OPERATIONAL SAFETY FOR A KBS-3H REPOSITORY

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Abstract

In 2001 SKB prepared an R&D programme /1/ for the KBS-3H, horizontal emplacement design of the repository for encapsulated spent nuclear fuel as an alternative repository design to KBS-3V, vertical emplacement. Both are based on the so-called KBS-3 method with multi-barrier systems but the orientation of the canister differs as illustrated in **Figure 1**. It should also be noted that KBS-3V is the reference repository design for spent nuclear fuel in Sweden. The repository for spent fuel is planned to be constructed at a depth of about 500 metres in crystalline bedrock. The total amount of spent fuel within the Swedish programme if the reactors are operated 50 – 60 years will be in the order of 9, 000 tonnes or about 6, 000 canisters. The deposition capacity is planned to be in the order of 160 canisters per year. Start-up for emplacement of canisters with encapsulated spent nuclear fuel is now scheduled for 2020 /SKB R&D Report 2007/.

The purpose of this paper is to present preliminary analysis on operational safety for a KBS-3H repository highlighting the two main areas where the KBS-3H and KBS-3V designs differ. The areas are the activities in the reloading station and in the disposal drift

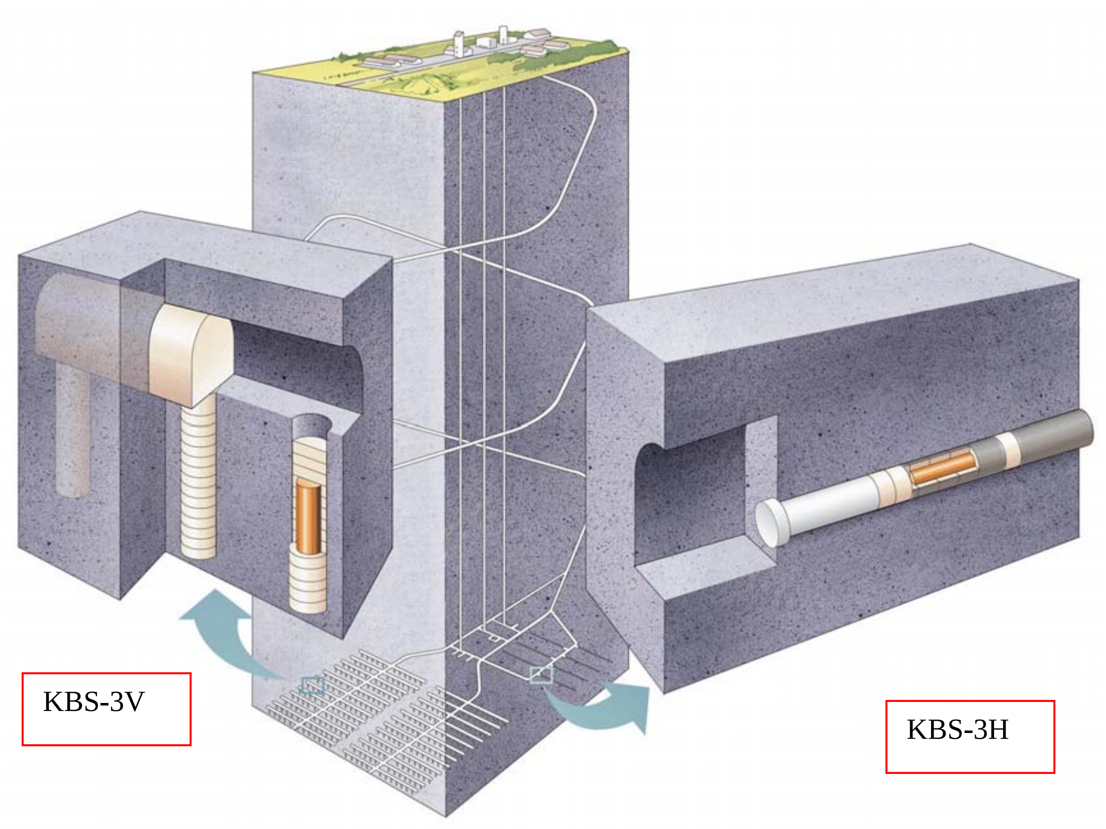

Figure 1: Artist impression of the multi barrier KBS-3 method showing both the vertical deposition (KBS-3V) on the left and the horizontal deposition (KBS-3H) on the right

1 Introduction

In the KBS-3H design, the copper canister with encapsulated spent nuclear fuel and buffer are placed inside a perforated steel cylinder and disposed of as one package, normally called the Super Container (SC). The different components of the SC are transported separately to the reloading station at repository level. The KBS-3H design requires a shielded handling cell in the reloading station for the assembly of the SC. The SC is then transported to the chamber in front of the deposit drift in a “transport tube" that is required for the handling of the SC and radiation shielding. For the KBS-3V design, the copper canister will be reloaded directly from the transport cask into the shielded tube of the deposition machine in the reloading station. The buffer material will be placed in the vertical deposition hole before emplacement of the canister and only the buffer top parts will be installed with the canister in place.

In the KBS-3H design, the SC container is emplaced with a special deposition machine designed for handling heavy loads in to the up to 300 m long horizontal deposition drift. The KBS-3H drift has a diameter of only 1.85m and the SC has a diameter of 1.765m to which the height of the container feet shall be added, about 50 mm. The radial clearances are therefore small and will restrain the handling of the SC in the drifts. The KBS-3H design does not require backfilling of the deposition drifts but installation of distance blocks are needed between the SC for not exceeding the allowed maximum temperatures in the buffer. The thermal load on each canister is limited to 1 700 W for both KBS-3V and KBS-3H. The artist impression of the KBS-3 repository is shown in **Figure 2** and the location of the reloading station is shown on the figure as well as the arrangement of the horizontal drifts.

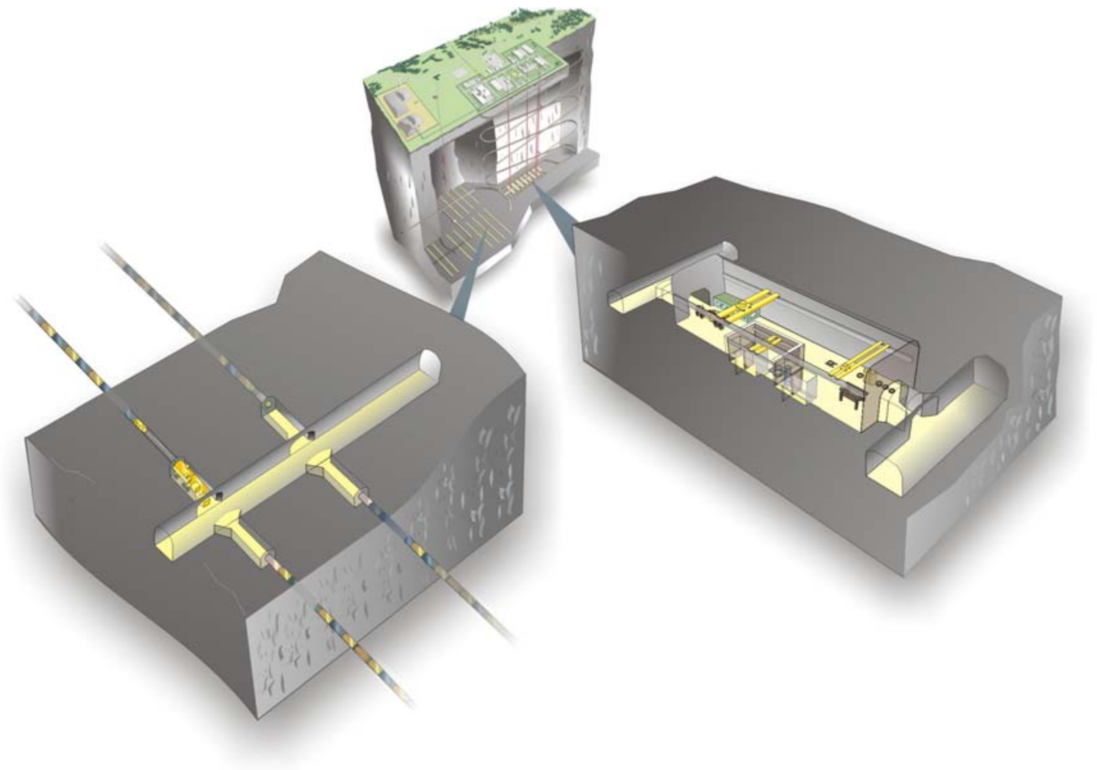

Figure 2: Artist impression of the KBS-3H repository with the reloading station to the right and some disposal drifts on the left side

Figure 3 shows the main components in the KBS-3H design with the super container which contains the copper canister with encapsulated spent nuclear fuel, the compacted buffer material and the perforated steel shell. **Figure 3** also shows the deposition machine and the installation in the chamber with transport tube and Start Tube plus the 300m long horizontal disposal drift. The assembly of the SC is done at the repository level in a radiation shielded cell inside the reloading station. The layout of the reloading station is shown in **Figure 4** and **Figure 5.**

The main differences between the KBS-3V and KBS-3H repository designs are in the reloading station and activities associated with emplacement of the SC and distance blocks. This paper is focused on presenting the differences in operation safety or risk analysis for these two areas.

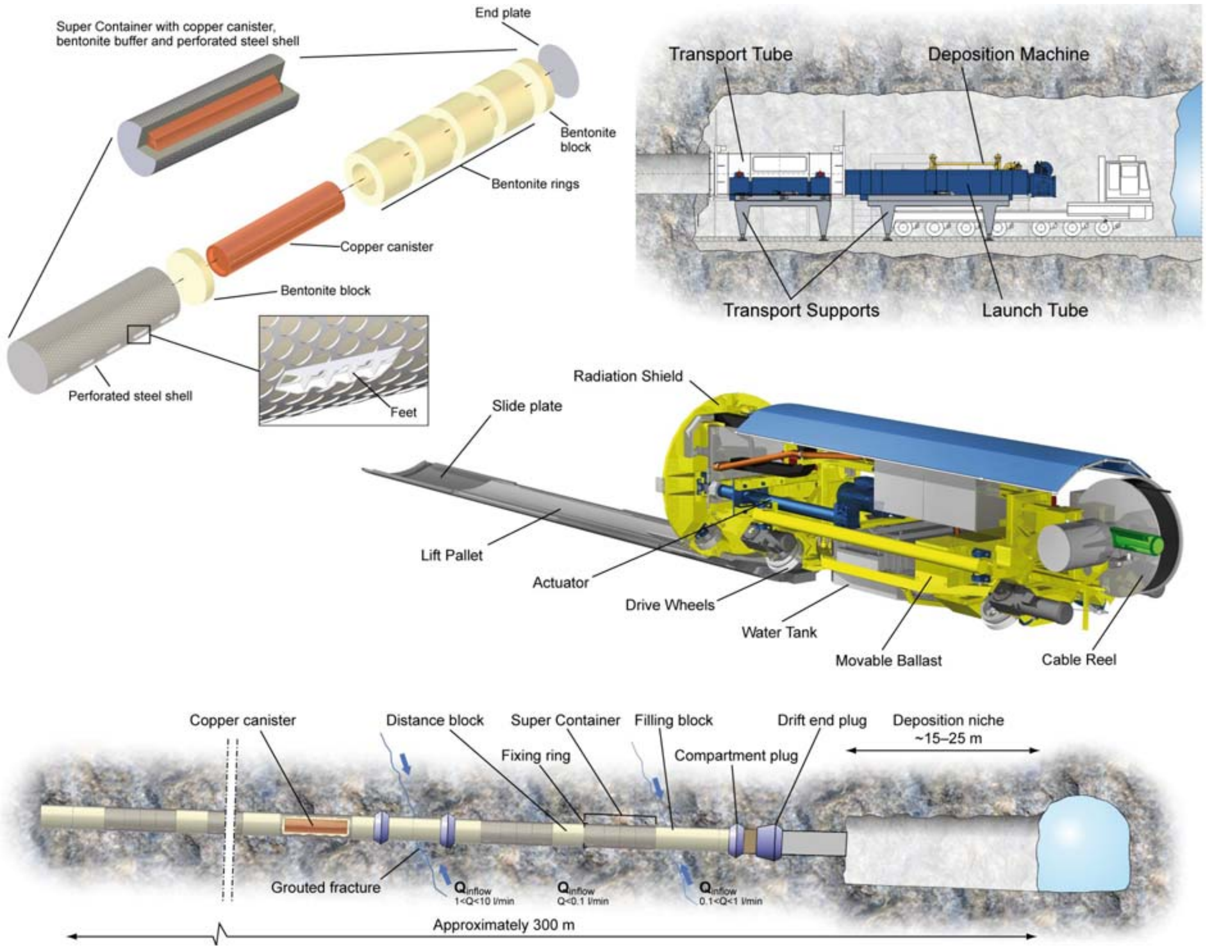

Figure 3: The main components in the KBS-3H concept

2 Reloading Station for KBS-3H Design

The reloading station will have a different function in the KBS-3H design compared to KBS-3V. In KBS-3H the main activities in the reloading station are:

- The pre-assembly of the Super Container is done in the reloading station but outside the shielded handling cell. This pre-assembly will be done inside the transport tube standing vertical on a small wagon in the transport tube pit and with the top gamma gate removed, see **Figure 4** and **Figure 5**. First, the SC perforated shell is placed inside the transport tube and then all buffer material, the top lid of the shell and the transport tube top gamma gate. The complete SC except the spent fuel (SF) copper canister is now ready to be transferred into the transport tube. The top lid of the Super Container is of cause not welded and the top gamma gate is not bolted to the shell of the transport tube at this stage.

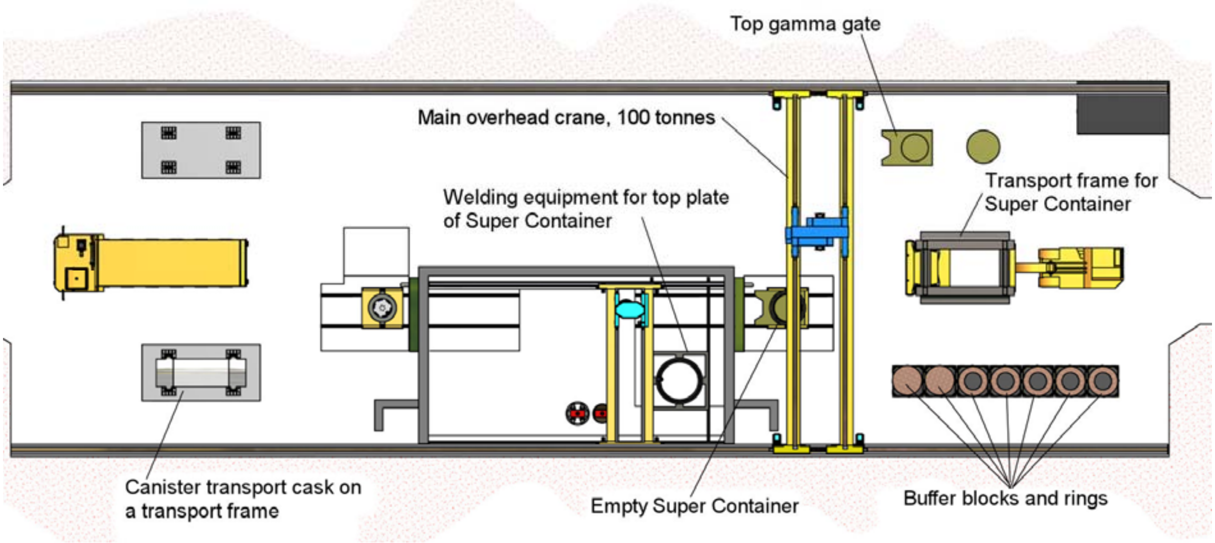

Figure 4: Preliminary plan view of the reloading station with the shielded handling cell. The empty transport tube is standing on a wagon in the loading pit but outside the cell. The transport cask for the spent fuel canister standing on its wagon in the loading bit also outside the cell

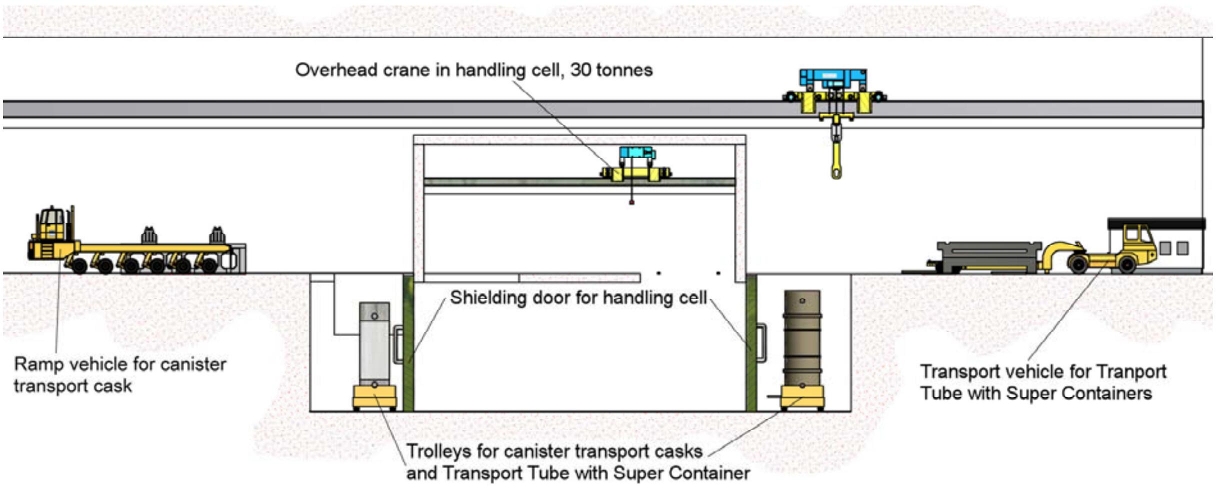

Figure 5: Preliminary section of the reloading station with the shielded handling cell showing the transport tube for the Super Container and the transport cask for the spent fuel canister outside the handling cell

- As soon as the pre-assembled of the SC is completed and the top gamma gate is in place the transport tube can be transferred with the wagon into the shielded cell for receiving the SF copper canister. In the handling cell, first the top gamma gate is removed as well as the top plate and the top buffer (bentonite) plug, see **Figure 6.**
- The transport cask has been unloaded from the ramp transfer vehicle and the outer protection lid is removed as a preparation for lifting the canister out of the cask. The cask is then placed on a small wagon in the transport cask pit for transport inside the handling cell. Inside the handling cell the inner radiation shielding lid of the transport cask will be removed and the cask is now open.
- The canister can now be lifted out of the cask and placed inside the buffer material in the SC, see left part of **Figure 6**. With the canister in place, the top bentonite block is placed on top of

the canister inside the shell. The top plate of the shell is then installed and welded to the SC shell. All these activities are done inside the transport tube.

- After completion of the welding and control of the results, the top gamma gate can be bolted to the transport tube. The transport tube is now ready for being removed from the handling cell.
- The empty transport cask for the SF canister can now also be prepared for removal including replacing the inner and outer lids of the cask. These operations do not differ from those in the KBS-3V with the exception of the removal of the canister, which is done inside the handling cell in order to provide radiation protection during the transfer of the canister from the cask to the prepared SC in the transport tube.
- The last operation in the reloading station is the transfer of the filled transport tube to the trailer for transport to the chamber in the repository area for emplacement into the deposition drift.

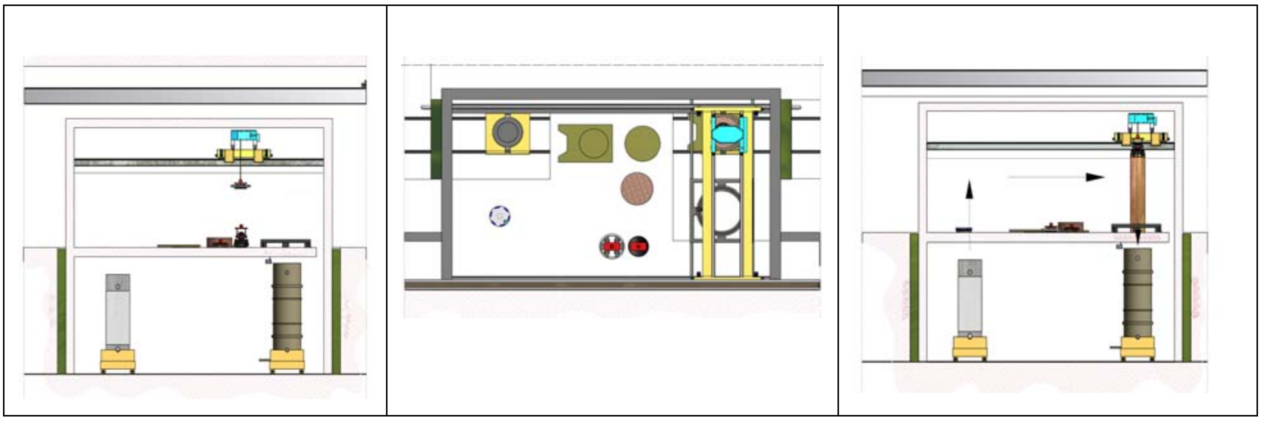

Figure 6: The illustration to the very left shows the removal of the top gamma gate, the SC top lid and the top buffer block. The plan view in the middle just shows the parts that are removed.
The illustration to the very right shows the transfer of the canister
from the transport cask to the SC inside the transport tube

Table 1 presents a **"what-if analysis"** performed for the reloading station and the shielded handling cell.

Table 1: What-if analysis for the Reloading station and the shielded handling cell

No	Event	Consequence	Cause	Measure	Detection	Comment
1	Dropped transport cask when unloading the ramp veichle and also during lowering the cask into the unloading pit outside the reloading station.	Canister can be damaged and has to be transported back to encapsulation plant.	Dropped load/mechanical failure/faulty connection of lifting grip.	The lift into the unloading pit is divided in two steps. Each step will be lower than the limit that the transport canister can withstand.	Acceleration instrument in the cask.-	“safe lifting equipment.”
2	Tipped transport cask when in lowered position.	Only availability.		Design of the wagon and assoiated equipment should prevent tipping of the transport cask.		
3	The door into the shielded handling cell is spuriously opened. The same is also valid for the SC side.	Potential radioactive radiation.	Incorrect operator action or mechanical failure.	There will be inter-locking to prevent incorrect opening.	It is presumed that the inter-lock will be tested every time the door is opened.	
4	Dropped copper canister when lifted out of transport cask inside handling cell.	Risk for damage of the copper canister. However, calculation shows release of radioactive will not occure in the handling cell.	Dropped load/mechanical failure of the grapple unit and the hosting equipment.	The grapple unit and the hoisting equipment will be specially designed. The design requirement is that it should not be possible to release the grappel unit as long as the grab is on load. The grab hook has got indication showing when the canister has been correctly grabbed.	-	An equivalent type of lift has to be performed in KBS-3V. This risk is not a sole potential problem for 3H.
5	Dropped copper canister inside the handling cell.	Availability.	Dropped load/mechanical failure.	Same as 4.	-	The lift height above the floor inside the handling cell is small.
6	Dropped copper canister on/in the SC.	Same as 4.	Dropped load/mechanical failure.	Same as 4.	-	There is an open issue if it is possible to opening the grab hook if the copper canister is incorrectly lowered and bounces on either the floor or the SC.

No	Event	Consequence	Cause	Measure	Detection	Comment
7	Incorrectly assembled SC (not discovered).	Incorrect presumptions for the long term analysis	Incorrect operator action or mechanical failure.		-	The requirements set for ”initial state” for the saftey case must be distinctly, measurable and easy to verify.
8	Incorrectly placed copper canister in SC;	If the copper canister hits the SC, then bentonite could possible come loose and fall to the bottom of the SC – causing that the SC cannot be assembled in a correct way. Incorrect presumptions for the long term analysis if not discovered.	Not correctly situated traverse crane inside the handling cell due to failure in the positioning equipment.	The lowering into the SC is guided by a funnel, i.e. small failures will have no effect. Large position problems will be discovered via monitoring. The top bentonite ring is vissually inspected after the insertion of the copper canister.	The equipment will be tested every time the traverse crane carries load.	Note: The verification of a correctly assembled ”bentonite package” must be done.
9	Incorrectly placed copper canister in SC;	-“-	Failure in the wagon positioning equipment.	See also 8.	The equipment will be tested every time the traverse crane carries load.	
10	Incorrectly placed copper canister in SC;	-”-	Failure of the small transport wagon.	The weels of the wagon are locked during the loading of the canister into the SC.	Will be discover by the monitoring system in the shielded cell.	
11	Incorrectly mounted top block of the SC	If the copper canister is not lowered sufficiently or if the rings and top block is not mounted correctly – then the top lid of the SC can not be welded correctly. May cause incorrect presumptions for the long term analysis if not discovered.	Incorrectly positioned copper canister, see no 8-10. Incorrect mounting of the top block.	Visual verification of a correct assembly of all buffer parts in the SC shell including the top block.	See Measure.	Note: The verification of a correctly assembled ”bentonite package” must be done.
12	The welding of the top plate of the SC affects the bentonite.	No consequence, see comment.		The design of the parts to be welded and the welding method must be made in a way that the bentonite is not unacceptably affected.		It is presumed that the welding will be performed in a way that will not affect the bentonite.

No	Event	Consequence	Cause	Measure	Detection	Comment
13	Dropping of the gamma gate on the SC during assambly ot the transport tube inside the shielded handling cell	Potentially damaged copper canister and buffer material.		The Gamma gate shall be designed so that it cannot be dropped on the SC.		
14	Dropped transport tube during lifting from pit outside the shieded handling cell and placing the transport tube on the loading frame.	Potential damage of the transport tube and the copper canister and buffer material.	Dropped load/mechanical failure/faulty connection of lifting grip.	Visiual inspection of the transport tube. Opening of the transport tube and also the SC for replacement of buffer material and eventually return of the cansiter to the encapsulation plant.		This type of lift corresponds to lifting of transport casks and should be relaible.
14	Fire in the handling cell			The shielded handling cell will have s fire protection system.		The possible fire ignition source is the traverse crane (motor, oil in gear box and electrical equipment.)

3 Conclusions Regarding Identified Accident Risks in the Reloading Station and the Handling Cell.

Obviously there are a number of additional risks compared to KBS-3V during the assembly of the SC in the reloading station. But the work in the shielded handling cell must also be compared to the actions where the copper canister has to be lowered into the deposition hole filled with buffer rings in the depository area in the KBS-3V design.

The following additional risks, compared to KBS-3V are identified for this part of the process:

- Lowering of the copper canister into the SC filled with bentonite buffer and lift of transport tube with the SC.
- The canister is moved from the transport cask into the SC inside the transport tube in the shielded handling cell.
- The shielded handling cell contains equipment that may cause additional risks, e.g. increase the fire ignition probability.

The risk in the transport of the transport cask with the canister in the ramp is the same as for the KBS-3V design and therefore not discussed in the paper.

4 Identified Operational Accident Risks in the Depository Area and in the Drift

The transport of the loaded transport tube to the chamber in the deposition area is similar to the transport of the canister inside the shielded tube in the deposition machine for the KBS-3V design.

However, the installation of the SC and distance blocks inside the 300m long drift with diameter of 1.85m is shown on **Figure 7** differs a lot between KBS-3V and KBS-3H**.** The equipment needed for the handling and emplacement of the SC into the deposition drift is presented in a separate paper in this conference and is therefore not presented here.

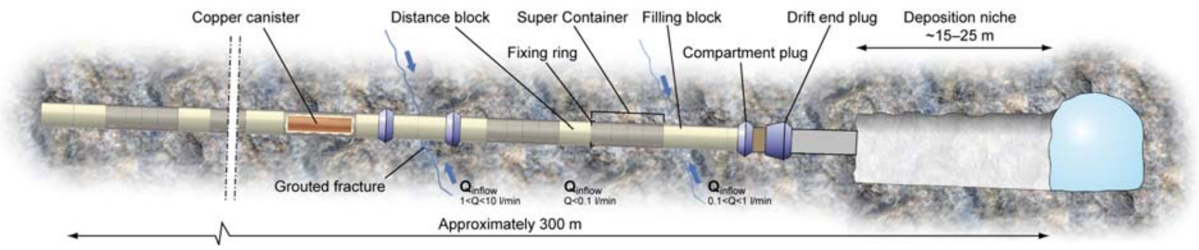

Figure 7: Artist impression of the KBS-3H deposition drift

When the transport tube with the SC has been transported to the repository area, the following activities are performed:

- placing the transport frame with the transport tube in the correct position in the chamber in front of the deposition drift;
- docking of the transport tube to the deposition drift;
- docking of the deposit machine to the transport tube;
- initialization of the deposit process for the SC;
- transportation of the SC inside the deposition drift;

- emplacement of the SC in the deposition drift;
- transport and emplacement of distance blocks in the drift;
- if needed also fixing rings and compartment plugs may be installed depending of the inflow of water into the deposition drift. Post-grouting for reduction of ground water inflow into the drifts is part of the preparation of the drift before start emplacement work;
- construction of the sealing plug but these activities is similar as for the KBS-3V design.

Table 2, presents a **"what-if"** analysis for this process.

5 Conclusions about Identified Failure Risks During Emplacement of the Super Container and Distance Blocks

Compared to the KBS-3V design the following advantage is identified:

- The lifting of the SC is done with water cushions and the lifting height is very low. No risk for dropping the waste package.
- No backfilling of large deposition drifts, about 6 000 m^3 each, is required.

The following disadvantages from a safety/availability point of view are identified:

- The consequences of malfunction of the deposition equipment including fire need to be investigated further and the small diameter of the drift makes it difficult to carry out correcting actions. However, the deposition machine should in all cases be possible to take back for repair if anything happens.
- If the ground water flow into the drift is too high, piping in the buffer may occur. Installations of compartment steel plugs in a drift may solve this problem but it is still a risk that must be investigated further. The requirements on ground water management are higher for KBS-3H then for KBS-3V.
- The events that can have severe impacts on availability are more in the KBS-3H design, since this is more technologically complex than 3V.

Table 2: What-if for deposit area

No.	Event	Consequence	Cause	Measure	Detection	Comment
1	The transport tube and the gamma gate is damaged during the transport to the chamber.		The transportation vehicle hits something.	The function of the gamma gates must be tested.	-	The transport tube and the gamma gate shall be able to withstand such an event.
2	Docking of the transport tube to the deposition drift not sufficiently exact	When the gamma gate is opened, possible radiation to personnel.	Incorrect manual action (not in position)	Visual inspection. The radiation is fairly small and it will require that personnel is very close to be exposed.	Visual inspection	Instrument to measure the exadt position needed.
3	The gamma gate on the deposition machine side is opened too early	Radiation on personnel	Incorrect manual action	The radiation is fairly small and it will require that personnel is very close to be exposed. There is a radiation shield mounted on the deposition machine and hence this is only relevant if the gamma gate is opened before the deposit machine has not been brought into position	Radiation monitors with proper alarm settings is supposed to be present	The gamma gate has to be slightly opened when the deposition machine is set in position (due to the slide plate).
4	The deposition machine gets stuck and pushes the transport tube back – an opening between the drift and the transport canister occurs	The scenario is not relevant, see measure.	E.g. the slide plate gets stuck in the level crossing to the drift	The reaction force that can be created is not sufficient to move the transport tube back. The docking maneuver cylinders prohibit movement and the support rack is bolted to the rock.	-	
5	The deposition machine breaks down when in the deposition drift.	Possible radiation of the person that executes repair work in place (if necessary) Availability (it may take time to fix)	Mechanical failure	The machine can be retracted with a wire. There is a radiation protection mounted between the SC and the “engine” if the repair work has to be done in the drift	-	
6	The deposition machine gets stuck when in the deposition drift (see e.g. 7)	See 5. Mainly an availability issue.	Mechanical failure, unevenness in the drift etc.	The wire for retraction will minimize the possible events.	-	This risk must be minimized.

No.	Event	Consequence	Cause	Measure	Detection	Comment
7	The SC gets stuck; tips due to failure of angle gauge	Mainly an availability issue. Should not damage the SC.	Mechanical failure	The "climbing" will have to be done in many steps, since the possible climbing is reduced by the slide plate and the guides for the slide plate.	See measure.	This is an identified issue for the machine and a known potential problem.
8	The guides on the deposition machine hit the feet on the SC	Availability issue	Mechanical failure	The guide will only have possibility to hit one pair of feet. The SC will still be standing even if the first two pair of feet are demolished.	-	
9	The final positioning of the SC in the drift is not correct	Will affect the long term safety analysis.	Mechanical failure or operator error	The positioning of the slide plate is measured with laser, i.e. the distance from the slide plate to the distance block is possible to get. The camera on the slide plate will detect if the SC is correctly placed (and hence the SC position is also possible to get). The carriage is moved forward until stop.	Laser measurement and "drive until it takes stop".	The measures to verify the position of the SC need more details.
10	The positioning of the bentonite distance blocks are incorrect	Will affect the long term safety analysis	Mechanical failure or operator error	The carriage is moved forward until stop.	-	No measurement of correct distance when in position.
11	Hitting the distance blocks/SC with speed with the transported SC/distance block	Will probably have no effect, since the carriage has a fairly low speed.	Mechanical failure or operator error	Limited speed when operators control speed (5cm/s) close to the final position	-	The consequence may need clarification, since the positioning is based on "drive until stop"
12	Incorrect amount of bentonite/SCs inserted into the storage or in incorrect order	Will affect the long term safety analysis	Operator error	Administrative routines. The positioning is determined in advance. Logging of position and graphical plots of the inventory.	-	Possible alarm from the computer if the final position is incorrect.
13	Too large flow of water around the SC or bentonite distance blocks – undetected or incorrectly measured	Will affect the long term safety analysis (possibly the bentonite will be "flushed" away)	Mechanical failure or operator error of flow measurement	The water flow is measured and sealed if necessary		The installation of compartment steel plugs will reduce the possible affected areas if they are tight.

No.	Event	Consequence	Cause	Measure	Detection	Comment
14	Too large flow of water, steel plugs not sufficiently leak tight	See 13.	Incorrectly positioned plug or unevenness in the rock around the steel plug.	The position of the plugs are determined in advance and the mill out can be verified.		See 13.
15	Fire in the deposition machine when in the deposition drift	The machine will have to be recovered.	Mechanical failure	The fire-load is kept as small. There is a fire extinguisher situated on the deposition machine. No fire load is close to the SC. The deposition machine is separated from the SC by the radiation shield.		The temperature in the drift in case of fire has to be studied?