FINAL REPOSITORY FOR SPENT NUCLEAR FUEL IN GRANITE – THE KBS-3V CONCEPT IN SWEDEN AND FINLAND

Authors: Stig Pettersson[1], Bengt Lönnerberg[1]
[1]SKB

Abstract

Both Sweden and Finland has advanced plans for design, construction and operation of the final underground repositories for direct disposal of spent nuclear fuel. Both countries have the same type of host rock – granite. They are also investigating alternative concept for disposal, vertical or horizontal disposal of the canisters with encapsulated spent nuclear fuel, normally called KBS-3V or the KBS-3H disposal concept as shown in **Figure 1**.

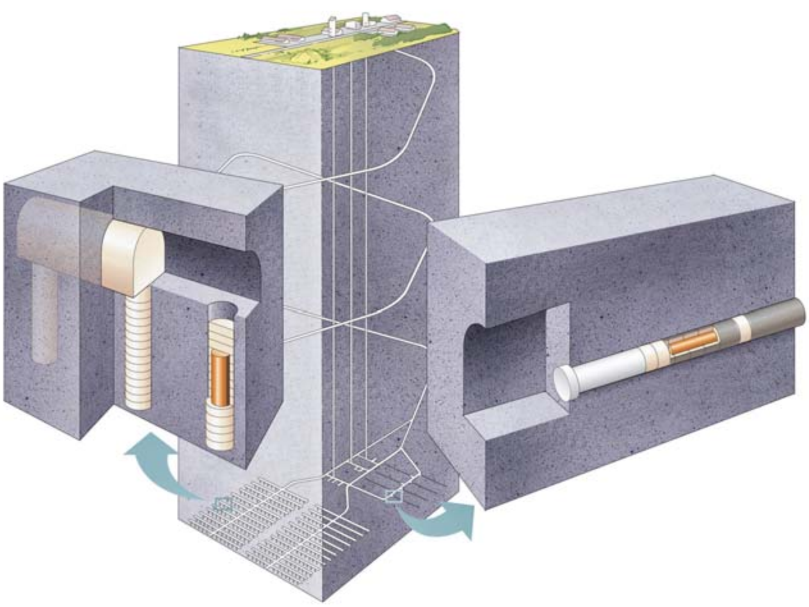

Figure 1*:* The principles for the two concepts, KBS-3V with vertical emplacement of the canister in short bore holes and KBS-3H with horizontal emplacement in long disposal drifts.

This paper deals with the design and operation of the KBS-3V based on the work done within Sweden and SKB. The development in Finland for the final repository for spent nuclear fuel is identical and there is a close cooperation between SKB in Sweden and Posiva in Finland.

1 Description of the Deep Repository for KBS-3V

1.1 General

The KBS-3 system is based on a multi barrier concept (SKB, 2007) and the different barriers are shown in **Figure 2**. The work with compiling the design requirements for the underground part of the deep repository has been ongoing for some time within the SKB organisation. Today the design requirements for the underground part are documented in a big number of reports that have been produced by specialists and working groups over rather a long time period.

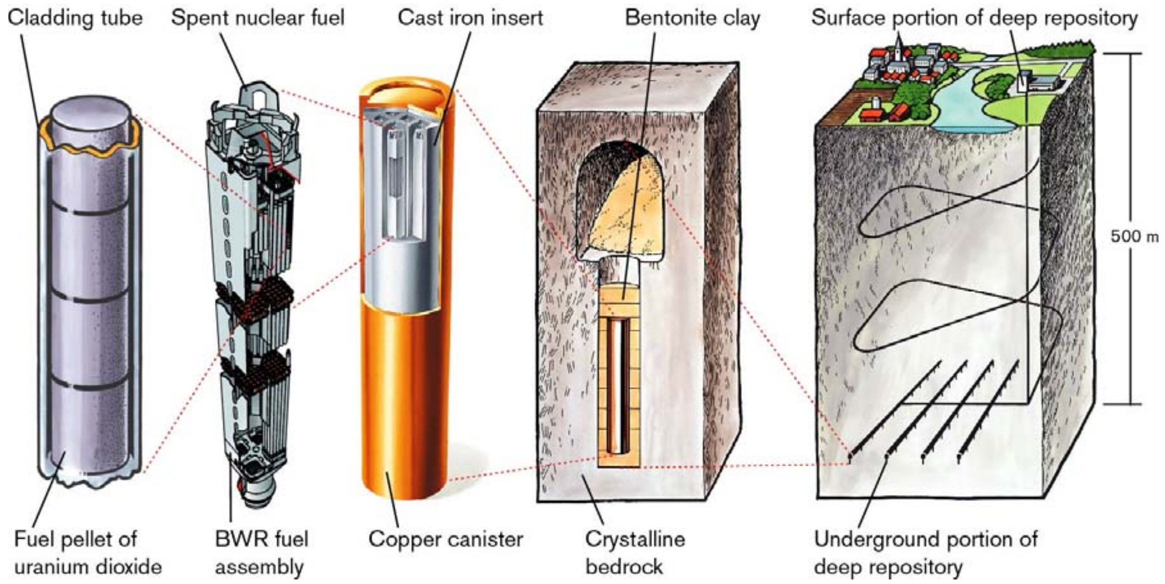

Figure 2: Illustrations of the barrier system for the deep repository for spent nuclear fuel

For each barrier the following is determined during the development work:

- specification;
- design determining parameters;
- dependency on other parts of the repository barriers;
- design determining the situation during construction and operation;
- design determining processes after closure of the repository.

For the design and optimisation of the different parts of the disposal concept the following has to be considered:

- safety during construction;
- safety during operation;
- long term safety after closure;
- environment issues;
- technology and feasibility;
- costs;
- possibility to retrieve the canisters with spent fuel.

1.2 Access between Ground and Repository Level and Basic Layout of the Repository

Over the years, a number of generic studies of the layout of the operational area(s) above ground and underground facilities of the repository have been performed. Different access routes from the ground level to the repository level at 500 m below ground have also been investigated. The access routes studied are mainly by shafts only or a ramp access for the heavy and bulky transports in combination with different service shafts. Furthermore, a ramp alternative could be arranged as a spiral or as a straight ramp in combination with service shafts. The different access alternatives are presented in a report (SKB, 2003).

The selected reference alternative with a combination of shafts and a spiral ramp is illustrated in **Figure 3**. In the evaluation process of the access routes it is important to have a good knowledge of the cost and time schedule for shaft sinking down to the repository level in order to compare this with a ramp access. The time needed for the excavation of the shaft down to the repository level will be about 18 months shorter compared with ramp. Other factors that may influence the selection between access routes are constructability, operational safety, logistics during operation and long term safety.

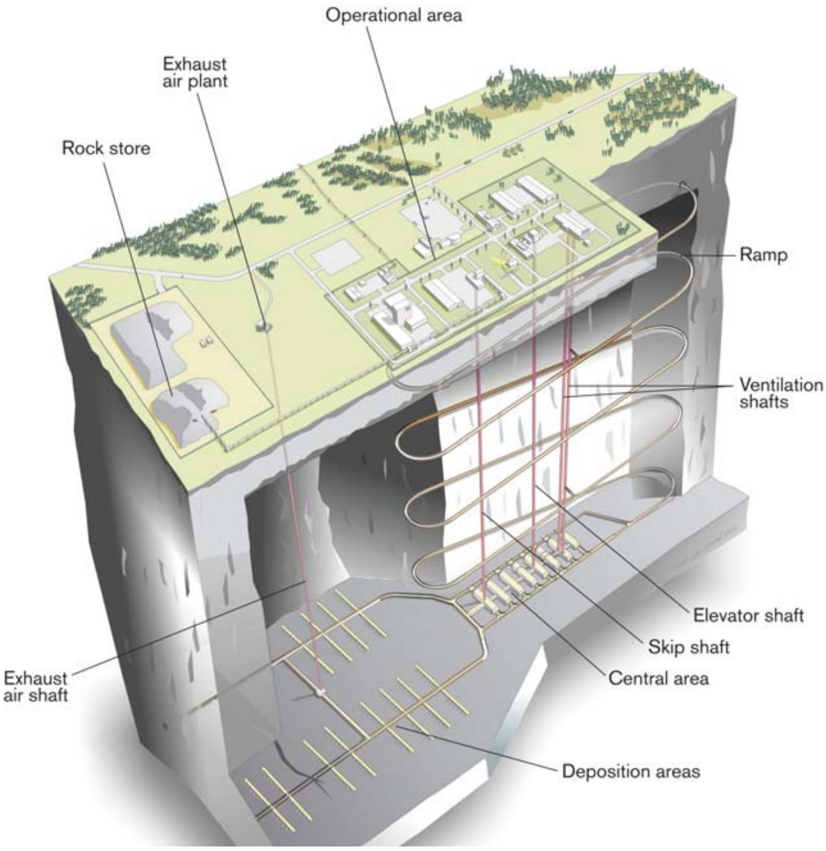

Figure 3: Illustration of the deep repository and the main functions

The underground part of the repository consists of a service area and areas for deposition of canisters with spent fuel. SKB reference design entails that:

- the drifts are excavated using conventional drill and blast technology;
- the canisters are deposited one by one in holes bored in the floors of the drifts;
- the buffer consists of highly compacted pure bentonite;
- backfilling after completed deposition of canisters in a tunnel is made with blocks of swelling clay, e.g. Friedland-clay.

In the reference case, the deposition drifts are separated by 40 metres and the spacing between the deposition holes is six metres. The latter distance is determined by the need to limit the temperature on the canister surface.

The operational area comprises a terminal building for receiving transport casks containing encapsulated fuel, a production building for preparation of buffer and backfill material, a supply building for electric power, offices, workshop and information buildings and a garage. The operational area also includes an elevator and ventilation building over the main shaft, buildings for offices and personnel and a restaurant building.

The operational area needs about 0.3 square kilometres. **Figure 4** shows an artist impression as a 3D-model of the operational area of the repository if located in the Oskarshamn area. A surface for storage of excavated rock occupies a large portion of this area. Local conditions may influence the size and arrangement of the operational area.

Figure 4: Artist impression as a 3D-model of the operational area of the repository if located in the Oskarshamn area

The excavation of disposal drifts will be made successively. When the disposal starts, some 10 drifts will be already available in one branch of the deposition area. About five drifts will be filled in a year and in the meantime another ten drifts are excavated in the parallel branch. The works can then be shifted at intervals of approximately one year with stepwise excavation of some five drifts until the required number of some 150 disposal drifts has been reached.

1.3 Overview of the underground portion

The underground portion consists of the service area and the area for deposition of canisters with spent fuel. The principles with a central service area and a construction and an operational area are shown in **Figure 5**. The central service area comprises halls for operation and service.

The deposition drifts are linked to the service area by tunnels for transport, communication, ventilation and utility lines. The deposition holes are approximately 8.2 m deep and have a diameter of 1.75 m. The canisters are embedded in a buffer of highly compacted bentonite, delivered from the production building through the skip shaft.

Preliminary figures for excavated volumes (2.35 Mm^3):

Deposition drifts and holes 1 300, 000 m^3

Transport and main tunnels	650, 000	m^3
Service area halls	150, 000	m^3
Ramp	200, 000	m^3
Shafts	50, 000	m^3

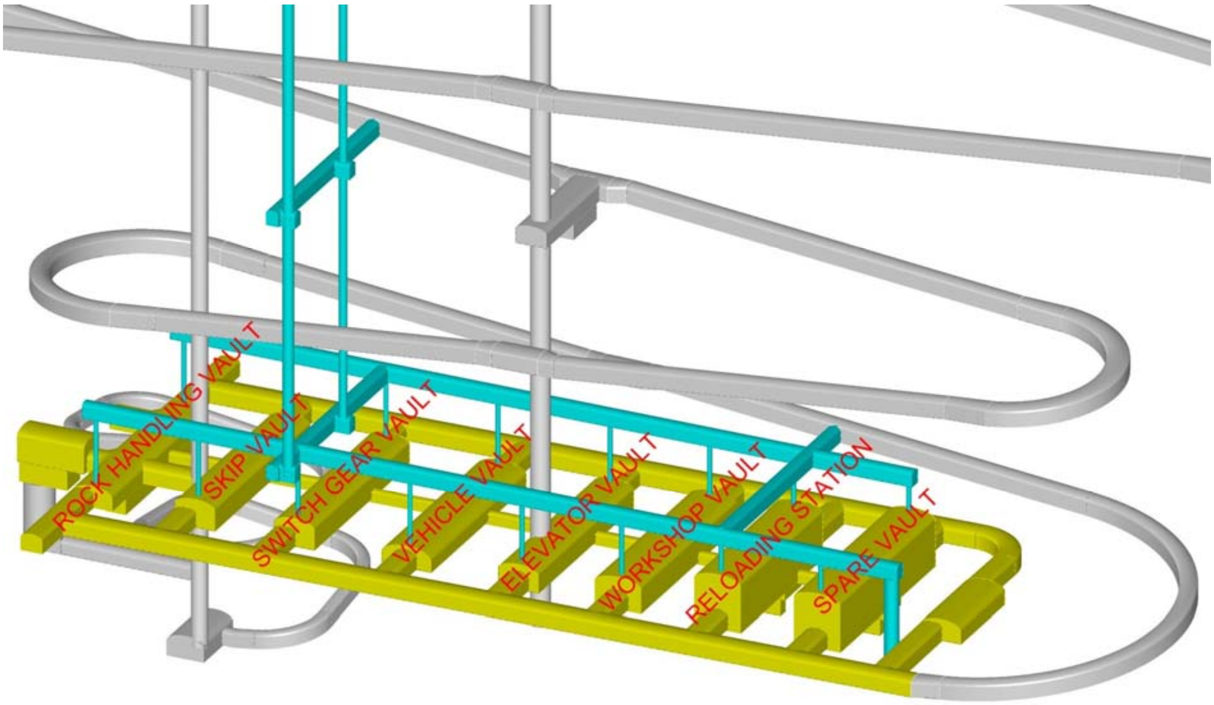

Figure 5: 3D-illustration of the service area on repository level.

1.4 Deposition drifts

The total deposition area is planned for disposal of about 6,000 canisters. This capacity necessitates excavation of about 150 disposal drifts if each drift on an average can take 40 canisters. The drifts are assumed to be straight and parallel. They are connected to main communication tunnels, which are forming a loop with the rest of the drift system. The length of the deposition drifts have to be adapted to the rock quality and properties, such as fracture zones, which can result in a division into smaller parts. In average a length of about 300 m is considered for the deposition drifts. A generic layout is shown in **Figure 6**.

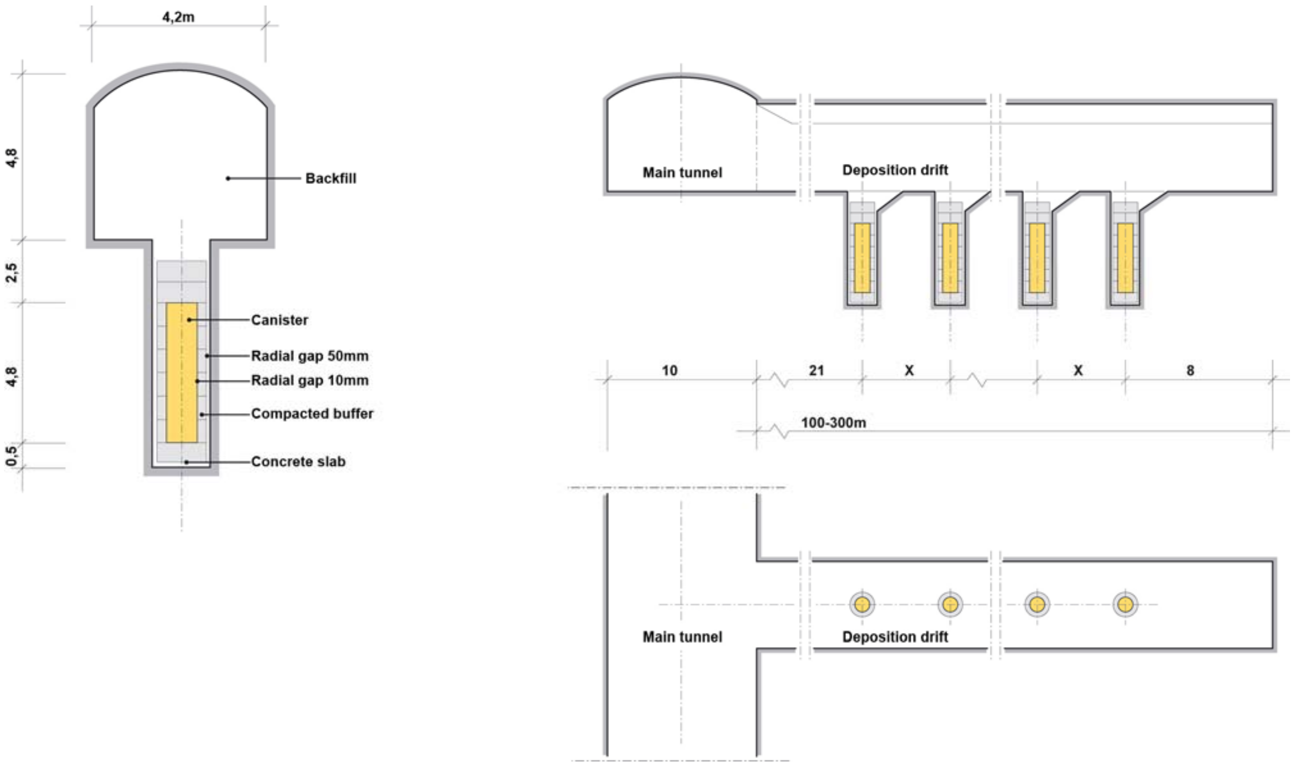

Figure 6: Sections through the deposition drift with deposition hole

1.5 Central service area

The service area consists of six halls and a tunnel-shaft arrangement for rock masses and backfill material. The area covers about 275*110 m. All halls are connected at each end to the two parallel transport drifts. A third, smaller personnel drift, also parallel to the others, connects to the middle of each hall. The halls are in order:

1. One hall for reloading the canisters from the transport cask to the radiation shielding tube which is part of the deposition machine.
2. One hall containing a workshop and storage. The workshop is suitable for minor maintenance and repair works, while larger overhauls will be made on ground.
3. One personnel and information hall. It is connected via a shaft to the elevator building on ground level. The hall constitutes the base for the underground personnel and the information part serves as a meeting and information point for visitors.
4. One vehicle hall for parking vehicles when not in operation. There are also batteries charging sites for electrical vehicles.
5. One skip hall connected to the skip. Bentonite blocks and backfill material in containers are collected in the hall before distribution to the deposition and backfill drifts.
6. One hall where trucks deliver the excavated rock and empty the muck into a silo. From the silo the muck is lifted by the skip to the ground. The hall also contains two basins for collecting drainage water from all the underground area. It has a sedimentation and oil separating function and is provided with pumps for transferring the water for further treatment on the ground surface. The hall has also a pool for fire fighting water.

Fresh air is conducted from the ventilation building on ground level through a shaft to a distribution tunnel system. The air is distributed to the various halls, to the ramp and to the deposition areas. Exhaust air from the service area is led back through a separate shaft to the ventilation building.

Exhaust air from other parts passes the ramp or through the deposition area to an additional outer shaft. Electric power is supplied through the exhaust ventilation shaft to the electrical hall from where it is distributed to the various underground consumers. The dimensions of the halls are between 12 and 15 m in width and between 8 and 15 m in height. They are 50-66 m in length.

1.6 Access ramp, shafts for ventilation, personal elevator shaft, shaft for transport of rock and buffer plus backfill material

During the operation of the repository the ramp will be used mainly for the transports of the transport cask with encapsulated spent fuel. Bulky equipment and some service transport may also use the ramp. The excavated rock will be transported in the skip shaft as well as the buffer and backfill material. The ramp starts within the operational area on ground.

The ramp is 5.5 m in width and 5 m high and the average ramp slope is 1:10. The ramp has several passing places with a width of 10 m and without any slope. The length of the ramp is about 5 km.

Fire separating doors are placed in the ramp above each passing place. Meeting or passing places are provided with security chambers.

There are a number of shafts between the ground level and the central service area at repository level. There will be a skip shaft for transport of excavated rock and also buffer and backfill material, two shafts for ventilation and one elevator shaft for transport of personnel.

2 Operation of the Deep Repository for KBS-3V

Excavation of new deposition drifts will be done in parallel with emplacement of canisters with encapsulated spent fuel but in separate areas. As the type of work is very different it is important to separate the construction and operation sides of the repository.

Operation includes all activities as emplacement of buffer and canisters in each deposition drift, backfilling of the drift and construction of a sealing concrete plug at the opening of the drift.

The main steps for emplacement of buffer and canister with spent fuel are shown in **Figure 7**. All excavation work and drilling and preparation of the deposition holes are part of the construction work. All deposition holes are covered with a plate for personnel safety and all holes are assumed to be filled with water. This is the start conditions for the block diagram in **Figure 7**.

The equipment for handling the buffer, blocks and rings, has not been designed yet but it is assumed that it will be some type of gantry crane as used for the Prototype repository at Äspö. **Figure 8** is an illustration of that gantry crane but the requirements for the equipment in the final repository must be more refined and there must be a positioning system for the correct emplacement of the buffer material and for handling and installation of the radiation shielding normally just called “gamma gate”.

The emplacement of the buffer up to the top of the canister is done before the canister is emplaced. In the meantime the canister is transferred from the canister transport cask to the deposition machine in the reloading station which is one of the halls in the central area. A preliminary design of the reloading station is shown in **Figure 9** and **Figure 10**.

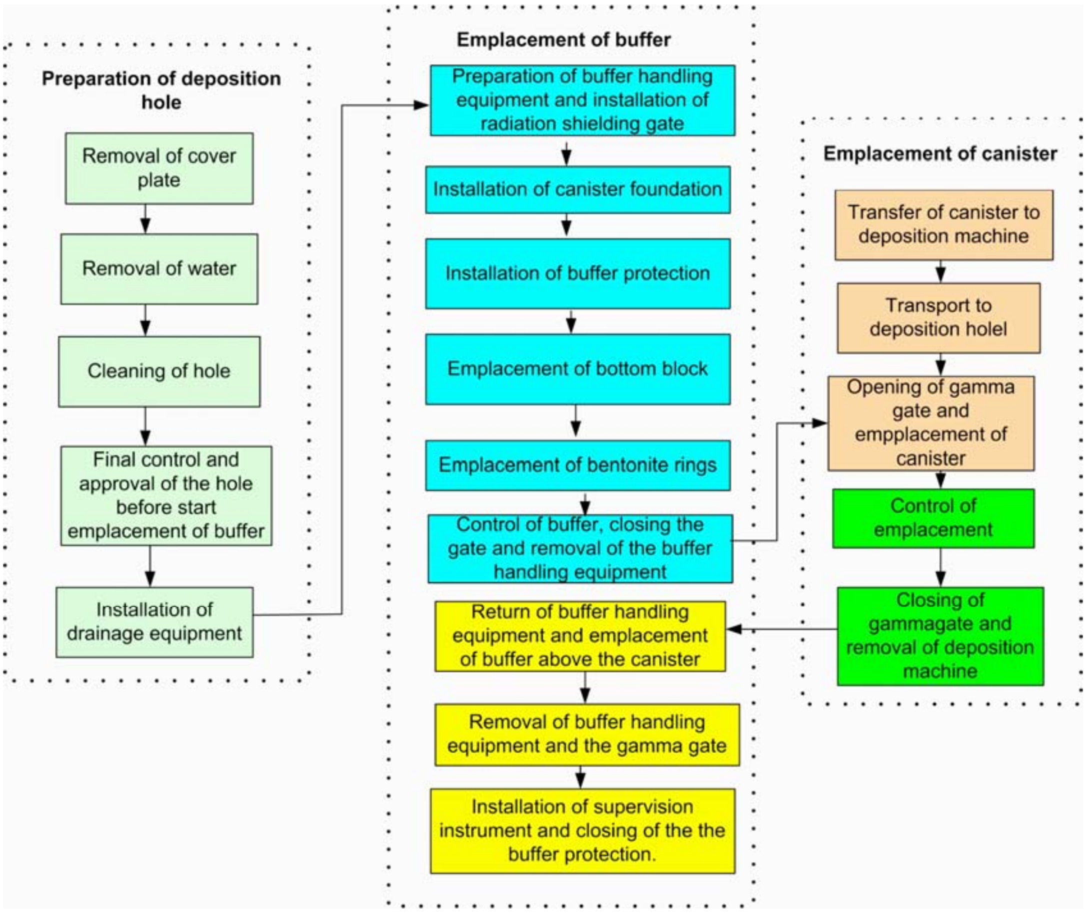

Figure 7: Block diagram showing the main step during the emplacement of buffer and canister with spent fuel in the deposition hole

The handling and positioning of the gamma gate will be done with the gantry crane intended for the buffer emplacement. The buffer material will be transported to the gantry crane using a forklift truck as shown in **Figure 8**. The buffer material will be placed on a pallet already in the production building and the block will be protected in order not to dry or pick up moisture during transport and storage.

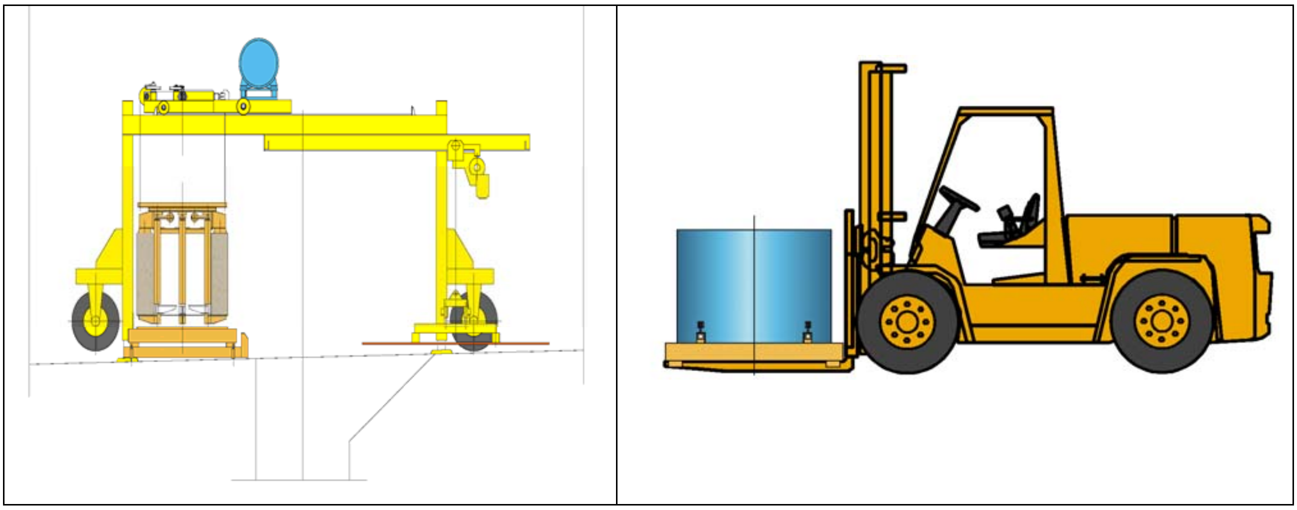

Figure 8: Illustration of the handling equipment for the buffer material

The transfer of the canister from the transport cask to the deposition machine will be done in a specially designed reloading station in the reloading hall. The plan view of the reloading station is shown in **Figure 9** and a cross section is shown in **Figure 10**.

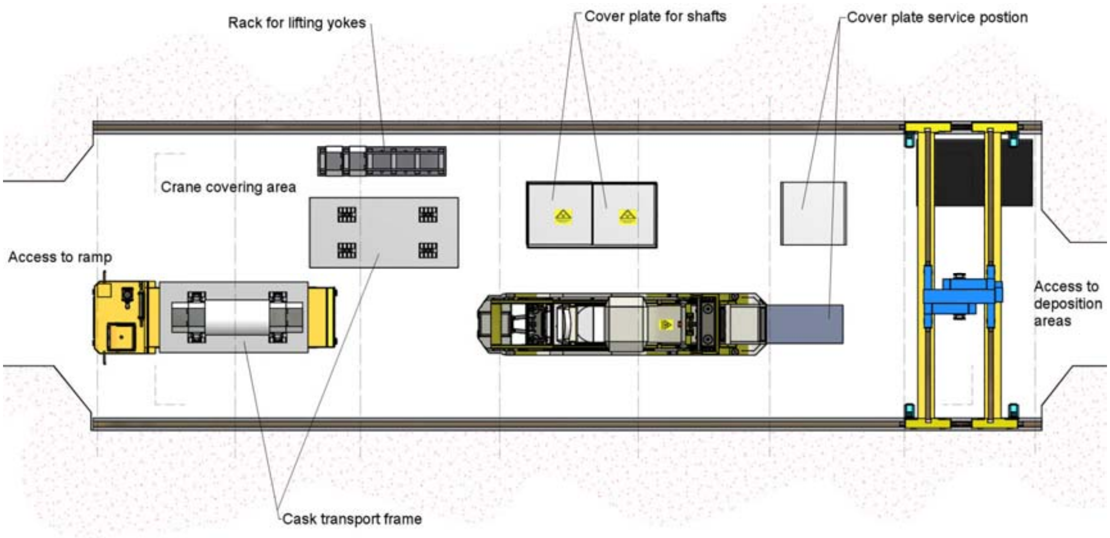

Figure 9: Illustration of the reloading station, plan view

The transport cask with the canister will be placed down in an unloading pit and the deposition machine will be placed over that pit. The opening of the lid of the transport cask and the transfer of the canister into the shielded tube on the deposition machine will be done remotely controlled and with full radiation shielding during the transfer as shown in **Figure 10**. The extent of inspection of the canister during this process is not decided yet, but will include identification and surface inspection. When the transfer has been completed the deposition machine can move to the deposition hole prepared with buffer up to the height of the canister.

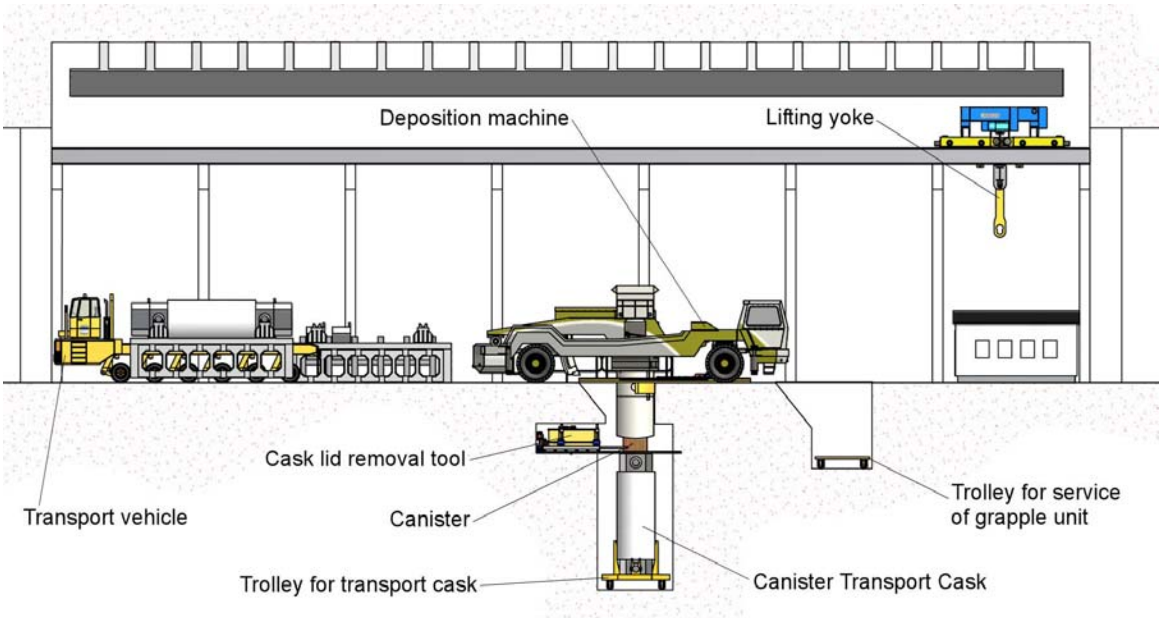

Figure 10: Illustration of the reloading station, cross section showing the transfer of the canister from the transport cask to the shielded tube of the deposition machine

After the correct positioning of the machine by the navigation and positioning system, the gamma gate can be opened and the deposition takes place. The gate is then closed until the upper buffer blocks are emplaced up to the floor level. The deposition sequence is shown in **Figure 11**.

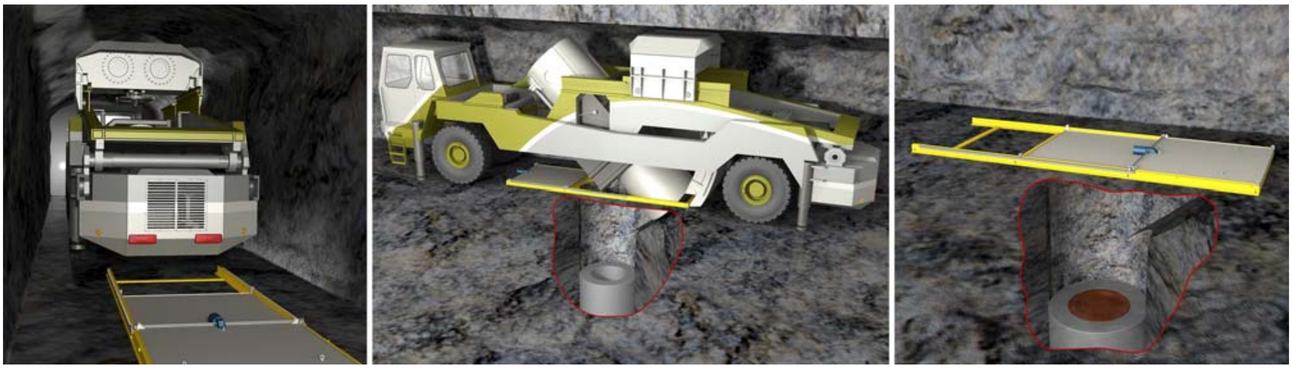

Figure 11: 3D-model of the deposition machine during emplacement of the canister in the deposition hole

When all canisters in one deposition drift have been emplaced the backfilling and final sealing of the drift can start. It has been discussed to carry out stepwise backfilling but the reference is that backfilling of the whole drift in one sequence. The backfilling will be done with pre-compacted blocks of swelling clay and with some additional pellets for filling the void between the blocks and the rock wall and the roof of the drift. The principle for emplacement of the blocks is still not decided but different methods and equipment will be tested. **Figure 12** shows one method of emplacement of the backfill blocks.

The backfilling of drifts will be a challenge. The speed for backfilling must be high so as to avoid piping and problem with water. It is planned to take down about 350 – 400 tons of backfilling material per 24 hours. The backfilling of one drift is estimated to take 10 – 12 full weeks working all days in the week and around the clock. The transport logistic for the backfill material from the production building in the operational area on ground down to the repository level and out into the drift and fed to the emplacement equipment as well as filling the void between the blocks and the walls and the roof will not be an easy task.

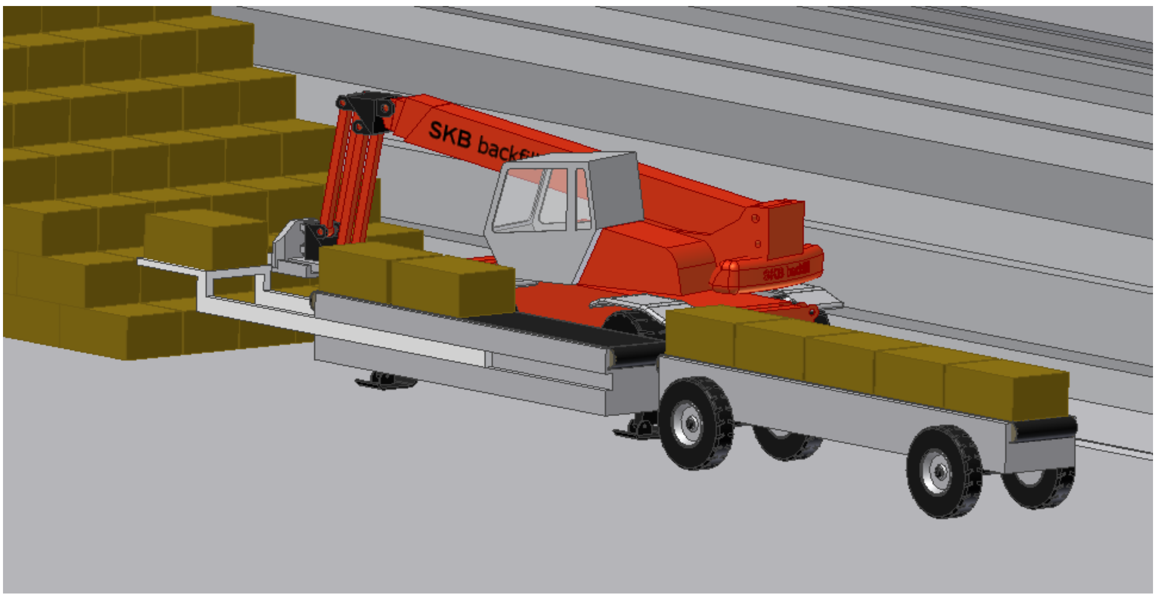

Figure 12: 3D-illustration of handling of backfilling blocks in the drift.

Once the backfilling is completed it is time for construction of the sealing plug. SKB is investigating different designs of this plug. The plug will be a cast low-pH concrete plug but it is still debated if it will be a short reinforced plug or a longer tapered plug or if we need a bentonite plug between the backfill and the concrete construction. The different designs of the plug are shown in **Figure 13** and **Figure 14**.

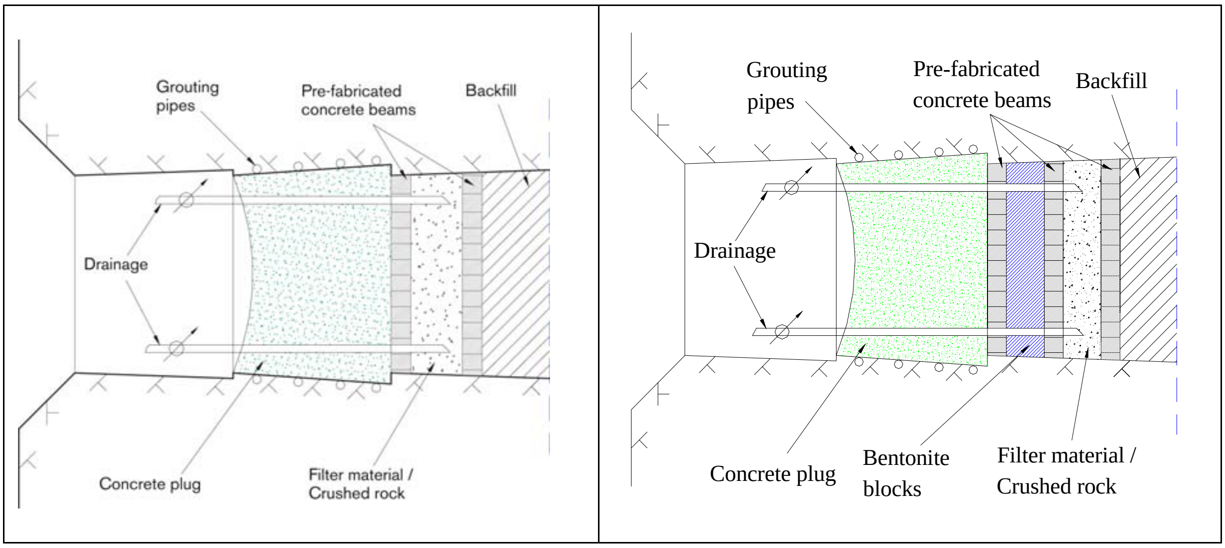

Figure 13: Illustration of a tapered plug without or with bentonite plug between the backfill and concrete plug. The concrete planks are needed for construction reasons and the filter is for reducing the hydraulic pressure on the plug during curing of the concrete

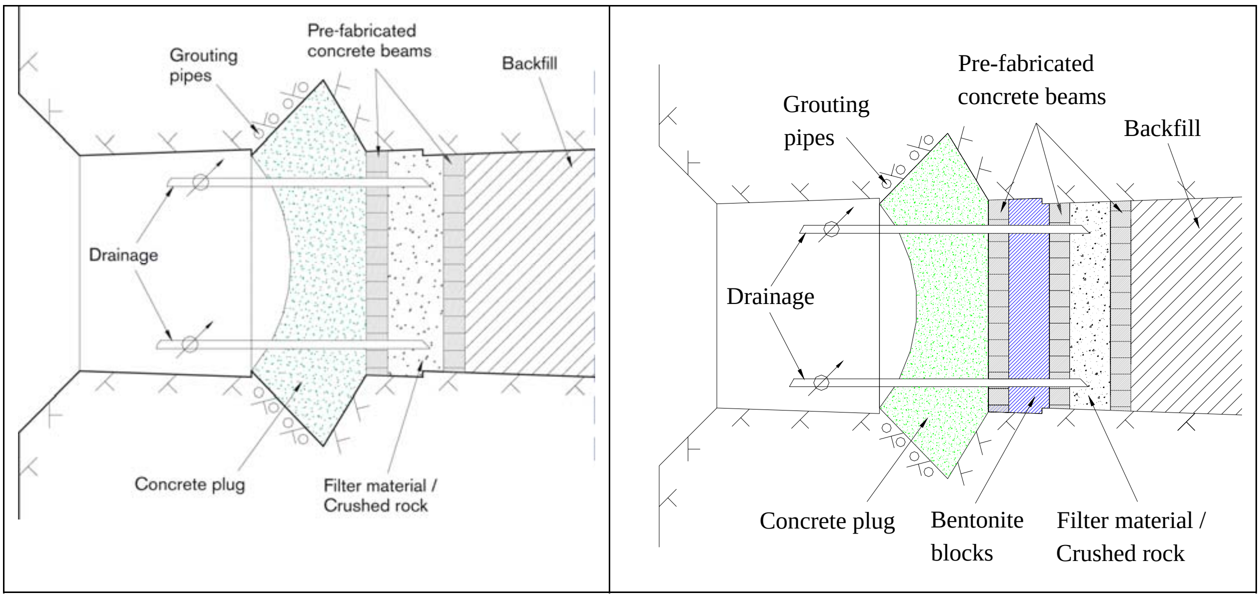

Figure 14: Illustration of a short reinforced plug with or without bentonite plug

3 Closing of the Repository

When all the spent nuclear fuel has been encapsulated and disposed of and all deposition drifts are backfilled and sealed the repository will be closed. Backfilling and closure of all openings in the underground area will require a new permit from the authorities. The requirements and methods for backfilling are not decided yet but some feasibility studies have been performed in order to develop new technology and get the required input for the long term safety assessments of the repository.

4 Operational and Long term Safety of the Repository

The operational safety of the repository will be presented in the "Preliminary Safety Assessment Report" and the long term safety (Safety Case) will be presented in a report called "Safety Report Site" (SR-Site). A preliminary version of the SR-Site has already been presented and has been subject for an international review, see (SKB, 2004).

References:

SKB, 2003. Utredning rörande tillträdesvägar till djupförvarets deponeringsområden Schakt eller ramp? (Study on access routs between ground and depository level. Shaft or ramp?) SKB R-03-11. Svensk Kärnbränslehantering AB

SKB, 2004. Interim main report of the safety assessment, SR-Can, SKB, TR-04-11. Svensk Kärnbränslehantering AB

SKB, 2007. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, SKB RD&D Programme 2007, September 2007. Svensk Kärnbränslehantering AB