containment and isolation of the used fuel in a deep geological repository in a suitable rock formation such as crystalline rock or sedimentary rock. Retrievability of the used fuel is an important element of the APM plan.

Retrievability is the ability in principle to recover used fuel containers once they have been placed in the repository. Retrieval is the concrete action of removal of the containers. Retrievability implies including specific provisions in the repository design in order to make retrieval feasible should it be judged necessary.

This report describes a conceptual design for a used fuel container retrieval system and the associated container retrieval operation in a deep geological repository designed for crystalline rock. The conceptual design for the repository in crystalline rock uses the vertical in-floor borehole container placement method (SNC Lavalin 2011). The retrieval system design and the retrieval process described here provide the capability of retrieving a used fuel container from an arbitrary location in the repository during a period that encompasses the repository operation and an extended monitoring period prior to final decommissioning and closure of the APM facility. The scope of the system and associated container removal process are defined for the equipment and tasks required to access the target borehole, remove the container and place it into a transfer flask. The retrieval process is essentially based on reversing the container placement operation and using the container transfer flask for subsequent transport of the retrieved container to the repository surface facilities.

The principal activities associated with the container retrieval process have been studied and demonstrated via the Canister Retrieval Test at SKB's Äspö Hard Rock Laboratory in Sweden from 2000 through to 2008 (Eng 2008, SKB 2010). The international Canister Retrieval Test demonstrated the retrieval of a full size used fuel container following its placement in an instrumented borehole in crystalline rock and a monitored period of five years during which the bentonite buffer surrounding the container reached full saturation. The Canister Retrieval Test is further described in Appendix A.

2. REPOSITORY CONCEPTUAL DESIGN FOR CRYSTALLINE ROCK

The APM deep geological repository concept entails encapsulating the used nuclear fuel in durable containers and sealing the containers in a repository located at a depth of approximately 500m in a stable geological formation. This report specifically considers a repository designed for crystalline rock using an in-floor borehole configuration for used fuel containers.

The vertical in-floor borehole container placement method has been selected for use in the development of conceptual designs and cost estimates for a repository in crystalline rock by several national nuclear waste management organizations. This concept has also been studied in Sweden, Finland and Canada as part of the development of deep geological repository concepts in crystalline rock (SKB 2007, Vieno and Nordman 1999, Villagran et al. 2011). An illustration of the APM repository concept is shown in Figure 1.

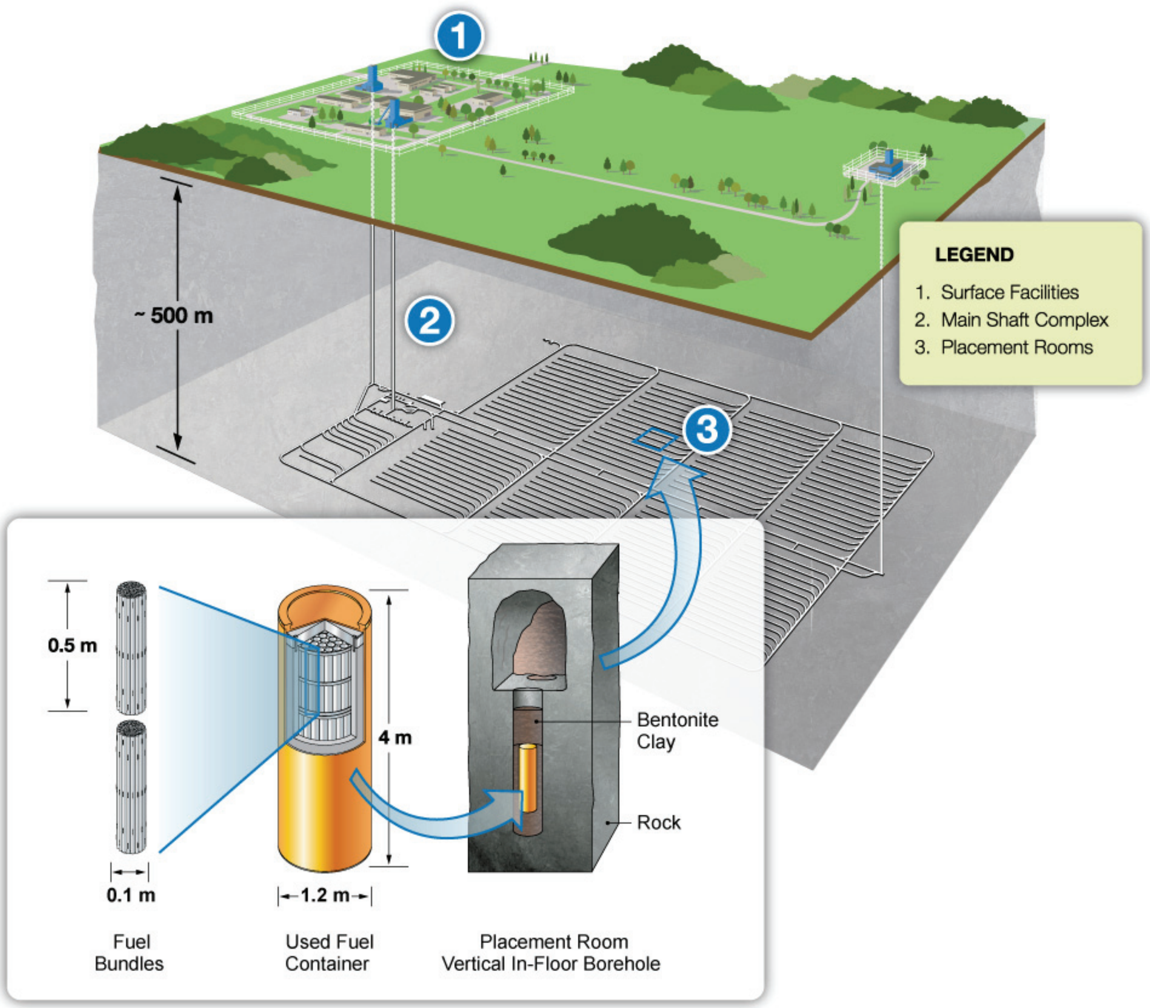


Figure 1: Conceptual Design for a Deep Geological Repository in Crystalline Rock with In-floor Borehole Placement of Used Fuel Containers.

2.1 UNDERGROUND FACILITIES

For the purpose of preliminary design and safety studies for a hypothetical site in crystalline rock, the used fuel container repository is assumed to be developed on a single level, at a depth of approximately 500 m. The repository access and ventilation are provided via three vertical shafts. The horizontal underground development includes perimeter drifts, cross-cuts, used fuel container placement rooms and related underground support facilities. The repository configuration is illustrated in Figure 2 (SNC-Lavalin 2011).

The used fuel container placement rooms consist of a series of parallel tunnels arranged in eight panels. Each placement room has a centre-to-centre spacing of 40 m and a single access from the corresponding repository cross-cut. The entrance to the room has a 50 m turning radius to facilitate the movement of the container transfer cask and related system. The length of the rooms is about 400 m and the boreholes where the used fuel containers are placed are spaced 4.2 m apart (center to center). The used fuel containers placement density is designed to minimize the repository underground footprint while, at the same time, satisfying thermal design requirements.

Within the boreholes, the containers are surrounded by highly-compacted bentonite disks and rings that form the primary isolation barrier between the container and the rock. This material, (referred to as the Buffer) is designed to inhibit groundwater flow, block or delay the transport of radioactive species and inhibit the development of bacteria. Following the completion of used fuel container placement operations within a particular room, the room will be sealed with dense and light backfill. A placement room longitudinal cross section is shown in Figure 3 (SNC-Lavalin 2011).

2.2 ENGINEERED BARRIERS

2.2.1 Development of Swelling Pressure

The clay-based buffer would have a specified, uniform water content at the time of installation. During the first few years after placement of used fuel containers in a repository placement room, the heat from the containers would cause this moisture to be redistributed, with the region closest to the containers becoming drier than the peripheral region. This moisture redistribution process will be reversed over time and, in the longer term, the moisture content of the clay will increase until full saturation of the buffer is achieved. This is the normal predicted process through which the buffer attains its maximum swelling pressure, which ensures protection of the container surface and a diffusion-dominated transport regime. The pore water will be practically immobilised in the bentonite pores, blocking advective transport.

The amount of time required to achieve this condition can be estimated based on the geometry of the container placement room, the properties of the sealing materials and the overall permeability of the rock. Previous analyses have estimated, for a range in hydraulic conductivity from 10^{-11} m/s to 10^{-14} m/s, a range of saturation times from 20 to 20,000 years (McMurry et al. 2003). For the purpose of container retrieval, it may be difficult to predict the degree of saturation of the buffer in a particular borehole at any specific time, therefore the development of methods for retrieval of the used fuel containers should conservatively assume that the maximum swelling pressure of the buffer have been attained.

2.2.2 Used Fuel Container

The current reference design for a used fuel container in crystalline rock (IV-25 copper container) has a capacity of 360 bundles. The container, shown in Figure 4, has a copper outer shell that provides a long-lived corrosion barrier and a steel inner vessel that provides mechanical strength; their main design parameters are given in Table 1 and Table 2. The total mass of the container is 26,700 kg

The dimensions of the placement borehole are determined by the used fuel container dimensions and the required thickness of sealing material. In this case the sealing material (buffer) placed between the container and the rock consists of cylindrical and ring-shaped blocks of highly compacted bentonite. A minimum thickness of 35 cm of buffer material is required, which results in a minimum borehole diameter of approximately 2.0 m.

Table 1: Reference Copper Shell Parameters

IV-25 Outer Copper Vessel	
Total vessel height	3,842 mm
Copper vessel outside diameter	1,247 mm
Copper vessel inside diameter	1,197 mm
Copper vessel wall thickness	25 mm
Lid height	110 mm
Minimum copper lid and bottom thickness	25 mm
Mass of copper vessel with lid and bottom	4,170 kg
Vessel Material	Oxygen-free, phosphorous-doped, high purity copper

Table 2: Reference Steel Vessel Parameters

IV-25 Inner Steel Vessel	
Total inner vessel height	3,700 mm
Inner vessel outside diameter	1,195 mm
Inner vessel inside diameter	990 mm
Wall thickness	102.5 mm
Height of steel lid and bottom	350 mm
Minimum steel lid and bottom thickness	170 mm
Weight of inner vessel	12,650 kg
Vessel Material	ASTM A516 Gr 70 steel
Inner backfill gas	Inert gas at atmospheric pressure

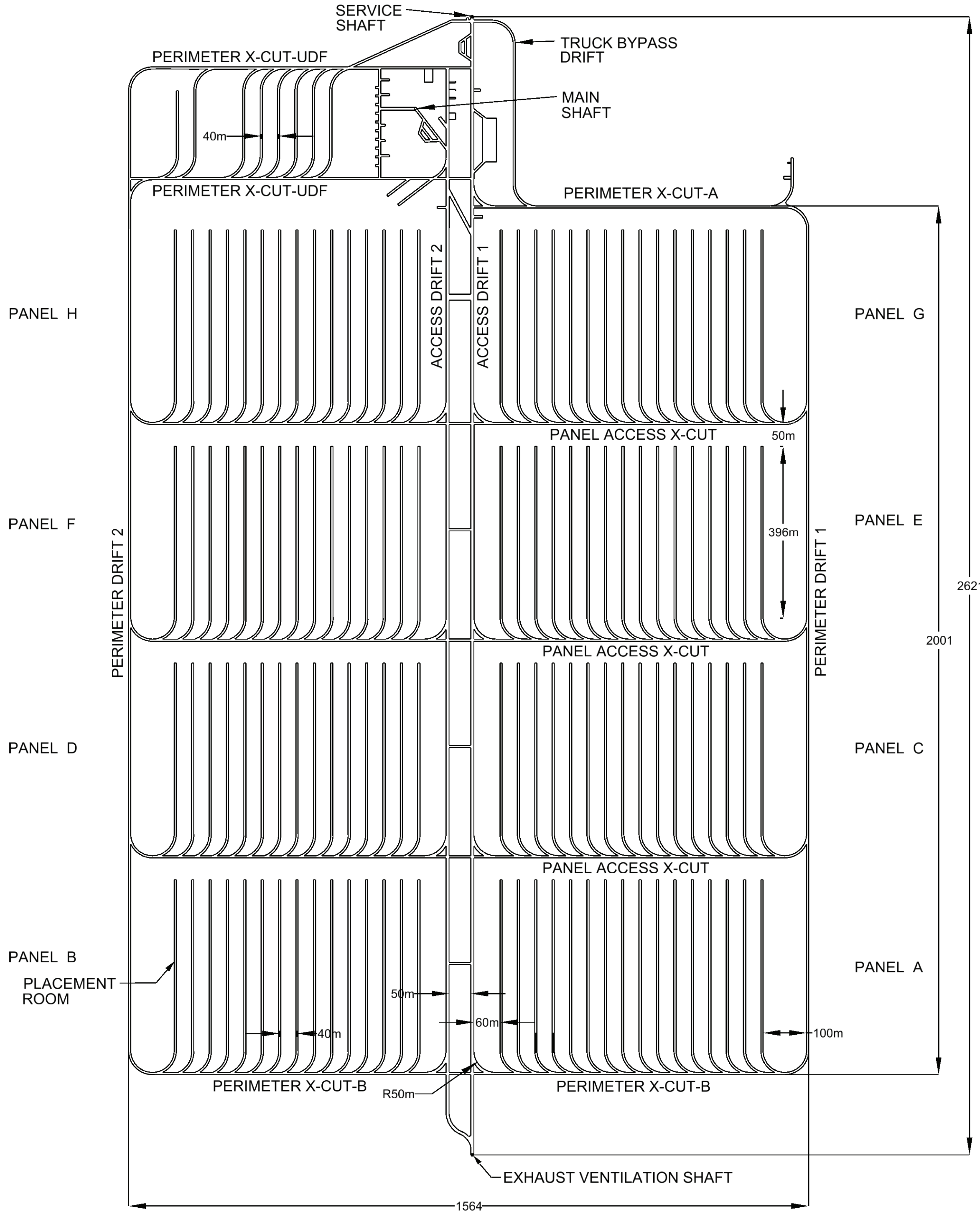


Figure 2: Underground Repository Layout for the In-floor Borehole Placement Method.

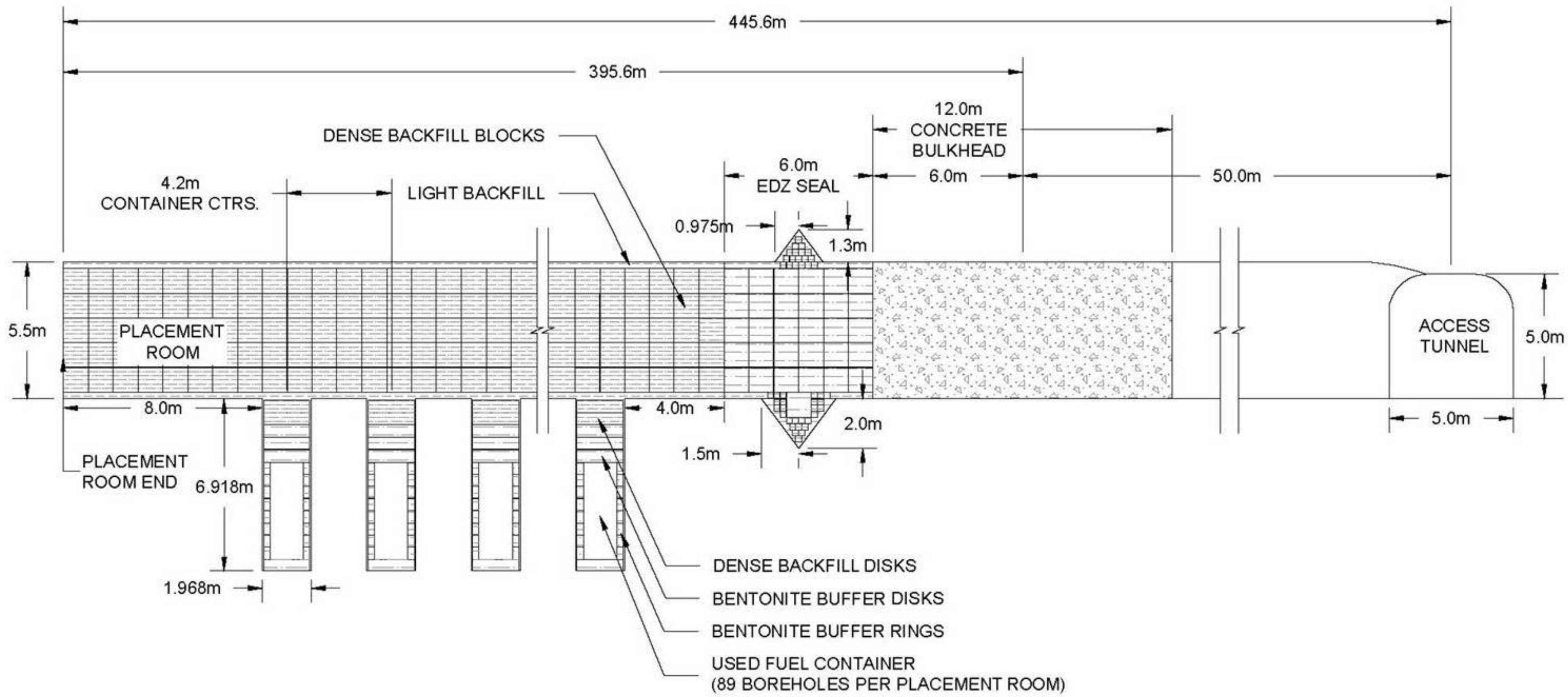


Figure 3: Repository Placement Room Longitudinal Section

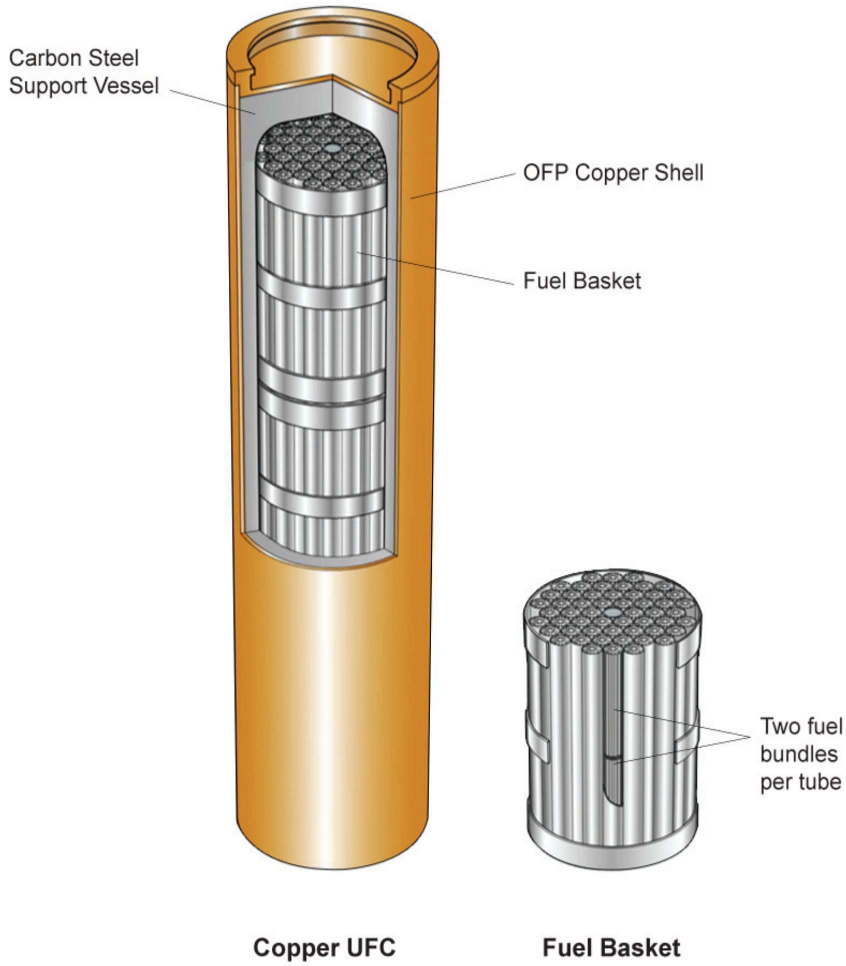


Figure 4: Copper Used-fuel Container and Fuel Basket Holding Two Layers of CANDU Fuel Bundles

3. RETRIEVAL SYSTEM DESIGN

3.1 SCOPE AND ASSUMPTIONS

The assumptions used for development of a conceptual design for the container retrieval system and container retrieval operations are summarized below.

The intended function of the used fuel container retrieval system will be to provide the capability to retrieve a container from an arbitrary location in the repository during a time period that includes the repository operational phase and the extended monitoring period. Container retrieval during the postclosure period is also considered possible but it would require additional excavation to gain access to the repository.

The system described here includes the components specifically required to access and remove a used fuel container as well as the normal equipment used for container transport and placement. For the purpose of the retrieval operation it is assumed that the target container is structurally sound and that it is placed in the correct position within the borehole. These assumptions are consistent with the repository and container design and the quality assurance processes associated with the container placement operations.

The tasks required to access the target borehole, remove the container and place it into a transfer flask will consist essentially of reversing the container placement operation and will make use of equipment from the repository construction systems to access the target container location. The container placement machine will be used for retrieval of the container from the borehole and the container transfer flask will be used for transport of the retrieved container to the repository surface facilities.

The repository design and development tasks are expected to include the construction of an underground demonstration facility where site-specific repository systems can be tested and demonstrated. This will make possible the functional demonstration of retrieval system components and the demonstration of a complete container retrieval operation at the APM facility. Safety will be a primary consideration for the retrieval processes.

3.2 SYSTEM REQUIREMENTS AND DESCRIPTION

The primary requirement of the container retrieval system is to provide the capability to retrieve a used fuel container from an arbitrary location in the repository during a time period that includes the repository operational phase and the extended monitoring period.

The system design shall also incorporate the required safety provisions, in the form of shielding and monitoring of radiation fields to ensure that container retrieval is a safe operation. The radiation shielding shall be designed to allow unrestricted movement of personnel during the container retrieval operation.

The used fuel container transfer and placement equipment, as well as equipment used for construction of the repository are considered part of the container retrieval system for the purpose of the container retrieval operation. The list of container retrieval equipment is shaded, blue indicating which pieces of equipment are common to both systems and yellow indicating the differences in the equipment list. Detailed description of the relevant equipment is provided in the updated conceptual design of a deep geological repository (SNC Lavalin 2011).

Table 3 lists the major equipment needed for both the container placement and container retrieval operations.

Table 3: Container Placement and Retrieval Equipment

Equipment from Container Placement	Equipment for Container Retrieval
Container transfer cask with integral winch and container lift clamp	Container transfer clask with integral winch and container lift clamp
Trolley for container transfer cask	Trolley for container transfer cask
Placement machine with gantry crane and trunion lift	Placement machine with gantry crane and trunion lift
Trolley for placement machine	Trolley for placement machine
Borehole shielding barrier with sliding doors, container clamp tool, camera and light, and winch	Borehole shielding barrier with sliding doors, container clamp tool, camera and light, and winch
Bentonite disc placement shield with integral winch	Not required
Bentonite pellet blowing equipment and trolley	Buffer removal system and trolley slurry pumps, water spray ring and winch, slurry tank
Temporary borehole cover	Temporary borehole cover
Trolley and locomotive	Trolley and locomotive

4. CONTAINER RETRIEVAL OPERATION

There are three major stages in a container retrieval operation:

- Providing access to the target borehole.
- Retrieving the container from the borehole.
- Transferring the container to the surface facilities.

The first two stages are addressed in detail in this report. Regarding the third step it is assumed that the container transfer cask and transfer system used to place the container in the repository are available, and that the transfer operation can be fully reversed in order to transport the used fuel container back to the surface facilities.

For the purpose of this report, it will be assumed that container retrieval occurs during a time period that includes repository operation and extended monitoring, prior to final closure of the facility. This report considers the tasks and equipment required to access the target container borehole assuming that the repository tunnels are open and that the container placement and transfer systems remain operational.

The container retrieval system concept uses proven industrial and mining processes to access a sealed placement room. In some cases, such as for removal of the room backfill, more than one option has been identified for the excavation/removal method. The overall retrieval operation, including gaining access to the container location, removing engineered barriers and retrieving the target container, includes the following major steps:

- Remove the placement room concrete bulkhead.
- Remove the 6 m thick clay seal; repeat sampling process upstream from the seal towards the target borehole.
- Remove room backfill material until a sufficient length of the placement room is open to accommodate the required retrieval system equipment.
- Install rail tracks and move in the equipment needed to remove the buffer material from the target borehole.
- Using both mechanical and hydraulic processes remove sufficient amount of buffer to loosen the container - during this operation, maintain continuous monitoring of radiation fields above the container location and monitoring of the room.
- When sufficient quantity of buffer material has been removed, position the gamma-gate and the container placement/removal machine over the borehole.
- Proceed to hoist the container into the container transfer cask.
- Reverse container transfer operations to bring the container back to the surface.
- Restore the condition of the placement room by backfilling the borehole and the room and replacing the room seal and bulkhead.

These steps are discussed and illustrated in further detail in the sections that follow. It must be emphasized here that although radiation monitoring is only mentioned in Step 6, it is a continuous task throughout the entire retrieval operation. Although high radiation fields or the presence of radioactive contaminants is extremely unlikely, continuous monitoring of gamma fields and frequent sampling and analysis of the groundwater are considered important to ensure operational safety.

Also, before extraction of the bulk of the buffer material, extracting samples (by drilling) from the buffer blocks will be required since their condition will be important for assessment of the engineered barriers evolution in that area of the repository.

4.1 GAINING ACCESS TO THE PLACEMENT ROOM

The drill and blast method used to excavate the crystalline rock tunnels would be unsuitable for use during the retrieval operation since the use of explosives could be highly disruptive in a repository either partially or completely full. Therefore, alternative methods are used for removal of the concrete bulkhead and the room backfill.

4.1.1 Removal of the Concrete Bulkhead

A non-explosive expansion agent will be used to break down the concrete bulkhead without mechanically disturbing adjacent boreholes. This is technology frequently used when controlled demolition of a structure is required. The expansion agent is placed in strategically drilled holes in the structure. Expansion of the agent, fracturing the structure, takes place over a period of hours or days depending on the geometry and characteristics of the structure materials. An illustration of this process, used to break down a large concrete block, is shown in Figure 5.

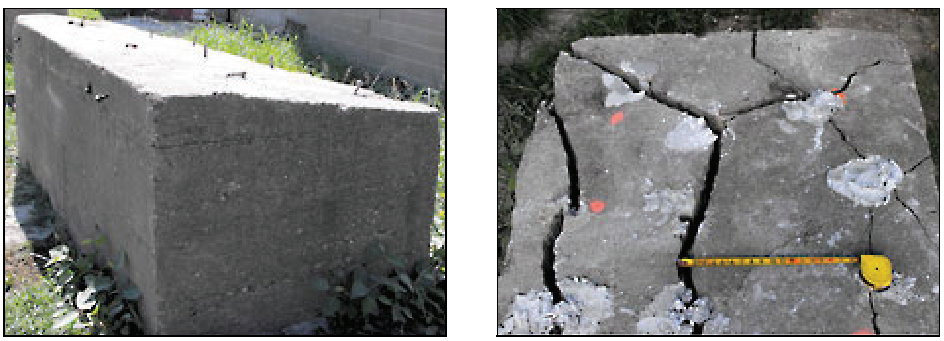


Figure 5: Use of Expansive Demolition Agent in Concrete

After the expansion agent swells generating sufficient pressure to break the concrete, the concrete fragments are removed using conventional methods. The advantages of this demolition method are that it does not cause any ground vibrations, generates only a minimal amount of gases or debris and is relatively easy to apply. For the large concrete bulkhead that seals the repository placement room this would be a time-consuming but inherently safe operation.

The same equipment (truck and loaders) used for removing broken rock during excavation of the tunnels would be used for removal and transport of the concrete bulkhead fragments to the service shaft.

4.1.2 Removal of Placement Room Seal and Backfill

The placement room seal located next to the concrete bulkhead will need to be removed. It would be important to assess the condition of the seal. Therefore, before the large scale removal of seal materials takes place, samples would need to be taken to measure the level of saturation of the clay at different seal locations. This would likely be implemented by horizontal core drilling. Also groundwater samples and rock samples from the peripheral region may be taken if required. Sampling and analysis of these materials could be useful for the assessment of near-field conditions relevant to the container removal operation. The 6 m thick bentonite seal would likely be removed in steps, coordinated with the extraction of material samples.

The proposed method for removal of highly compacted bentonite (HCB) blocks from the seal will depend on the hardness of the seal materials. If the swelling pressure has effectively eliminated block boundaries, mechanical methods such as a small road-header machine could be used to excavate the seal. Alternatively, if the seal cannot be excavated by mechanical methods because of its hardness, expansive demolition agent will be drilled at strategic locations into the seal and allowed to expand. Subsequently, the fragmented bentonite will be removed using conventional mining equipment. After the room seal is removed, the room backfill will need to be excavated over a distance to clear sufficient space for the container removal operations. The proposed method for removal the room seal could also be used for removal of the backfill, however other alternatives may be evaluated once the condition of the backfill blocks is known. For example, hydrodynamic methods could be used to facilitate separation of the blocks, followed by removal of backfill blocks on an individual basis. Figure 6 shows the cross-section of a placement room along a borehole axis.

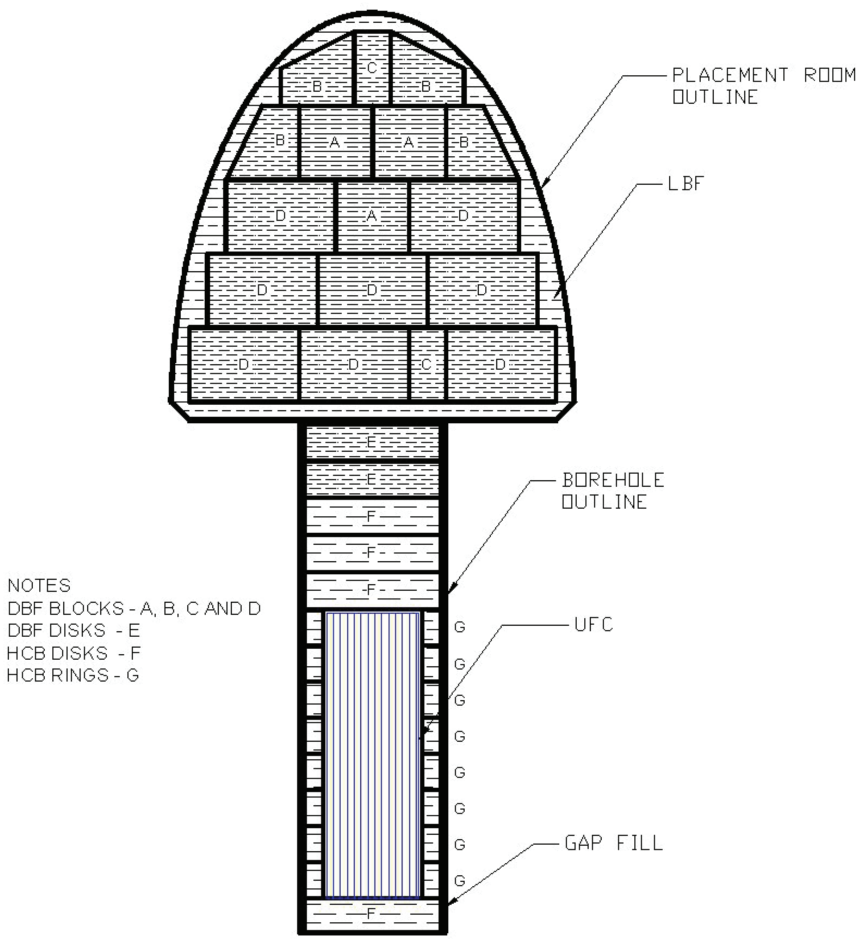


Figure 6: Cross Section of a Filled Placement Room Along the Borehole Axis

As Figure 6 indicates, the blocks placed in direct contact with the container are made of highly compacted bentonite (HCB) shaped in the form of discs or rings. The two upper disks in the borehole and the blocks in the core of the room are made of dense backfill material, and the gap between the dense backfill and the rock is filled with light backfill consisting of pneumatically placed bentonite-sand pellets. Gap fill material is used to fill the space between the HCB blocks and the borehole rock surface and between the HCB blocks and the used fuel container. The reference composition of these materials is as follows:

Highly Compacted Bentonite (HCB):	100% bentonite.
Dense Backfill (DBF):	5% bentonite, 25% clay, 70% crushed rock.
Light Backfill:	50% bentonite, 50% sand (pelletized)
Gap Fill:	100% bentonite pellets

After the backfill material is excavated along the required length of tunnel to reach the in-floor borehole, its removal from the placement room can be done by conventional construction equipment.

4.1.3 Removal of Bentonite Discs and Rings from the Borehole

To effectively remove the bentonite discs and rings in the borehole without mechanically disturbing the used fuel container, a hydrodynamic method is proposed, similar to the method demonstrated at the Canister Retrieval Test conducted at the Äspö Hard Rock Laboratory in Sweden (Eng, 2008). The basic process consists in dissolving the buffer by using a 4% $CaCl_2$ water solution and pumping it from the borehole in the form of a water slurry. This can be implemented as a continuous process until a sufficient portion of buffer is removed so that the container can be loosened and lifted out of the borehole by mechanical means using the container Placement Machine.

The main components of the buffer removal system include a tank for mixing the solution, a pump to transfer it to the borehole, agitators used to stir the $CaCl_2$ water solution in contact with the bentonite, a pump to remove the bentonite slurry from the borehole and a cyclone separator used to decant the bentonite and recycle the fluid phase.

The slurry produced in the borehole is pumped from the borehole to the cyclone separator, from which dried-up bentonite and a water stream is extracted. The water stream is directed to the solution mixing tank and recycled through the system. The dried bentonite is handled as a solid. Some of the components of the bentonite slurrying system used at the Canister Retrieval Test are illustrated below, in Figures 7 and 8.

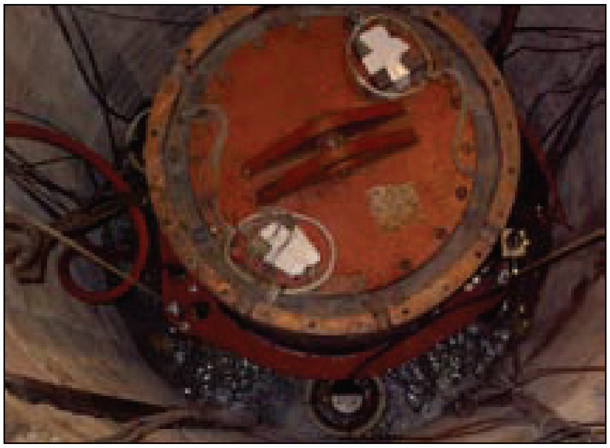


Figure 7: Slurrying of Bentonite Buffer (SKB 2010)

Figure 8: Dewatering of Bentonite Slurry (SKB 2010)

4.1.3.1 Slurry Decanting and Waste Handling

A by-product of the hydrodynamic process for removal of the buffer is the production of a bentonite slurry containing a large volume of water. Technology is currently available to deal with fine bentonite slurries, since it is a common requirement in many mining applications. The most common technology is based on mechanical dehydration of sludge based on a decanter centrifuge process by which separation of dehydrated sludge is achieved by a cyclone that operates at a variable speed. Such equipment can be customized to meet the requirements for the container retrieval application. Figure 9 shows a diagram of a typical decanter centrifuge, and Figure 10 shows a picture of an industrial unit.

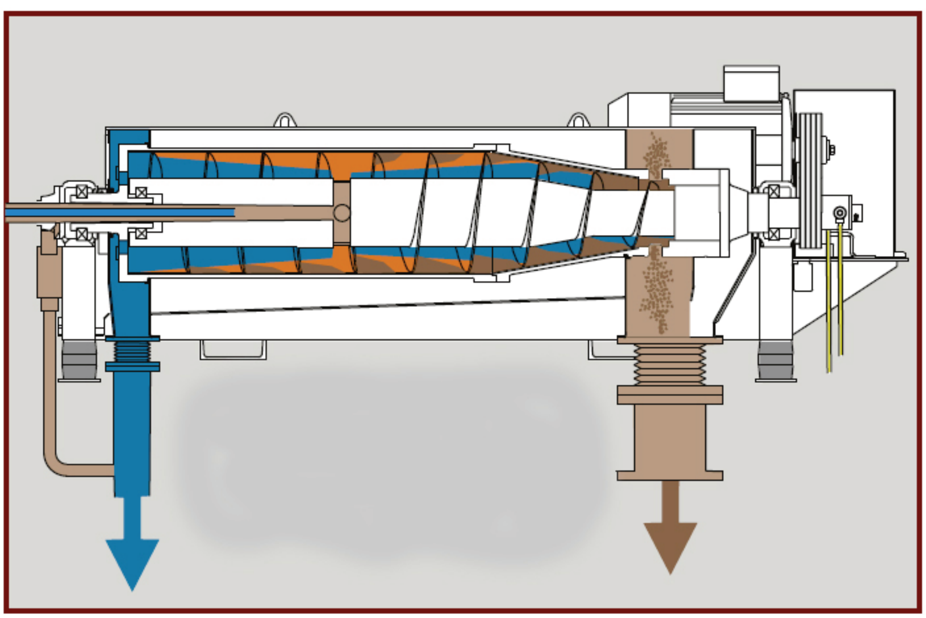


Figure 9: Diagram of Bentonite Decanting Centrifuge

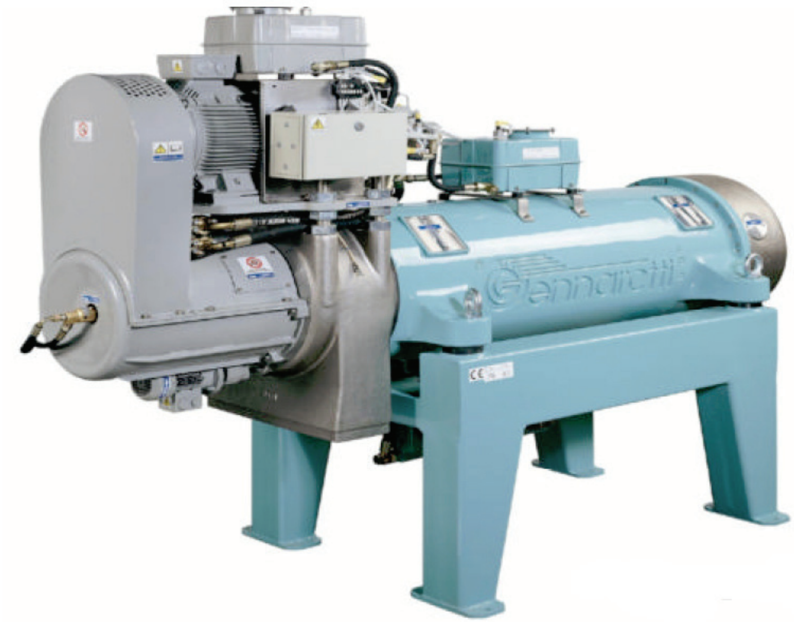


Figure 10: Slurry Decanting System for Industrial Applications

4.2 CONTAINER RETRIEVAL

Once access and services have been established at the target borehole location, the actual container retrieval operation can be initiated. A sequence of steps describing the container retrieval operation is described below.

Since the container removal system components need to be moved into the placement room, rail tracks need to be installed for the trolleys used to transport them. Electrical services and ventilation also need to be restored to the retrieval operation area. The equipment required for the container retrieval operation includes:

- container transfer cask and integral winch,
- container placement machine and integral gantry crane,
- shielding barrier with sliding door and spray ring,
- trolley with mixing tank, pumps and bentonite decanting system,
- temporary borehole cover, and
- locomotive and trolleys used to transport equipment in and out of the room.

After the services are restored to the target borehole location, the placement machine is moved into the placement room, positioned over the target borehole and connected to the electrical service. After the placement machine legs are lowered the placement machine trolley is withdrawn. Then, the borehole radiation shielding barrier is brought in and positioned over the target borehole using the placement machine gantry crane.

The next step is to bring, using the container transfer cask trolley, an empty transfer cask into the room and place it under the placement machine gantry crane. The gantry crane is then used to lift the transfer cask from the trolley. Subsequently, the trolley is moved away, and the transfer cask is rotated to the vertical position and lowered over the shielding barrier.

After the container transfer cask trolley is moved away, the buffer removal system mounted on a dedicated trolley is moved into the room, next to the placement machine. This system includes the tank for mixing the $CaCl_2$ water solution, the pump to transfer the solution to the borehole, the pump used to remove the bentonite slurry from the borehole and the cyclone separator used to decant the bentonite and recycle the process water. The spray ring used to deliver the solution to the buffer is pre-mounted on the shielding barrier and its height can be controlled as required. After all system components are connected, the buffer removal system is ready for operation.

Once this system is in place the hydrodynamic buffer removal process is initiated and continued until approximately the top 25% of the container is exposed. At that point, using the transfer cask winch, the container clamp is lowered and locked onto the container lid. This will maintain the container in the vertical position as more buffer material is removed. The buffer dissolution process is then continued until 75% to 80% of the container is exposed. At that point, the container lifting operation may be initiated.

During the lifting operation the buffer removal system spray ring is brought up to its highest position and continues to operate, removing residual bentonite from the container surface as the container is lifted into the transfer cask. Once the container is raised into the transfer cask, the cask shielding door and the borehole shielding door are closed. The shielding barrier and transfer cask are disconnected from electrical service. The buffer removal system is then disconnected and the system trolley is removed from the placement room and moved to storage.

Subsequently, the container transfer cask is rotated to the horizontal position and the transfer cask trolley is moved into position. Then the placement machine winch lowers the loaded transfer cask onto the trolley, which is then moved out of the placement room and to the main shaft area for transfer to the surface facilities. A trolley is used to bring a temporary borehole cover into the placement room. The placement machine is then used to remove the borehole shielding barrier and replace it with the temporary borehole cover, and the shielding barrier is moved to storage.

Finally the placement machine trolley is moved in and positioned under the placement machine. The placement machine legs are then slowly raised and the machine is lowered onto the trolley. Then the trolley and placement machine are moved to storage. The system components used for the container retrieval operation, and the removal operation steps are illustrated in detail in Figures 11 and 12.

5. CONTAINER RETRIEVAL SYSTEM MAINTENANCE

The container retrieval system has special maintenance needs beyond those of conventional equipment due to the potential long periods of equipment inactivity between uses and the requirement of being available over times spanning several decades. During the repository operations phase this does not translate into special requirements because the system components that are common to retrieval and container placement operations will be in current use and could be made available for the retrieval operation. Dedicated parts of the container retrieval system, such as the bentonite slurrying system and the bentonite dewatering system can be procured, assembled and commissioned as required.

Modularity will be a key feature the retrieval system that would make it easy to replace and update components over an extended period. Therefore, specific system components procured at an early stage can be replaced or upgraded as required during the repository operational phase. Concerns regarding either availability or obsolescence do not apply to common system components during the repository operational phase, since they will be maintained in service for routine operations. However, a detailed plan of upkeep, maintenance and replacement as required should be instituted for the extended monitoring period that follows the end of container placement operations.

6. CONCLUSIONS

A conceptual design of a used fuel container retrieval system has been described based on the reference container placement method for an APM deep geological repository constructed in crystalline rock. The system is largely based on the process and equipment used for development of the repository and on experience from an international demonstration project. The equipment required for the retrieval system and the steps of a retrieval operation have been identified and described at the conceptual level.

The proposed container retrieval methods described in this study constitute a good basis for development of a system design. The feasibility of the retrieval operation steps has been demonstrated to the level required for the development of generic repository designs.

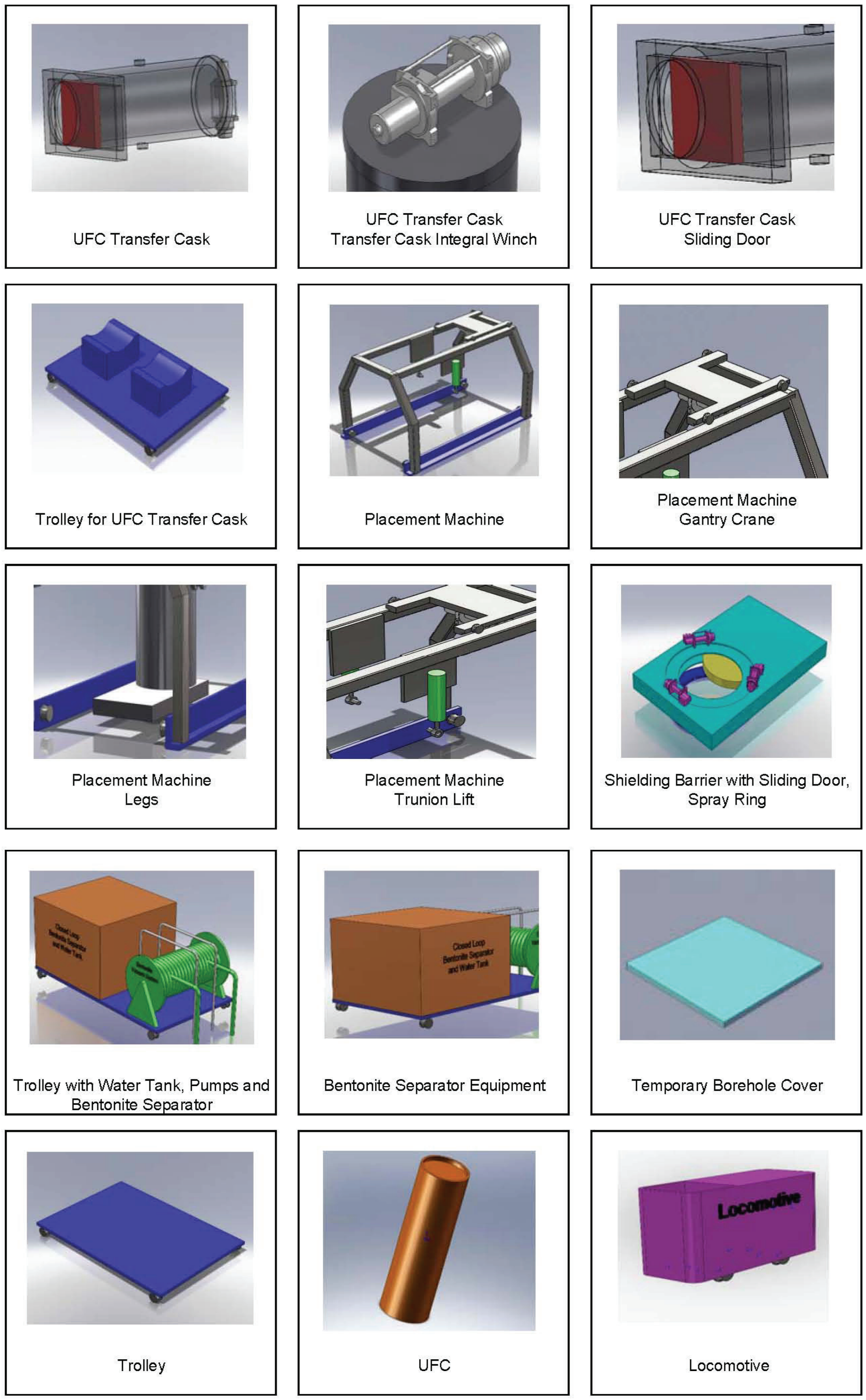
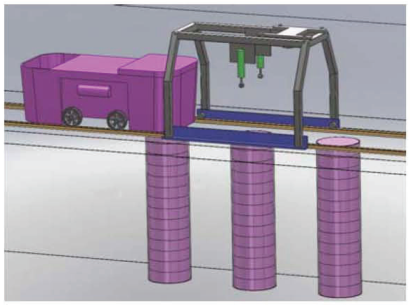
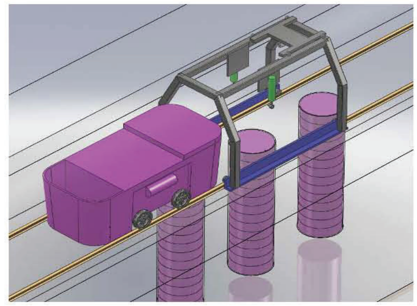


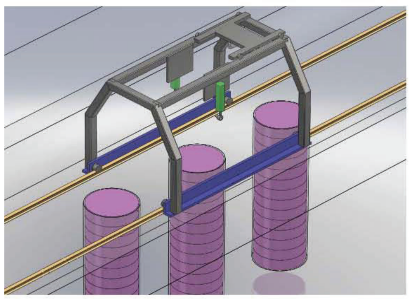
Figure 11: Container Retrieval Equipment - Graphical Representation (note: UFC=used fuel container).



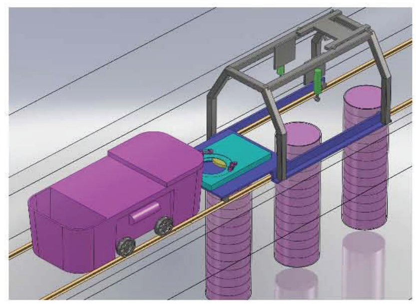
Phase 1
Transport and position Placement Machine over Borehole



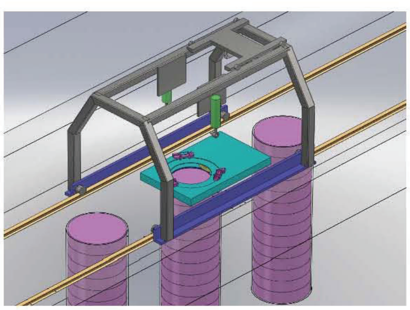
Phase 2
Connect Placement Machine to Services



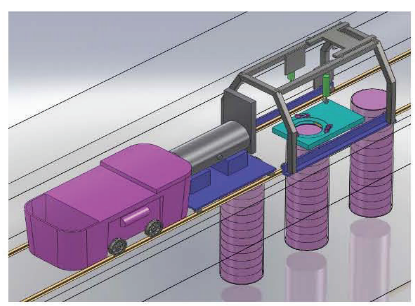
Phase 3
Lower Placement Machine Legs and move Placement Machine Trolley to Storage



Phase 4
Transport Shielding Barrier to Placement Machine

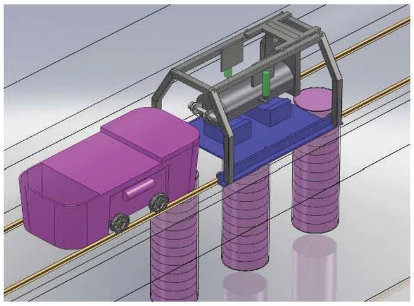


Phase 5
Positioning Shielding Barrier over Borehole

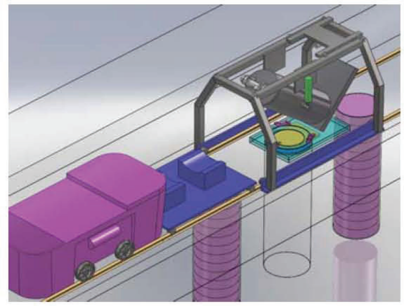


Phase 6
Move Trolley with Empty UFC Transfer Cask to Placement Machine

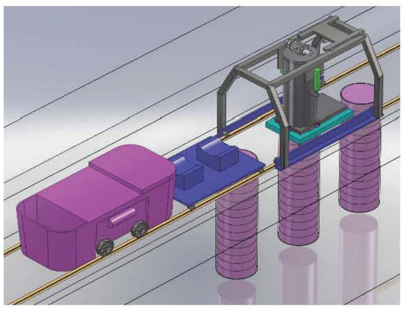
Figure 12: Container Retrieval Sequence of Operations (note: UFC=used fuel container).



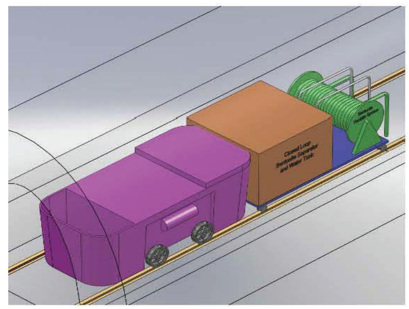
Phase 7
Lift Empty UFC Transfer Cask
using Placement Machine off Trolley



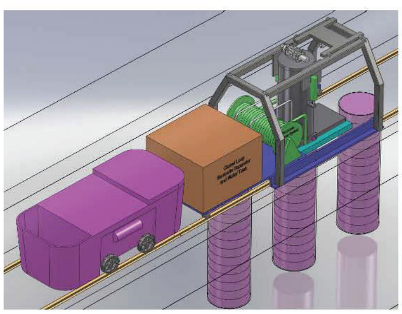
Phase 8
Rotate UFC Transfer Cask with
Placement Machine



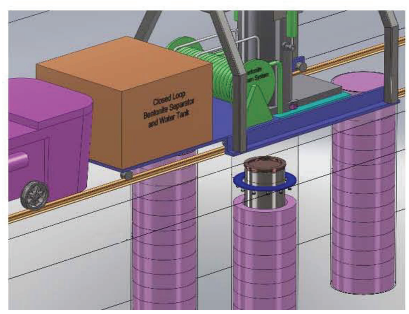
Phase 9
Lower UFC Transfer Cask onto Shielding
Barrier using Placement Machine



Phase 10
Connect Locomotive to Trolley with
Water Tank, Pumps and Bentonite Separator

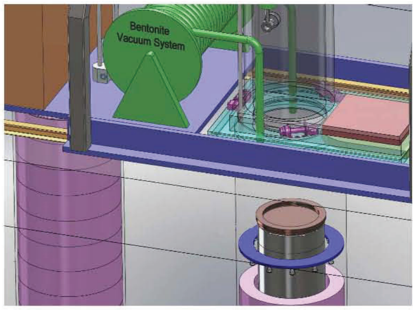


Phase 11
Move Trolley with Water Tank, Pumps and
Bentonite Separator and connect to Services
and Shielding Barrier

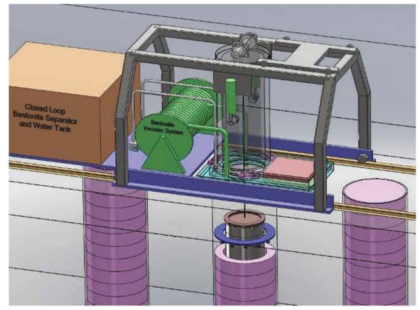


Phase 12
Start Pumps, Slurry Vacuum
and dissolve Bentonite, Continue
until 25% of UFC is Exposed

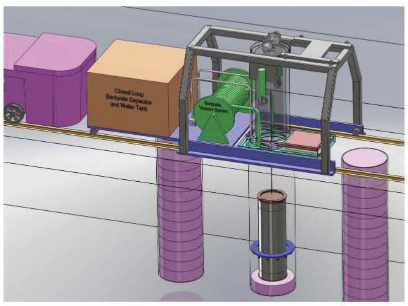
Figure 12: Container Retrieval Sequence of Operations (continued).



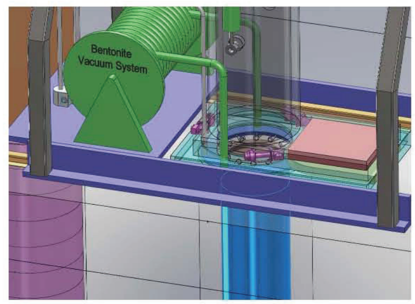
Phase 13
Open Shielding Barrier Sliding Door
and UFC Transfer Cask Sliding Door



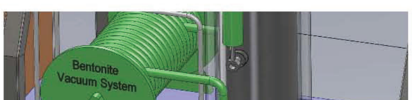
Phase 14
Lower UFC Clamp using Integral Winch
in Transfer Cask and connect to UFC



Phase 15
Continue Dissolving Bentonite
and Removing Slurry to Expose UFC



Phase 16
Raise Spray Ring to Shielding Barrier and
Use Sprays to rinse UFC during Lift



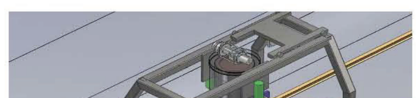


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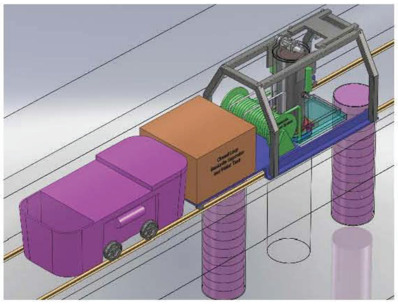
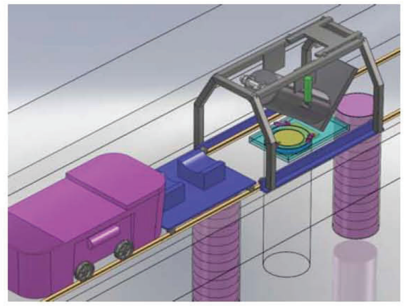
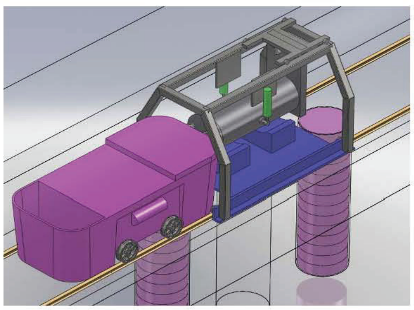
Figure 12: Container Retrieval Sequence of Operations (continued).



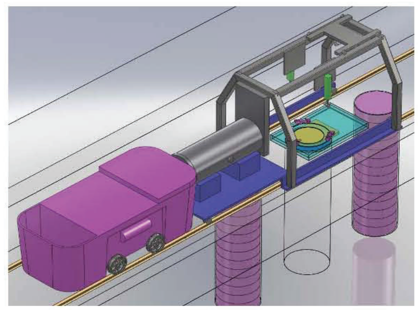
Phase 19
Connect Locomotive to Trolley with Bentonite Separation Equipment and move to Storage



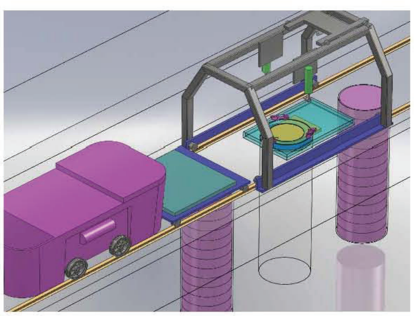
Phase 20
Lift and Rotate UFC Transfer Cask Using Placement Machine



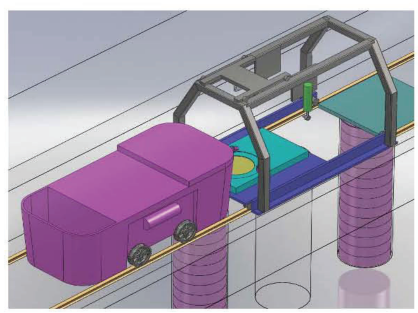
Phase 21
Move UFC Transfer Cask Trolley under UFC Transfer Cask



Phase 22
Lower UFC Transfer Cask onto UFC Transfer Cask Trolley and move to Storage



Phase 23
Move Trolley with Temporary Borehole Cover from Storage to Placement Machine



Phase 24
Lift Shielding Barrier onto Trolley using Placement Machine

Figure 12: Container Retrieval Sequence of Operations (concluded).

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APPENDIX A: INTERNATIONAL WORK ON CONTAINER RETRIEVAL

SKB is responsible for long-term management of used nuclear fuel in Sweden and has developed the Äspö Hard Rock Laboratory to conduct underground experiments and to demonstrate repository technology in a crystalline rock setting. The objective of the international Canister Retrieval Test, conducted between 2000 and 2008, was to demonstrate that the in-situ retrieval of full-scale used fuel containers is technically feasible during any phase of the repository operation, including after full saturation of the bentonite buffer surrounding the container (Eng 2008, SKB 2010). The experiment consisted in placing a full-scale, electrically heated fuel container (canister) in a deposition borehole at the Äspö Hard Rock Laboratory, monitoring the buffer evolution and retrieving the container after the buffer had reached full saturation. The test was conducted as a joint international project, with the participation of eight national nuclear waste management organizations. The test configuration is illustrated in Figure A1.

The project consisted of three major phases: an initial phase that included the installation of instrumentation, buffer and canister in a designated borehole in an experimental tunnel at the 420 level of the Äspö Hard Rock Laboratory. This first stage completed in 2000. The second phase consisted of the buffer saturation period, during which the behaviour of the buffer, the canister and the rock was monitored (Goudarzi et al. 2004, 2005a, 2005b, 2006) The third phase consisted of the actual retrieval of the canister and the evaluation of the collected data (Johannesson 2007, Eng 2008). The primary goals of the project were to verify the buffer saturation model and to conduct a full-scale demonstration of the proposed retrieval method from a borehole after full saturation of the buffer.

The heat load of a full canister was simulated using electric heaters, and the bentonite was hydrated via filter mats mounted vertically between the buffer rings and the rock. The set of parameters monitored during the test included stresses, strain and temperature, temperature in the rock surrounding the borehole and total pressure, suction, relative humidity and temperature in the buffer. The monitoring approach included using two types of measurement for every parameter and extracting a large number of buffer samples for off-site analysis. The monitored parameters included also the forces and displacement of the concrete plug anchored to the rock, that was used was used to provide containment at the upper end of the borehole (Goudarzi et al. 2005a, 2006, Eng, 2008). Temperature was monitored at approximately 100 points. A large number of samples were taken from the buffer blocks for laboratory tests prior to dismantling of the buffer (Johannesson, 2007). The experiment configuration is illustrated in Figure A1.

After samples were taken, the buffer was manually excavated down to approximately one half of the container length, after which removal of the buffer proceeded by using a hydrodynamic process. This process consisted of dissolving the buffer using a 4% $CaCl_2$ solution in water. The solution was pumped into the borehole and stirred by agitators, which resulted in disintegration of the buffer into a slurry that was subsequently pumped from the borehole. The method was implemented as a continuous process in which, after extraction from the borehole, the slurry was separated into bentonite and water by using a centrifuge, and the $CaCl_2$ solution then reused.

The Canister Retrieval Test was a successful demonstration of the feasibility of container retrieval from an in-floor borehole.

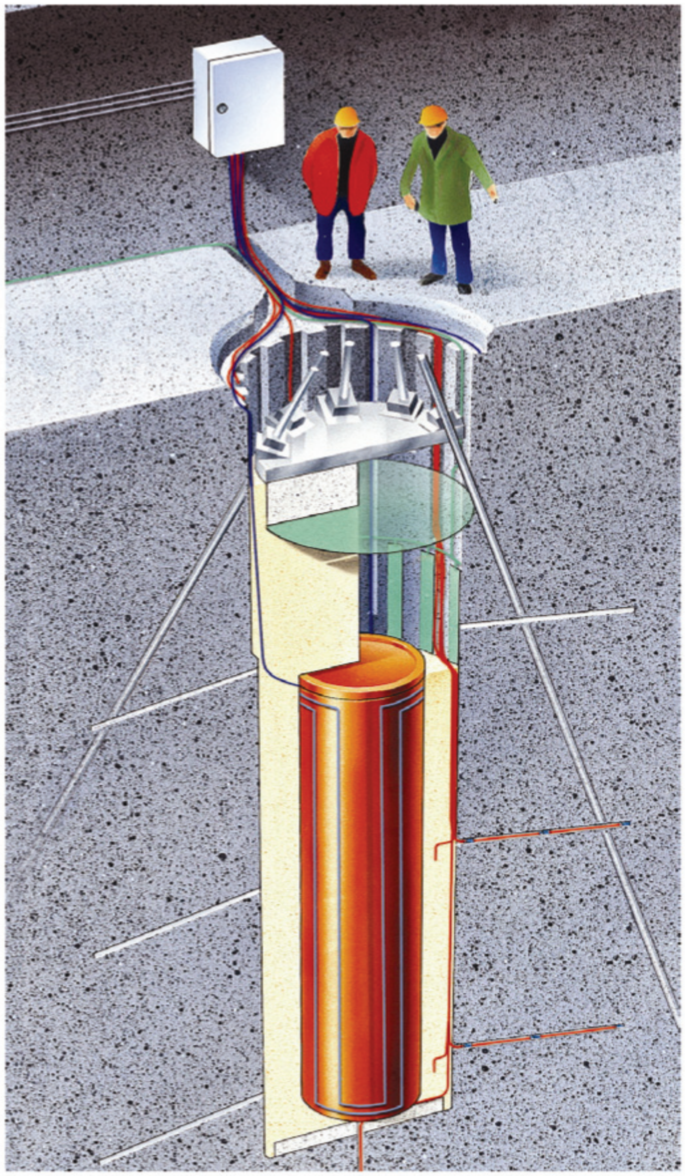

Figure A1. Canister Retrieval Test the Äspö Hard Rock Laboratory in Sweden (From Eng 2008, reproduced with permission from the author)

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