# Used Fuel Container Retrieval from a Deep Geological Repository in Sedimentary Rock

## Horizontal Tunnel Configuration

NWMO TR-2012-17

September 2012

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# ABSTRACT

**Title:** **Used Fuel Container Retrieval from a Deep Geological Repository in Sedimentary Rock Horizontal Tunnel Configuration**
**Report No.:** **NWMO TR-2012-17**
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**Company:** NWMO
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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 sedimentary rock. 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 horizontally on a pedestal of highly compacted bentonite surrounded by bentonite-based backfill materials. The horizontal placement tunnels have a circular cross section and the containers are positioned coaxially with the tunnel, which results in a uniform backfill thickness between the container and the host rock.

The container retrieval system described in this report provides the means to safely retrieve a used fuel container from its location in the repository and to transfer it to the repository surface facilities. The retrieval system key components include a process for dissolution and extraction of the tunnel backfill materials and specially designed equipment to free the used fuel container and place it into a container transfer cask for transport to the surface facilities.

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 for protection of personnel during all the steps of the operation. Monitoring of radiation fields and sampling of the underground environment can be conducted 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 the 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 or sedimentary rock.

This report describes a conceptual design for a used fuel container retrieval system and the container retrieval operation from a deep geological repository constructed in sedimentary rock. The conceptual design for a repository in sedimentary rock uses the horizontal container placement method. In this particular concept a number of containers are placed in a circular cross-section horizontal tunnel, supported by a compacted bentonite pedestal in a coaxial configuration with the tunnel and with a center-to-center spacing of 8 m. The space around and between containers is backfilled with pneumatically installed bentonite pellets. A more detailed description of the repository is provided in Section 2.

The retrieval system design described here provides the capability of retrieving used fuel containers from the repository during a period that includes the operational phase and an extended period during which the repository remains open and its monitoring systems and support continue to operate. This period ends with the final decommissioning and closure of the facility.

Because of the configuration of placement tunnels, containers must be removed sequentially, starting with the container closest to the tunnel entrance. The container placement machine is described at a conceptual level in the reference repository design (SNC-Lavalin 2011). Specially designed equipment would be required for locating and retrieving a container from the placement tunnel.

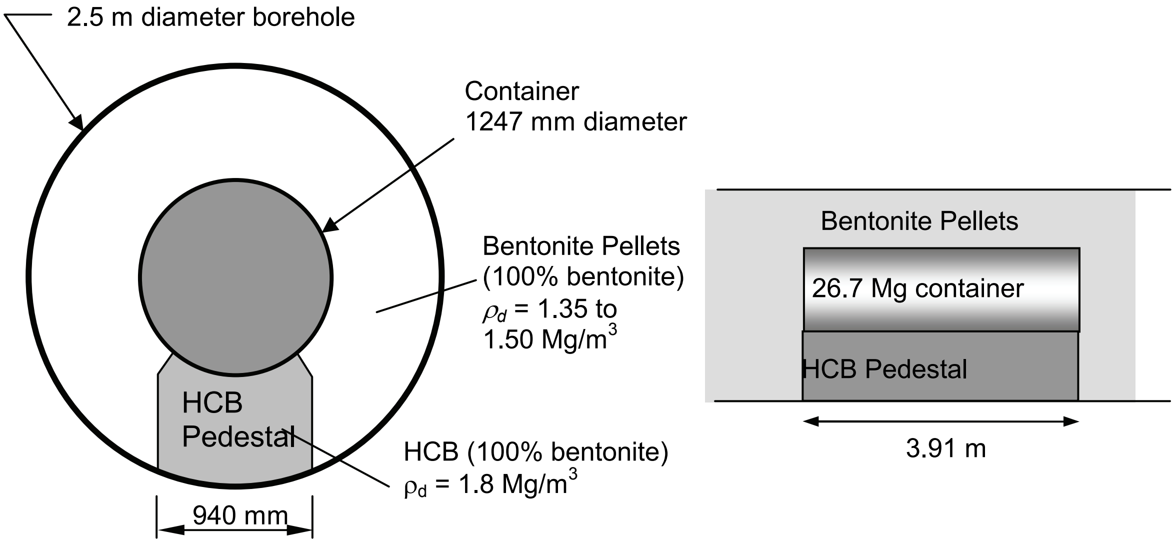

**Figure 1: Position of Used Fuel Container in a Placement Tunnel.**

# 2. REPOSITORY CONCEPTUAL DESIGN FOR SEDIMENTARY ROCK

The APM deep geological repository concept entails encapsulating the used nuclear fuel in durable containers and sealing the containers in a repository constructed at a depth of approximately 500 m in a stable geological formation. This report considers a repository designed for sedimentary rock, using a horizontal tunnel container placement method (SNC-Lavalin, 2011). This method has been used in repository designs by other nuclear waste management organizations such as ANDRA (France) and NAGRA (Switzerland). The NWMO repository concept for sedimentary rock is illustrated in Figure 2.

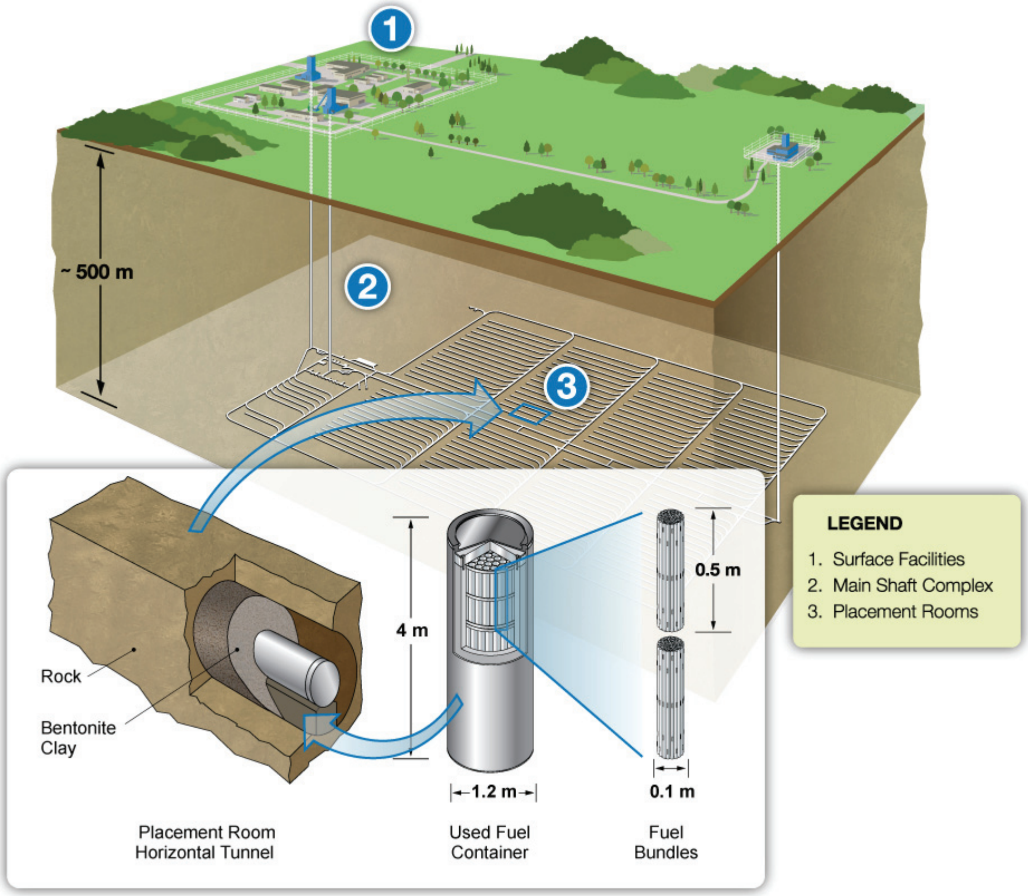

Figure 2: Conceptual Design for a Deep Geological Repository in Sedimentary Rock.

## 2.1 Used Fuel Container

One of the current used fuel container reference designs for a repository constructed in sedimentary rock uses a double vessel consisting of an outer, corrosion-resistant copper shell and an inner carbon steel vessel dimensioned to hold three carbon-steel fuel baskets. Each of the three baskets holds two layers of 60 used CANDU fuel bundles, which yields a total container capacity of 360 bundles.

The container's copper shell provides a corrosion barrier with a design life in excess of $10^5$ years; the inner steel vessel, which is designed to sustain an isotropic pressure of 45 MPa, provides the required mechanical support. An illustration of the IV-25 copper container is shown in Figure 3, and the main design parameters for both the copper and the steel vessel are given in Table 1 and Table 2 respectively.

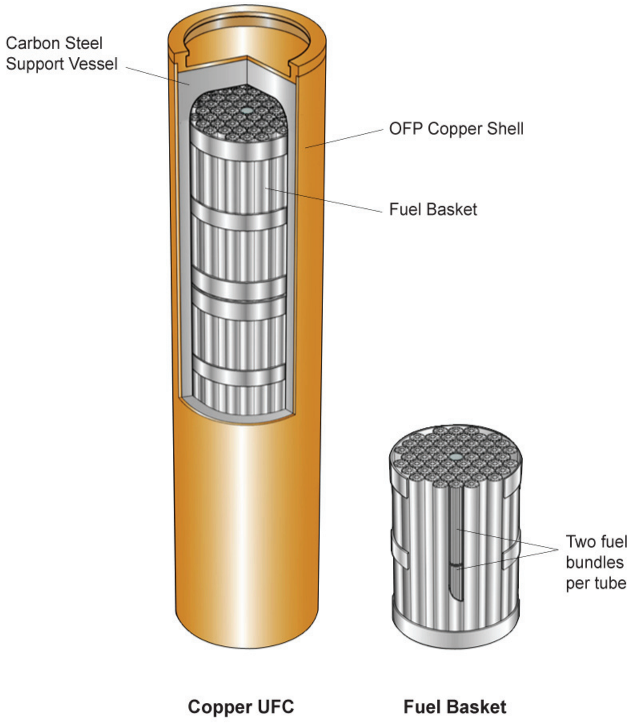

**Figure 3: Example Copper Used Fuel Container.**

**Table 1: Copper Shell Parameters**

| 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: Inner Steel Vessel Parameters**

| 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 |

### 2.2 Underground Facilities Layout

The underground repository layout includes horizontal perimeter drifts and cross-cuts connecting eight panels of used fuel container placement tunnels, as illustrated in Figure 4 (SNC-Lavalin 2011).

The container placement tunnels have a centre-to-centre spacing of 20 m, and each has a single access from a cross-cut tunnel. The entrance to each placement tunnel has a 50 m turning radius designed to allow the movement of heavy equipment using rail cars. The length of the placement tunnels is 412 m. The used fuel containers spacing along the tunnel is 8 m center-to-center. The container density is designed to minimize the repository underground footprint while satisfying thermal design requirements.

Within the placement tunnels, the containers are placed on a compacted bentonite pedestal and the volume around and between containers is backfilled with bentonite pellets that will eventually saturate and form the primary isolation barrier between the container and the rock. The backfill is designed to inhibit groundwater flow, blocking or delaying the transport of radioactive species. The backfill will also inhibit the development of bacteria, which will prevent the occurrence of certain corrosion agents near the container surface. When full, each container placement tunnel will be closed with concrete bulkhead. A longitudinal section of a placement tunnel is shown in Figure 5 (SNC-Lavalin 2011). The concrete bulkhead will act as a retainer against the potential swelling of the room backfill as the bentonite saturates. In the typical low permeability of sedimentary formations, saturation of the backfill is expected to take a much longer time than the repository preclosure period.

At the time of repository closure, a bentonite seal as that illustrated in Figure 5 will be installed next to the concrete bulkhead. This can be followed by a second concrete bullhead, and these three components will constitute the final placement tunnel closure seal.

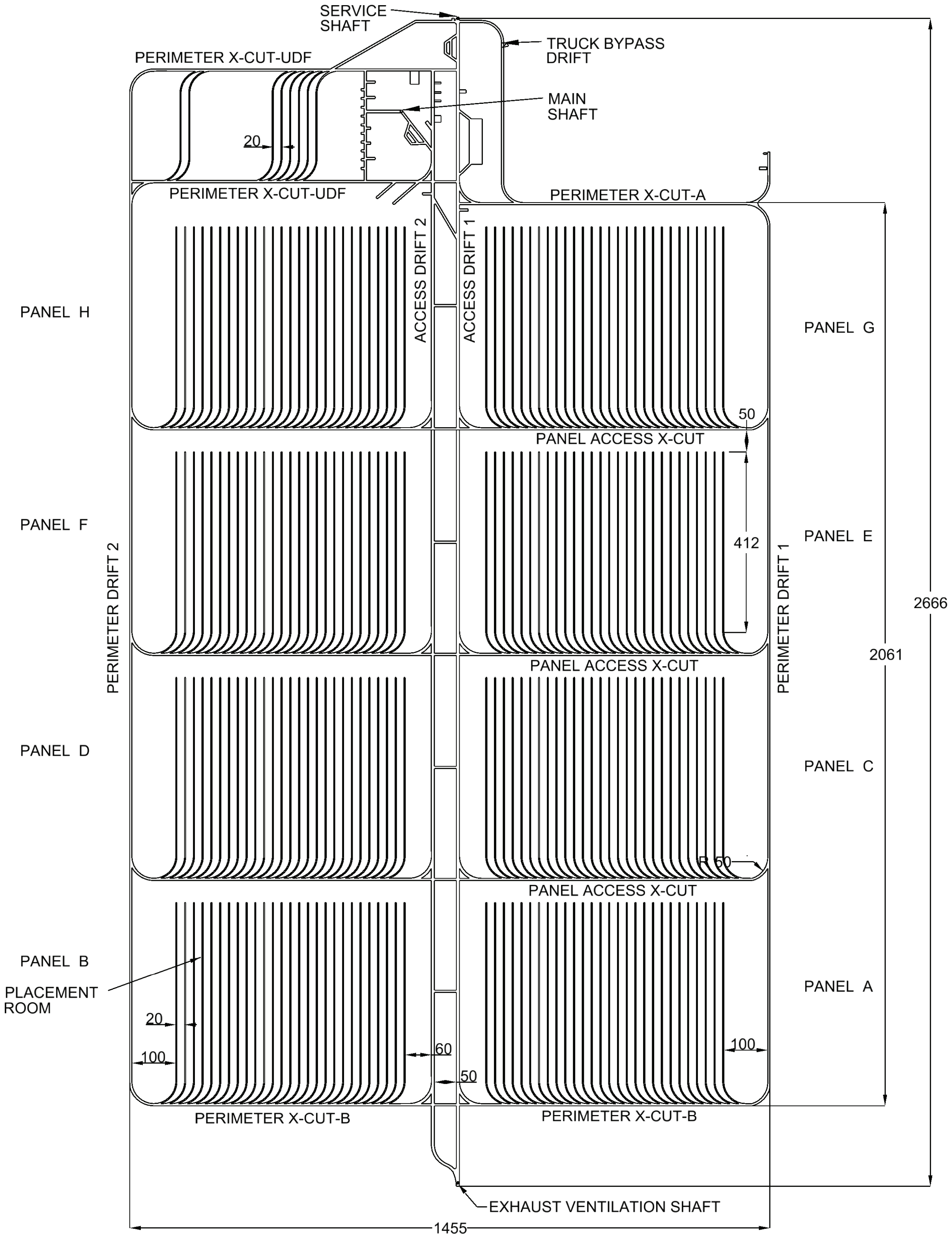

Figure 4: Example Underground Repository Layout in Sedimentary Rock.

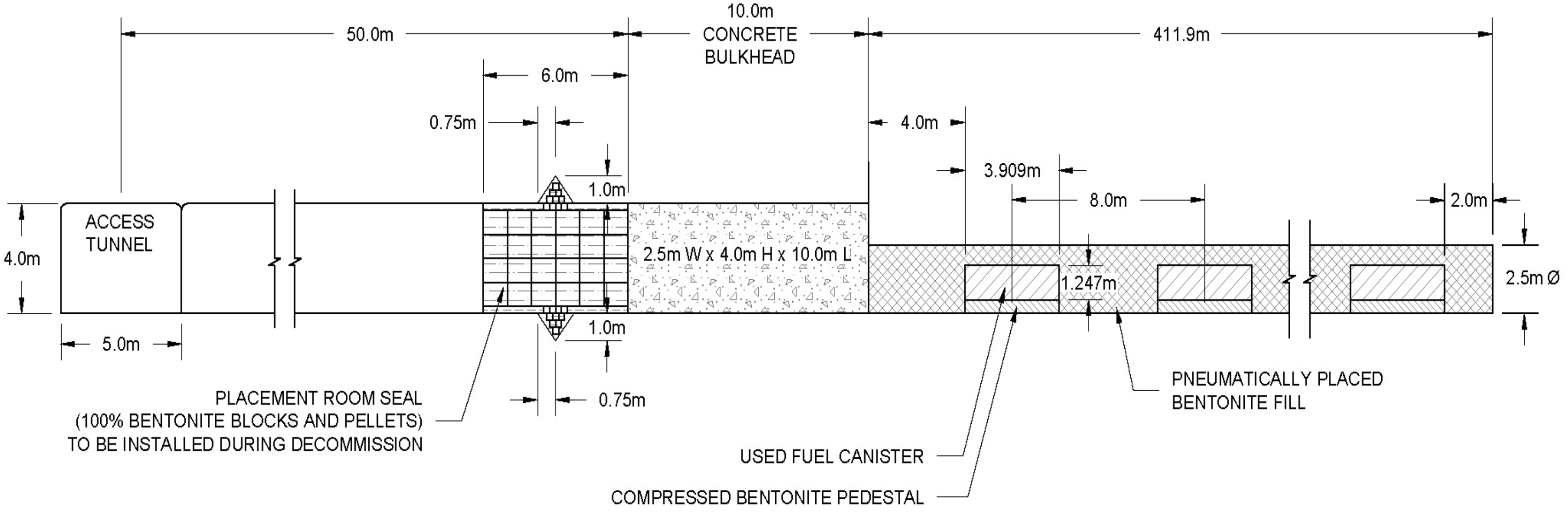

**Figure 5: Horizontal Tunnel Longitudinal Section.**

# 3. RETRIEVAL SYSTEM DESIGN

## 3.1 General System Requirements and Assumptions

The primary requirement of the used fuel container retrieval system is to provide the capability of retrieving a used fuel container from an arbitrary location in the repository during a time period that encompasses the repository operational phase and the monitored preclosure period. Container retrieval during the postclosure period would also be possible but it would require additional excavation to gain access to the repository.

For the purpose of this study, it is assumed that the container retrieval operation occurs during a period when the facility shafts and access tunnels are open and that ventilation, hoists and other services remain operational.

The configuration of the horizontal placement tunnels requires that both container placement and container retrieval be sequential operations. Therefore, accessing a target container from an arbitrary location in the repository requires that all the containers placed in that tunnel after the target container also be retrieved. Since the sequential retrieval operations are essentially identical, only the retrieval of a single container is described here.

Although the repository conventional services and container placement equipment are assumed to be functional and available for the operation, specially designed equipment will be required for freeing and retrieving the container from its position in the placement tunnel and placing it into the transfer cask for subsequent transport to the surface facilities. This equipment is described in Section 3.2.

Safety is a primary requirement for the retrieval processes. Consequently, the container retrieval system and auxiliary equipment are designed to provide appropriate radiation shielding and personnel protection throughout the container retrieval operation.

## 3.2 System Description

The used fuel container retrieval operation would require the use of conventional mining equipment to remove the placement tunnel closure seals made of concrete and clay and to excavate and remove tunnel backfill up to a certain distance of the container to be retrieved. This equipment will not be described in detail in this report.

In addition to the conventional equipment, four major components of the retrieval system, specially designed for the purpose, are required. The specialized equipment consists of a container retrieval machine (CRM), a container transfer cask (CTC), a power ram module (PRM) and a hydrodynamic backfill removal system. These four components and their function are briefly described in Table 3. Figures 6a, 6b and 7 show the CRM and the CTC. All the equipment is designed to move on rails. In the case of the backfill removal system, its components are mounted on a rail car, brought into the placement tunnel and connected to the CRM when required.

A more detailed description of the system and the retrieval operation is given in Section 4.

**Table 3: Key Container Retrieval Equipment**

| Retrieval System Components | Description and Function |
|---|---|
| Container Retrieval Machine (CRM), consisting of an integrated Advance Frame and Guide Cylinder unit and a detachable Power Module. | The three major components are the Advance Frame, the Guide Cylinder and the Power Module; all three capable of moving on tracks. The Advance Frame is used to locate and free the container from the tunnel backfill and, subsequently move it inside the CRM Guide Cylinder. The power required for its operation is supplied by the CRM Power Module, which can be decoupled from the Guide Cylinder when required. |
| Container Transfer Cask (CTC), equipped with two shielded gates and two sets of lifting trunnions. | This unit consists of a cylindrical cask provided with two shielded gates and two sets of lifting trunnions for crane handling. The CTC is designed for the safe transport of the UFC from the placement tunnel to the surface facilities. The CTC is moved using a dedicated trolley and a locomotive that has the capability to operate the CTC shielded doors. The CTC shielded doors can also be operated by the CRM and the Power Ram Machine. |
| Power Ram Machine | The PRM consists of a self powered unit and a long ram designed to transfer the container from the CRM to the CTC. It is placed behind the double-door CTC after the CTC is linked to the CRM guiding cylinder. Then, the ram is extended to connect with the container, which is supported by rollers inside the CRM guiding cylinder. Once the Ram has "grabbed" the container it pulls it into the CTC. After this is accomplished, the Ram decouples from the container and from the CTC and it is removed from the tunnel. |
| Backfill Removal System | This is a closed-circuit process system designed to supply to the CRM a $CaCl_2$ solution that is used to disintegrate the solid bentonite around the container converting into a slurry form, and to remove it from the tunnel. The system is moved into the tunnel and connected to the CRM. It supplies the solution and recovers the slurry. The system includes a decanter centrifuge that separates the slurry components into solid bentonite and a liquid phase. The liquid phase is pumped back into the solution tank and recycled through the process. |

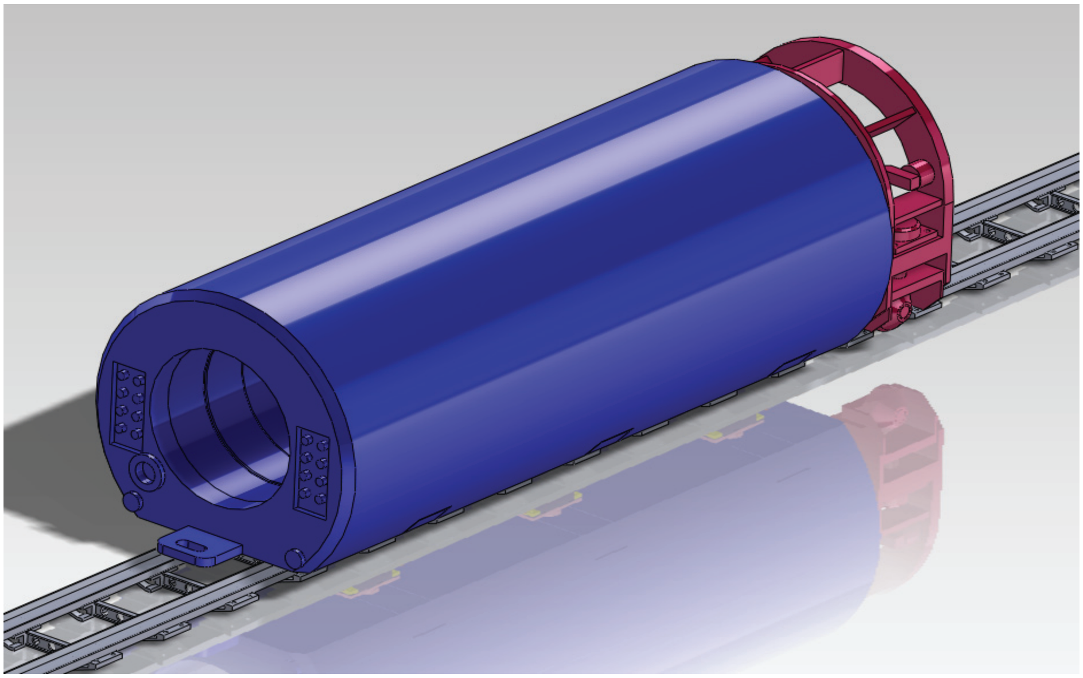

**Figure 6a: Container Retrieval Machine with shielding door open and Advance Frame retracted into the Guide Cylinder.**

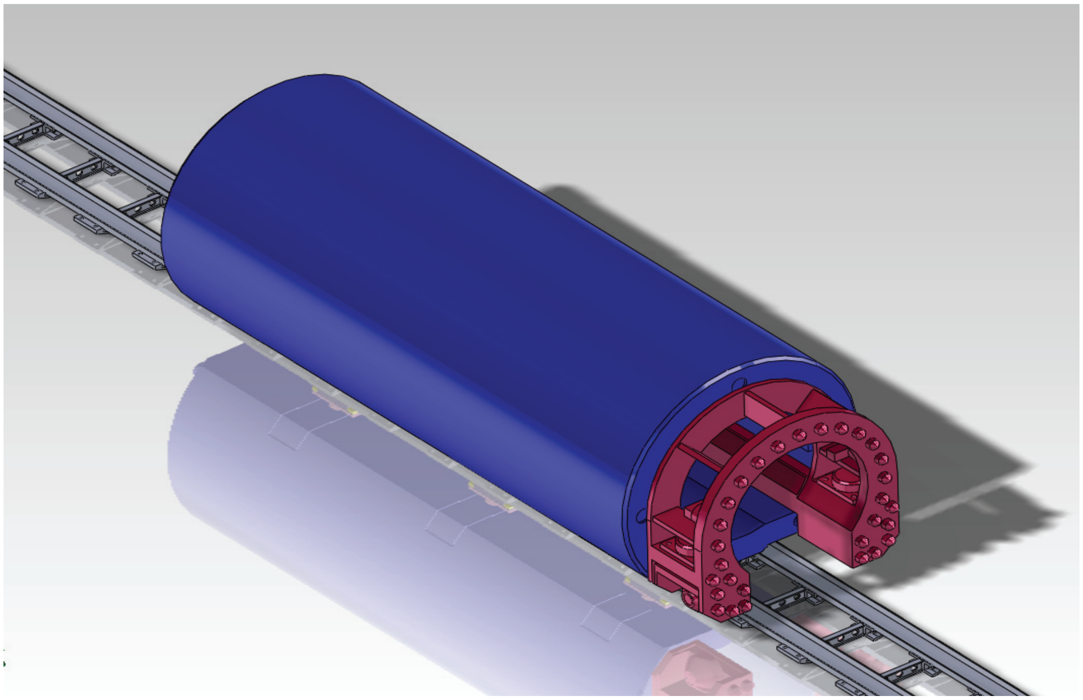

**Figure 6b: Container Retrieval Machine image showing the face of the Advance Frame.**

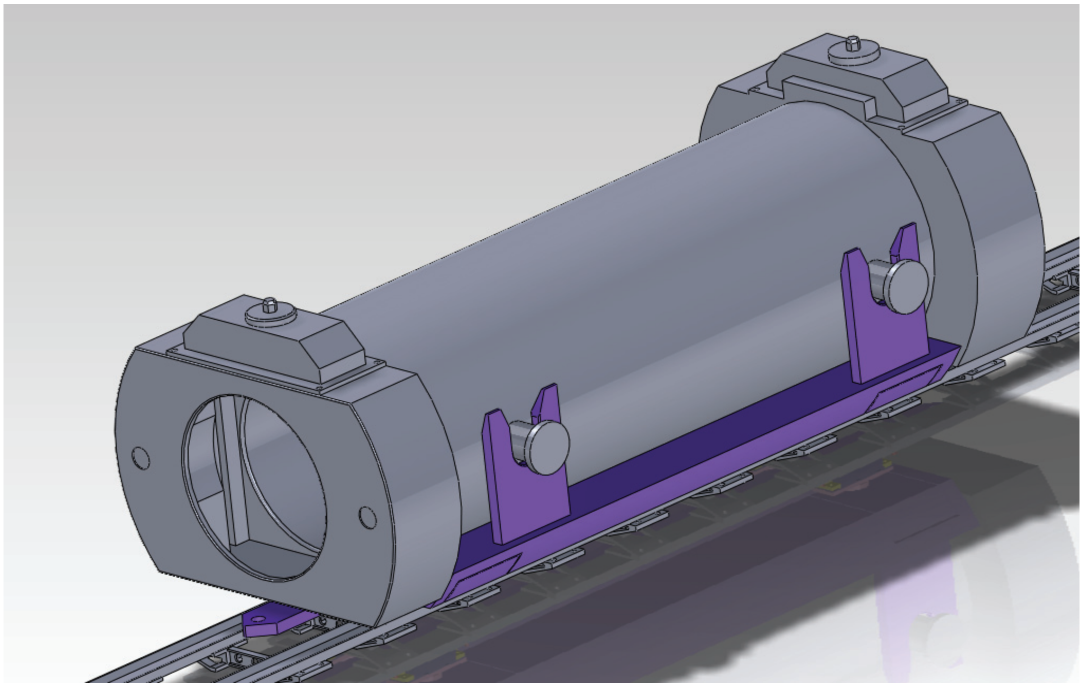

**Figure 7: Container Transfer Cask on transport trolley, with shielding doors in the open position.**

# 4. CONTAINER RETRIEVAL OPERATION

The major steps in a container retrieval operation are:

- Getting access to the target used fuel container
- Freeing the container from the tunnel backfill
- Loading the container into the Guide Cylinder
- Connecting the Container Transfer Cask to the Guide Cylinder
- Connecting the Ram Machine to the Transfer Cask
- Moving the container from the Guide Cylinder into the Transfer Cask
- Transferring the container to the repository surface facilities.

These steps are described in detail in the Sections 4.1 and 4.2.

## 4.1 Getting Access to the Target Used Fuel Container

Accessing a container placement tunnel, perhaps many decades after the container placement operations were completed, would present a unique opportunity to examine the condition of the tunnel, the seals and engineered barriers, and also of the containers. Therefore, in addition to the specific steps required to free and recover a container, material sampling and analysis will take place during the operation. The steps required for getting access to the container include:

- Removal of tunnel bulkhead and bentonite clay seal
- Excavation of a specified length of tunnel backfill
- Installation of low-profile rail tracks
- Restoration of services in the tunnel (electrical, ventilation, air and radiation monitoring)
- Moving the container retrieval machine into the tunnel
- Moving into the tunnel and connecting the bentonite dissolution system
- Moving the CRM advance frame towards the open face of the backfill
- Activating the backfill removal system

These steps are described in further detail below. Prior to starting the operation, groundwater samples from the EDZ peripheral to the bulkhead will be taken and analyzed. It must be noted that although radiation monitoring is not mentioned at each step, it is a continuous task throughout the operation. The occurrence of high radiation fields or the presence of radioactive contaminants in the work environment during container retrieval are extremely unlikely since appropriate shielding is provided by the retrieval system components and appropriate ventilation will be provided. However, continuous monitoring of gamma fields, as well as sampling and analysis of the air and groundwater will be conducted throughout the operation in all areas accessible to personnel.

### 4.1.1 Removal of the Concrete Bulkhead

The drill and blast method is deemed unsuitable for use in the retrieval operation; the use of explosives could be very disruptive in a repository either partially or completely full. Therefore, a non-explosive expansion agent will be used to break down the concrete bulkheads. 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. An illustration of this process, used to break down a large concrete block, is shown in Figure 8.

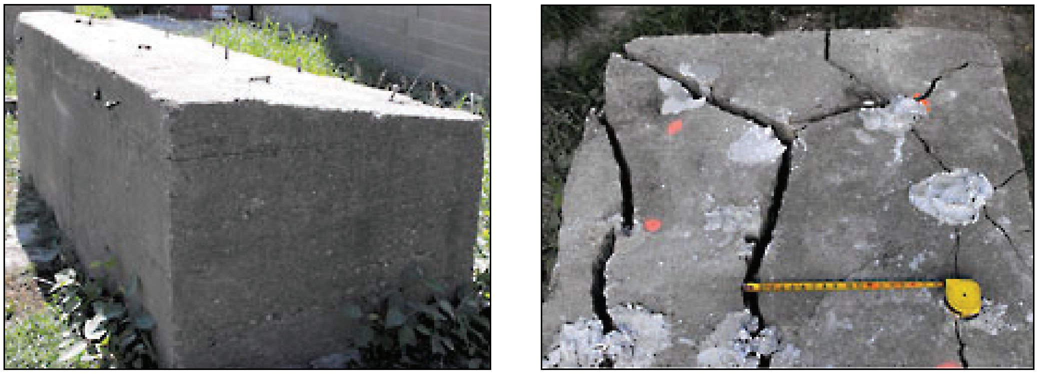

**Figure 8: Use of expansive demolition agent in concrete.**

After the expansion agent swells generating sufficient pressure to break the concrete, the concrete fragments are removed using conventional methods. This method does not cause any ground vibrations, generates only a minimal amount of gases and is relatively easy to apply. In the case of a large repository tunnel bulkhead this is envisaged to be a time-consuming but inherently safe operation. Conventional mining equipment (truck and loaders) would be used for removal and transport of the concrete fragments to the service shaft.

### 4.1.2 Removal of the Tunnel Bentonite Seal

The tunnel bentonite seal located next to the concrete bulkhead will need to be removed. It would be important to assess the condition of this seal and its effectiveness. Therefore, before the large-scale removal of seal material takes place, samples would be taken from different seal locations for laboratory tests. The sampling would likely be done by horizontal core drilling according to a specified pattern. Groundwater samples and, possibly, rock samples will also be taken. The results from sampling and analysis of the seal material would provide useful information for the assessment of repository performance. Accordingly, the 4 m long bentonite seal will be removed in a number of steps, coordinated with the extraction of material samples.

Depending on the hardness of the compacted bentonite blocks in the seal, their removal may be conducted using of either mechanical or hydrodynamic methods. This will be resolved at the time of the operation. The hydrodynamic method would be similar to that described in Section 4.1.3 as the method for removal of tunnel backfill.

### 4.1.3 Removal of Tunnel Backfill

After removal of the tunnel clay seal and concrete bulkheads, the backfill will be excavated by mechanical means up to a certain distance from the container. This distance should be as close as possible to the face of the container lid so that the CRM guide cylinder, which will move on tracks, can be brought close enough to the container for the retrieval operation.

The mechanical tool for removal of backfill is assumed to be a remotely operated roadheader. This will allow the operation to safely remove backfill up to distances of less than one meter of the container even if the radiation fields exceeded occupational safety limits. The machine would be fitted with sensors and a guiding system appropriate for the operation. A second robot will be used to install a temporary shield against the end of the excavation so that the task of laying the tracks can be accomplished in a safe radiological environment. Following installation and inspection of the track system, the temporary shield can be removed (also using robotic equipment) and the CRM and the bentonite removal system can be brought into the tunnel and connected.

Once the CRM is positioned at a specified distance from the container, the operation of removing the tunnel backfill materials surrounding the container will start. This operation essentially consists of the disintegration of the tunnel backfill using water jets mounted on the CRM advance frame. As the solid bentonite is turned into a slurry the CRM advance frame can be moved forward, around the container, until a sufficient portion of tunnel backfill is removed so that the advance frame roller beds can be positioned to lift the container. The hydrodynamic method is described in detail in Section 4.1.4. The removal of backfill in a slurry form is continued until the container is clear of backfill and can be moved into the CTC.

### 4.1.4 Removal of the bentonite surrounding the Container

The method used to remove the bentonite surrounding the used fuel container is based on the same principles of the method demonstrated in the Canister Retrieval Test, conducted at the Äspö Hard Rock Laboratory in Sweden (Johannesson, 2007; Eng, 2008). The process demonstrated in the test consists of using jets of a 4% $CaCl_2$ water solution impinging directly on bentonite buffer blocs placed around the test container. This solution alters the chemical bonds in the bentonite, turning it into a slurry that is subsequently collected and pumped to a decanter centrifuge.

The main components of the buffer removal system include a tank for mixing the solution, a pump and hoses to deliver the $CaCl_2$ solution to the advance frame water jets, and a vacuum system to collect the resulting bentonite slurry from the tunnel floor and transfer it to a decanter centrifuge where it is separated into bentonite in granular form and a liquid phase. A diagram and a picture of a decanter centrifuge are shown in Figures 9 and 10.

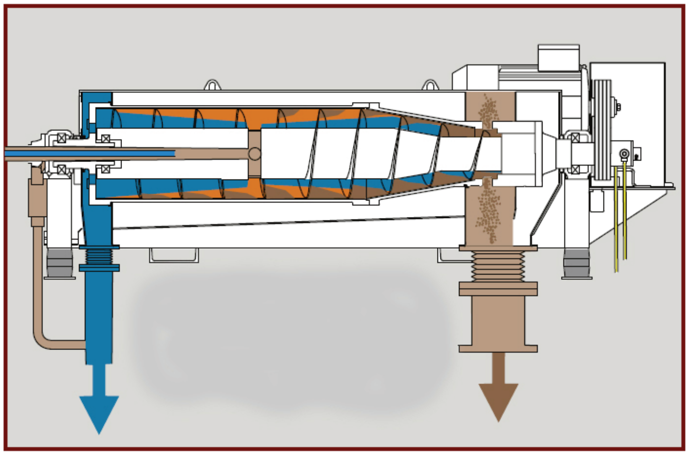

**Figure 9: Diagram of Bentonite Decanting Centrifuge.**

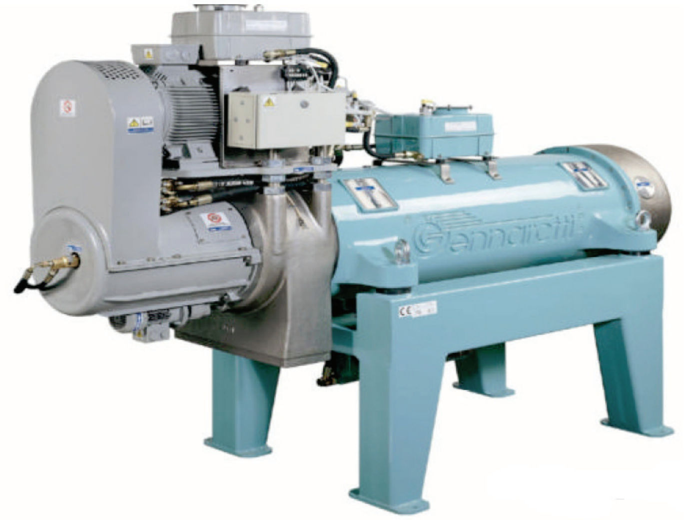

Figure 10: Slurry Decanting System for industrial applications.

The centrifuge separates the solid and liquid phases, with the liquid phase routed to the solution supply tank and recycled. The bentonite is recovered in granular form and temporarily stored on location. This method can be implemented as a continuous process until a sufficient portion of tunnel backfill is removed so that the container can be fully supported by the CRM advance frame roller beds. At his point the pedestal might have been fully or partially removed, however, even if a residual portion of bentonite pedestal remains under the container, the advance frame is designed such that the roller beds supporting the container do not interfere with the pedestal, and the CRM advance frame can lift the container and move it into the CRM guide cylinder.

### 4.2 Container Recovery and Transfer

The required equipment and sequence of steps for removing the container from the tunnel are described below. The equipment includes:

- container retrieval machine,
- container transfer cask,
- power ram machine,
- locomotive and trolley used to move the container transfer cask in and out of the placement tunnel.

By design, when the used fuel container is resting on the CRM advance frame roller beds, its axis will be on the vertical plane that contains the tunnel axis. The advance frame roller beds are supported by horizontal beams that can be lifted or lowered adjusting the container height. This allows the frame to lift the container from the pedestal, as described in Section 4.1.4.

As the CRM advance frame moves the container into the guide cylinder, water jets keep spraying $CaCl_2$ water solution on the container surface to remove any residual buffer material. Once the advance frame is fully retracted, the side beams are lowered, bringing the advance frame roller beds to their lowest position. This causes the container to move down until it rests on the guide cylinder roller beds, which aligns the container axis with the guide cylinder axis as well as with the rest of the retrieval equipment. These steps are illustrated in Figures 11 to 15.

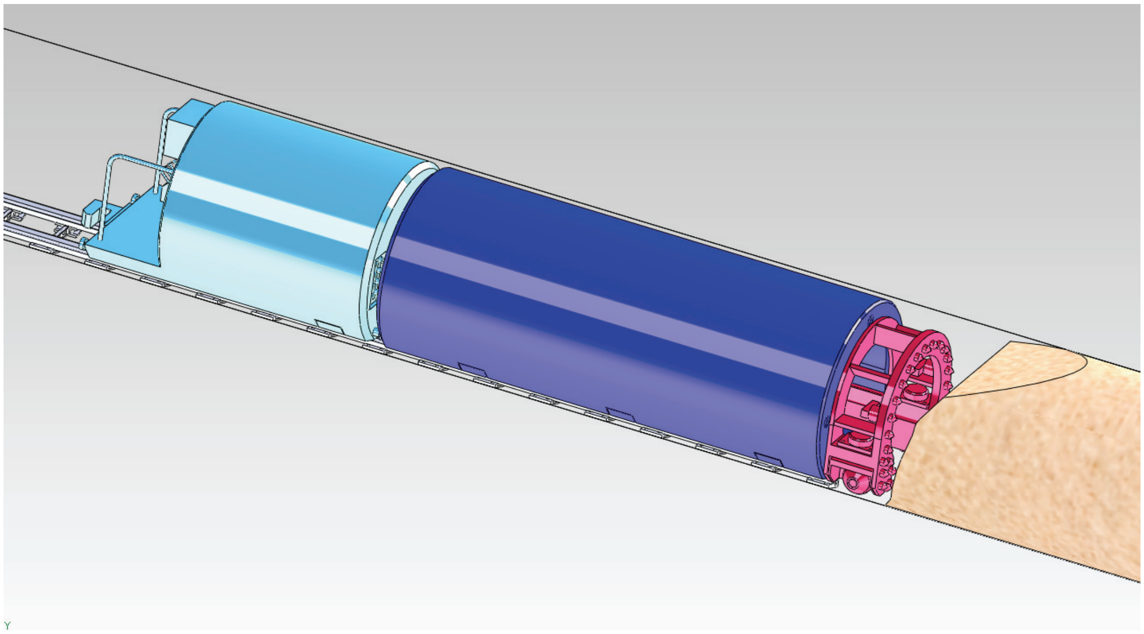

**Figure 11: Container Retrieval Machine, with Power Module attached, is positioned to initiate the removal of tunnel backfill around the Container.**

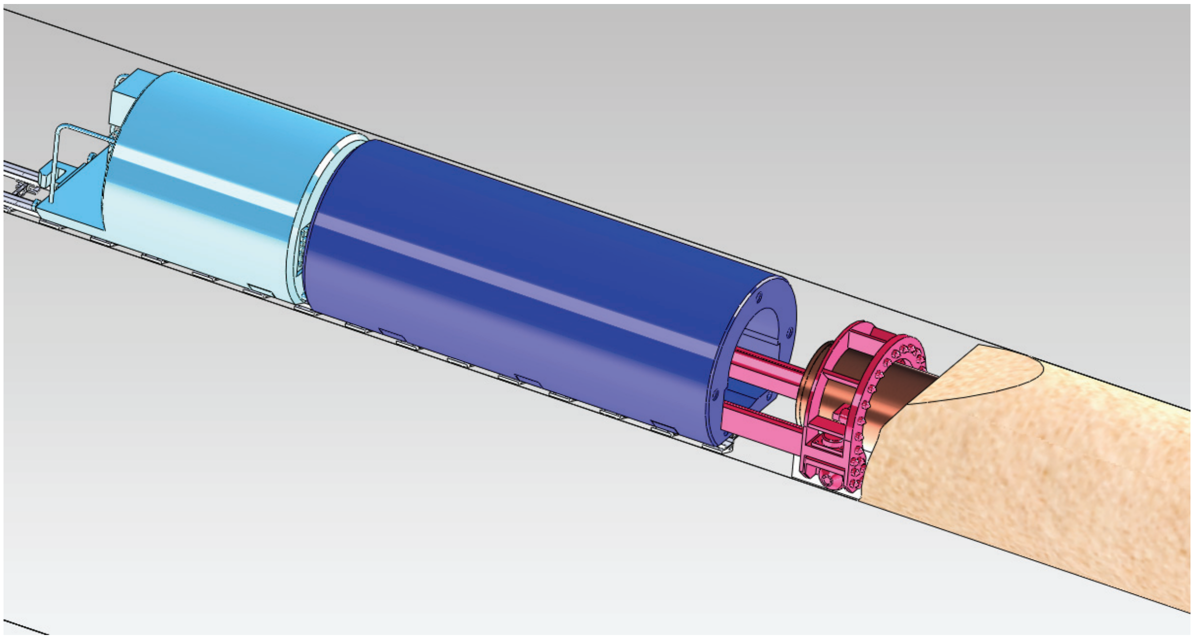

**Figure 12: The Advance Frame extends out of the Guide Cylinder as dissolution of the backfill progresses (for simplicity, the slurry removal system, is not shown in the figure).**

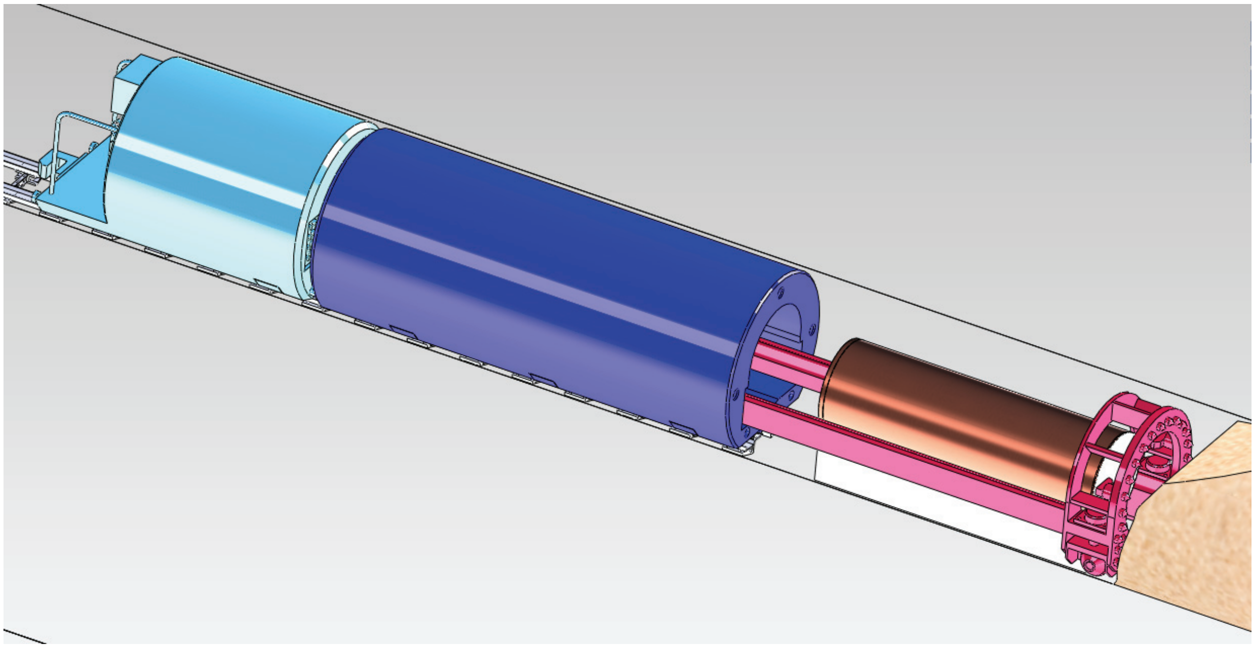

**Figure 13: The Advance frame Roller Beds lift the container, separating if from any residual portions of the pedestal.**

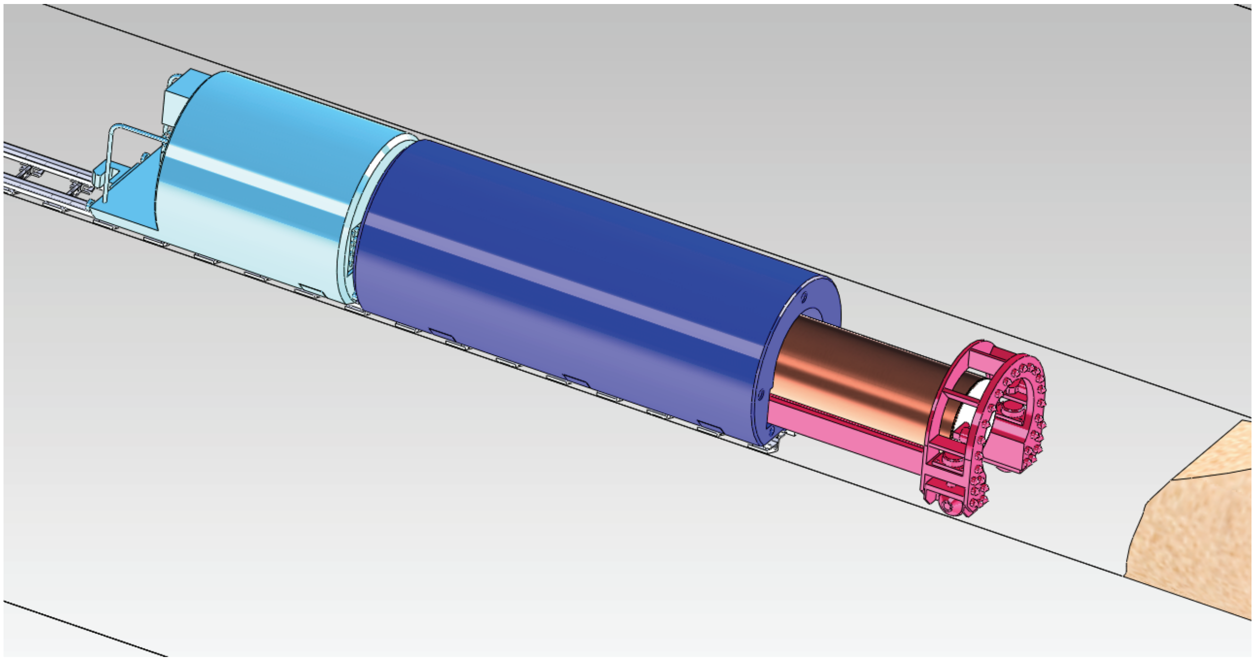

**Figure 14: The Advance Frame retracts into the Guide Cylinder as water jets continue to spray the container to remove any backfill residue.**

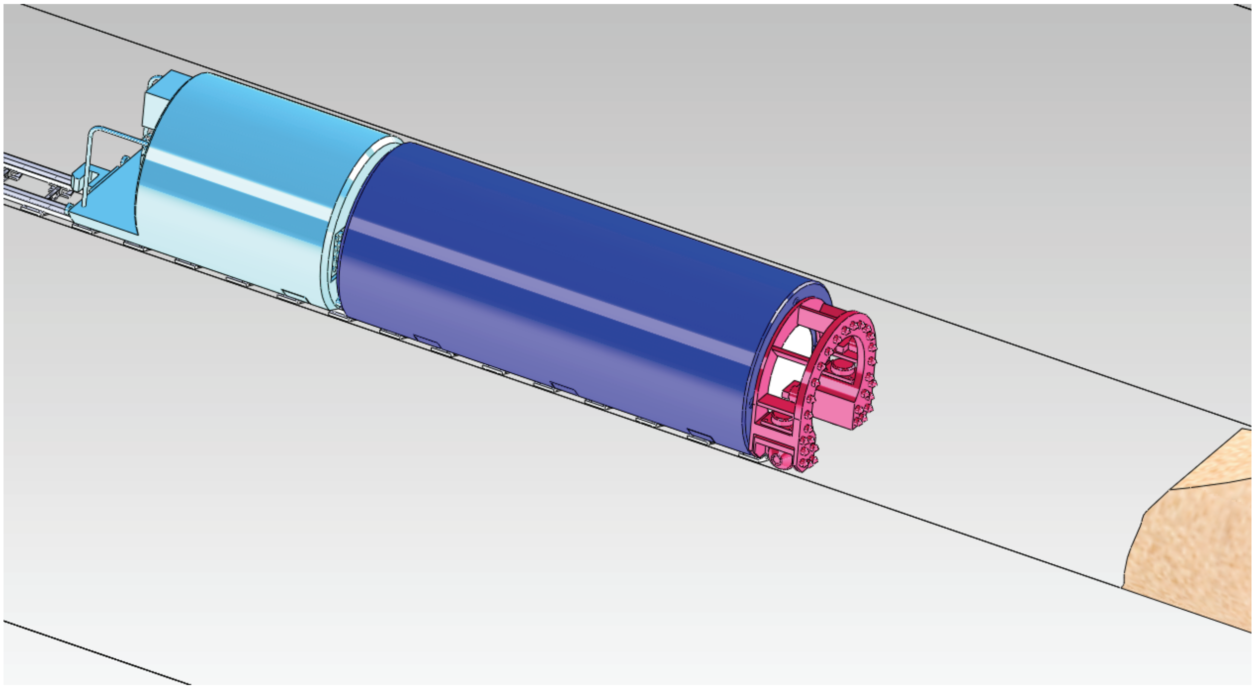

**Figure 15: After the Advance Frame is fully retracted into the Guide Cylinder, the side bars are lowered and the container rests on the Guide Cylinder Roller Beds, in precise alignment with the tunnel axis.**

The next steps in the operation are to open the shielded door in the CRM guide cylinder, disconnect the CRM Power Module from the Guide Cylinder and remove it from the tunnel.

Subsequently, the CTC is brought into the tunnel (mounted on its dedicated trolley) and placed next to the CRM Guide Tube (Figure 16). Then, the PRM is brought into the tunnel and connected to the CTC. With the shielding doors in both the CTC and the CRM open, the Ram guide is aligned with the CTC and the CRM (Figure 17). Then, the Ram is extended and connected to the container lid. As the ram retracts, the container is moved from the CRM Guide Tube into the CTC. The sequence of operations is illustrated in Figures 17, 18 and 19. Subsequently, the CTC shielded doors are closed and the PRM is disconnected and removed from the tunnel. A locomotive is then moved into the room and connected to the CTC trolley. The loaded CTC is then removed from the tunnel and transferred to the hoisting area for transport to the surface facilities.

When coupled to the CTC, the PRM has the capability of actuating the CTC shielded doors. This allows the PRM to verify the alignment of the Ram with the CRM and the CTC, and to close the CTC shielded doors after the transfer operation is completed.

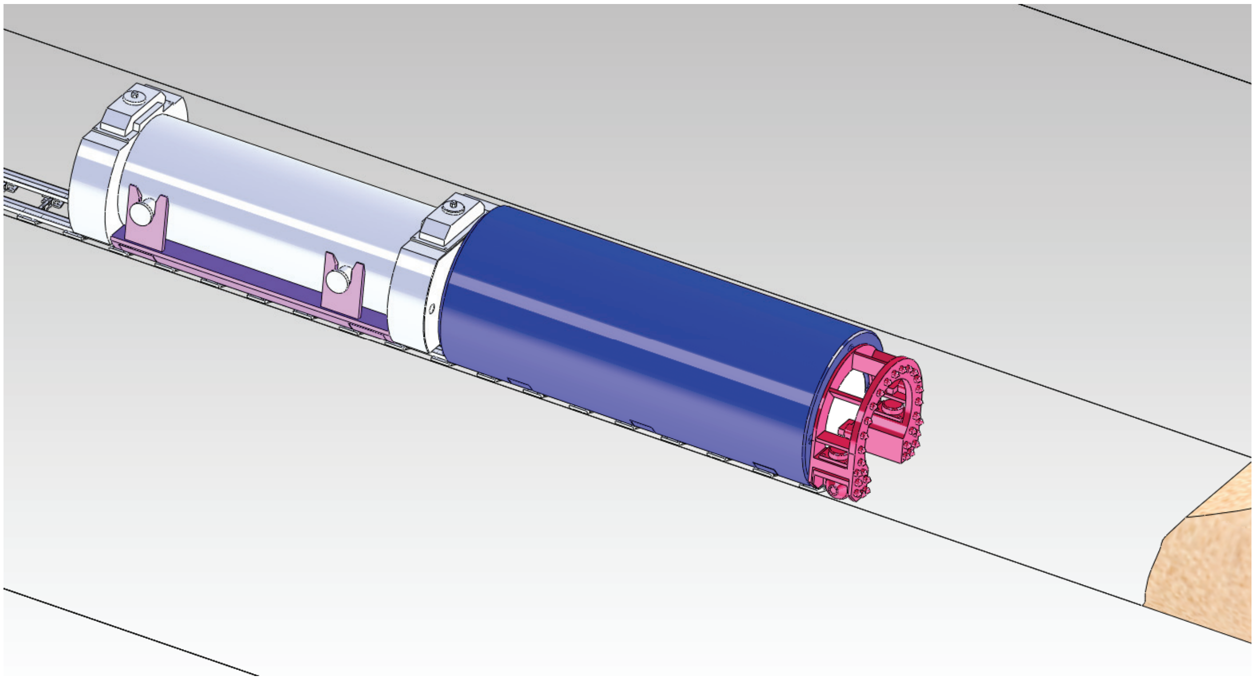

**Figure 16: The Container Transfer Cask is brought into the tunnel and placed next to the retrieval machine Guide Cylinder.**

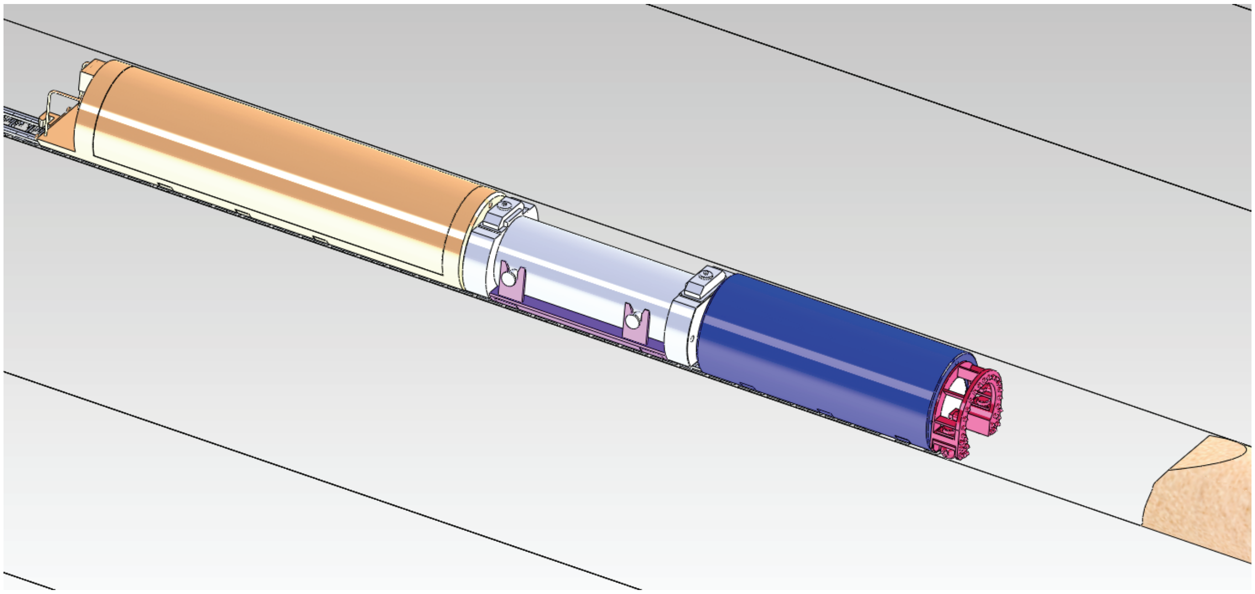

**Figure 17: The Power Ram Machine is brought into the tunnel and connected to the Container Transfer Cask. Subsequently, it opens the shielding doors in both the transfer cask and retrieval machine Guide Cylinder.**

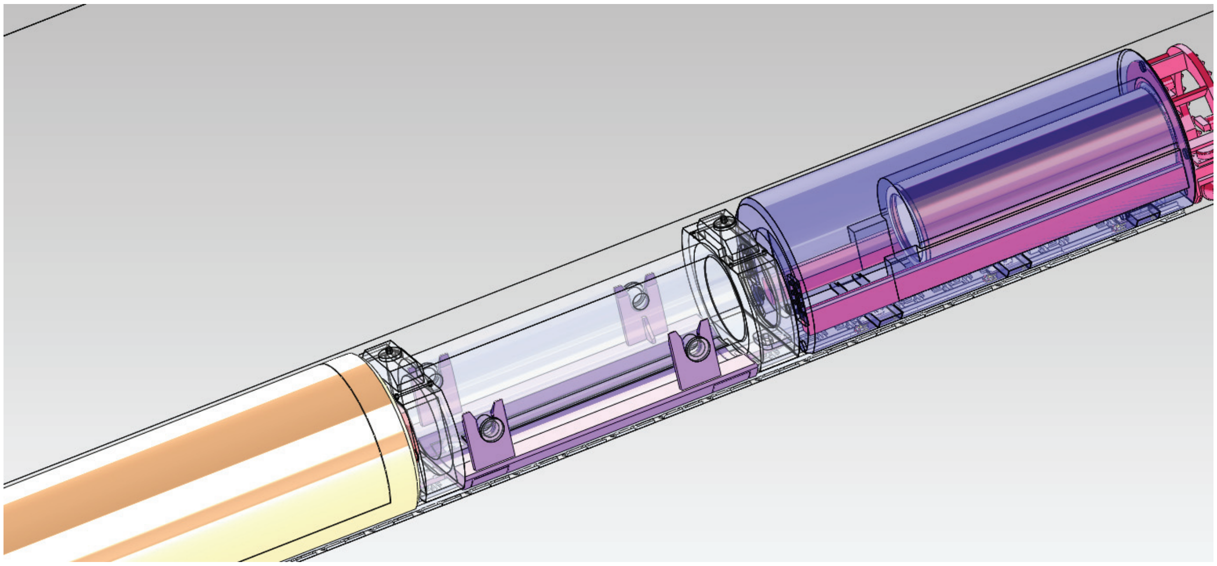

**Figure 18: The Power Ram is aligned with the transfer cask and retrieval machine Guide Cylinder.**

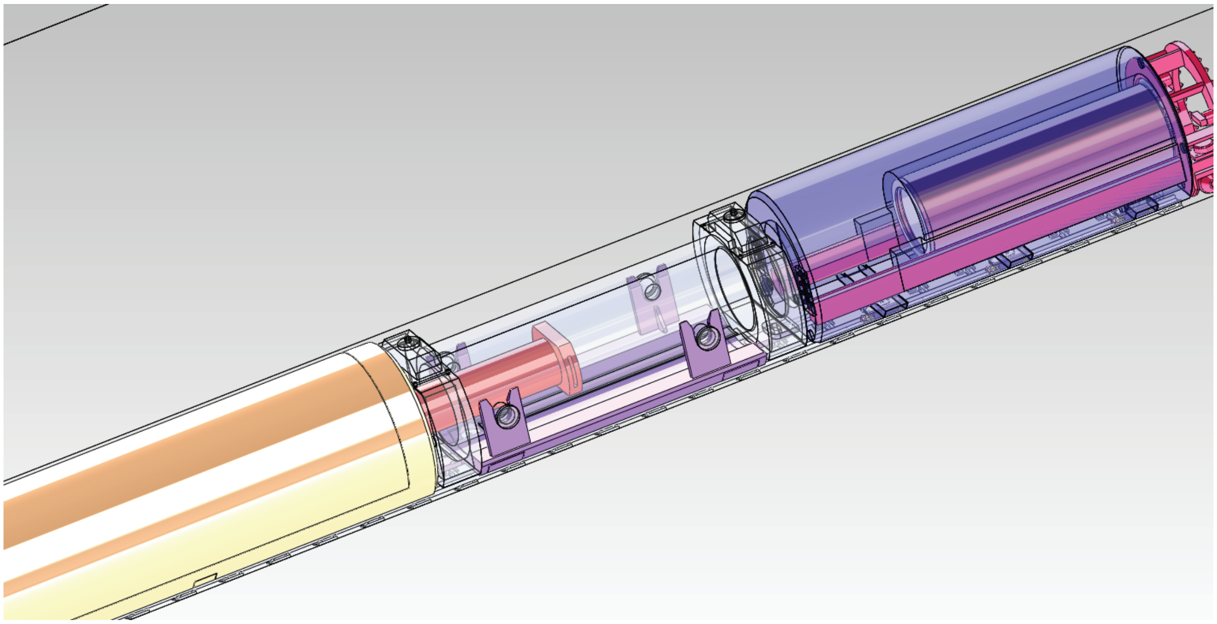

**Figure 19: After verifying the alignment of the retrieval system components, the Power Ram is extended towards the container.**

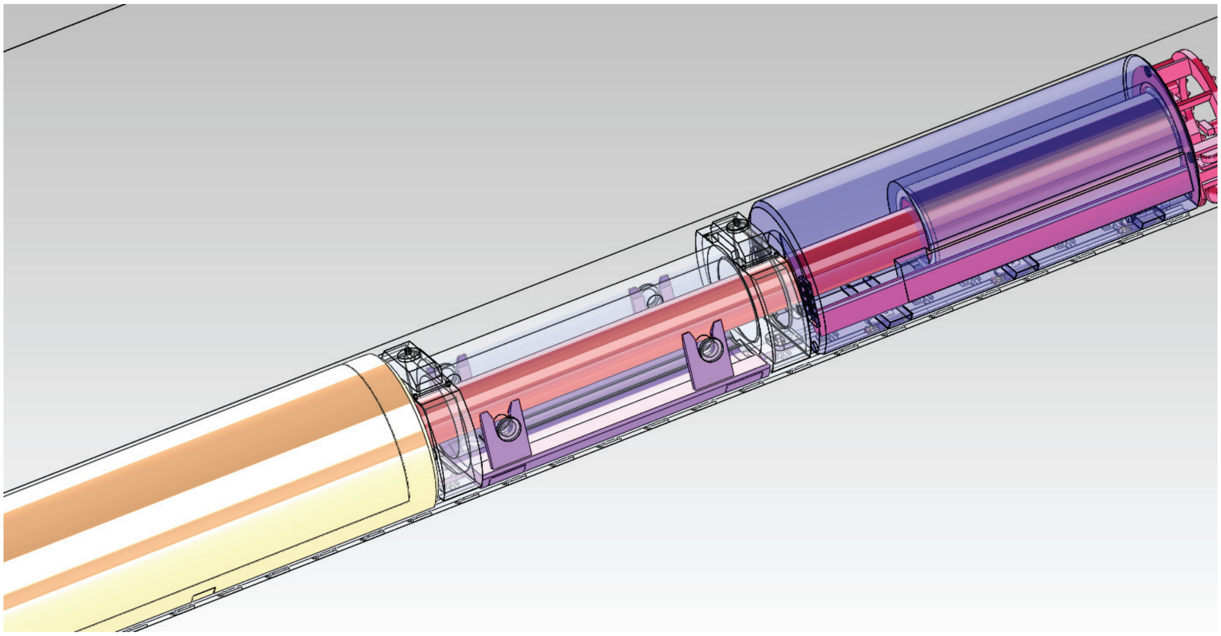

**Figure 20: The Ram connects with the container inside the retrieval machine Guide Cylinder.**

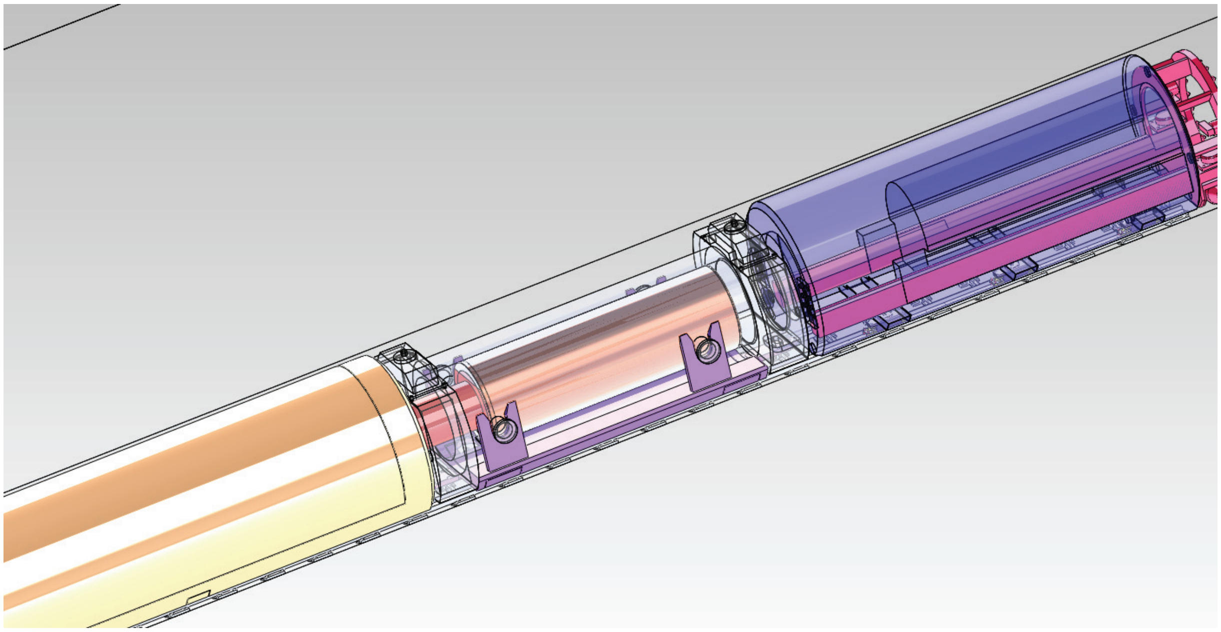

**Figure 21: The Power Ram Machine draws the container into the transfer cask. Subsequently, it closes the transfer cask shielding doors.**

## 4.3 Container Retrieval System Maintenance

The container retrieval system has special maintenance needs beyond those of conventional equipment due to the potentially long periods of equipment inactivity between uses and the requirement that it should be available over times spanning several decades.

Some systems, such as those of the water jet system for removal of the buffer can be procured and assembled based on commercially available equipment, and commissioned as required at any point in time. Specially designed system components such as the CRM, the CTC and the PRM, on the other hand, would have been built and demonstrated during the early stages of repository operation, and a suitable maintenance program for this equipment should be in place through the entire repository preclosure period.

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 system age can be replaced or upgraded as required during several decades.

## 5. DISCUSSION AND CONCLUSIONS

A container retrieval system design concept has been developed based on the NWMO reference design for a deep geological repository constructed in sedimentary rock. The equipment required for the retrieval system and the steps of a retrieval operation have been identified and described at the conceptual level.

The feasibility of the retrieval operation steps has been demonstrated and it is concluded that the proposed container retrieval method constitutes a good basis for further development of a used fuel container retrieval system design.

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