TESTING OF BENTONITE BUFFER INSTALLATION IN ONKALO UNDERGROUND CHARACTERIZATION FACILITY (URCF)

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Background

The Finnish company Posiva Oy is the expert organisation responsible for the final disposal of spent nuclear fuel of the owners of Teollisuuden Voima Oyj and Fortum Oyj.

Posiva Oy has constructed the ONKALO underground rock characterization facility (URCF) in Olkiluoto Finland. ONKALO is located at the same depth (~420 metres) as, and adjacent to the final repository for storage of Finlands spent nuclear fuel. The final repository will consist of deposition holes drilled ~ 8 m deep and 1.75 m in diameter into the floor of deposition tunnels excavated at ~420m depth. Into these boreholes the copper canisters containing the spent fuel will be installed and subsequently surrounded by a bentonite buffer. The bentonite buffer's outer diameter is 1.65 m; height is 7.8 m and it consists of 10 blocks, each weighing from 1.8 to 3.6 tons.

As part of ensuring that this storage method is robust and able to fulfil the isolation function required, there are requirements set for each component of the Engineered Barriers System (EBS). For example, the bentonite components of the Engineering Barrier System (EBS) have to fulfil certain density and homogeneity requirements to ensure safe functional performance for thousands of years.

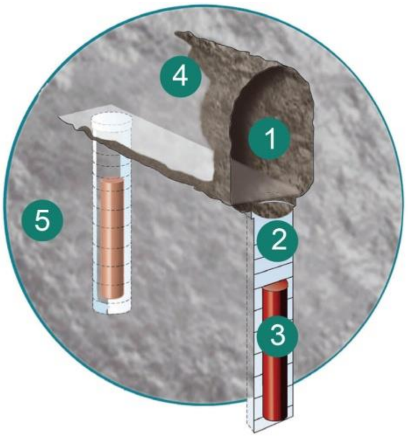

Fig. 1 KBS-3V Engineered Barriers System (EBS)

The KBS-3V repository design adopted by Posiva also calls for the deposition tunnels to be backfilled with highly compacted bentonite blocks. This geometry results in small gaps remaining between the buffer blocks and the surrounding rock in the deposition and also between the rock and the blocks installed in the deposition tunnels.

Compacted bentonite pellets are to be used to fill the gaps so as to ensure suitable thermal conditions develop, to restrict groundwater flow in the vicinity of the canister and to physically protect the canister.

LUCOEX WP 5:

In LUCOEX Work Package 5, Posiva has been developing the technologies associated with installation of the bentonite buffer in a vertical deposition in crystalline rock. This is part of the need to prove technical viability of the KBS-3V concept. WP5 aimed to develop the necessary machinery and quality control programme to accomplish buffer installation in the KBS-3V geometry. This work also included identifying how to address problems that might be encountered during installation of the buffer.

The first step of in WP5 was to show that it is possible to carry out buffer emplacement within the required time of 2 hours per borehole while maintaining an accuracy of +/-1 mm to the deposition hole's centreline. The time requirement excludes the time spent installing the spent fuel canister before the 4 topmost disc blocks. From that point a reliable means of filling the gap between the buffer blocks and the rock needs to be demonstrated. From there identification of and approach to addressing potential installation upsets need to be developed.

The work of WP5 started in 2011 with a study of options for the buffer installation procedure. The target was to find new ideas for the buffer block installation and handling. The result of the work was development of a buffer transport container, an installation machine (BIM) and a separate bentonite transportation device (BTD) to supply the BIM with buffer blocks. Manufacturing of the BIM and BTD machines and devices including the buffer transport container started in July 2012 and were completed in September 2013.

Fig. 2 Buffer installation machine (BIM).

Fig. 3 Buffer transport device (BTD).

Technological Requirements:

An important goal of the demonstrations is confirming the accurate positioning of the blocks. The requirement set for positioning the centre of the block is +/-1 mm. In Posiva's buffer design, the actual requirement of positioning accuracy is +/-2 mm. The more demanding requirement of positioning used in this work was to ensure that it will be possible to meet the required installation tolerances in the final repository. Additionally, concerns were raised regarding a recent (after 2012 start of equipment manufacture) regarding the sensitivity of buffer block to air humidity indicated that slow buffer installation could result in the swelling of installed buffer blocks, which will jeopardize the whole disposal process.

A requirement that drives much of the development work is the installation time of not more than two hours for the whole buffer.

The bentonite buffer is installed on the deposition holes by a remote controlled BIM. The BIM is transported to the deposition hole by a terminal tractor. Rough positioning is required to be performed with a 5 cm accuracy.

The accurate positioning is carried out by a laser tracker, utilising the focus points attached to the deposition tunnel. In accurate positioning, the BIM rises on legs and it is carefully moved in a transverse direction on top of the deposition hole. The accurate longitudinal positioning is made by the crane of the BIM during the block installation.

The BTD is used for transportation of buffer block containers from the deposition tunnel entrance into the tunnel and up to the BIM. The blocks are transported to the BIM one-by-one. The BTD is remotely controlled and moved by a terminal tractor.

Field Demonstrations of buffer installation

The installation of the buffer blocks into a borehole was tested in two places: first in the test hall, which is located at the ONKALO site, and then in the ONKALO URCF demonstration tunnel. The tests were performed with concrete blocks simulating buffer blocks and with actual bentonite blocks. In this installation concept, the blocks are placed in air-tight containers when they are transported to ONKALO. The container top (lid) also includes compartments for bentonite pellets. Buffer installation demonstrations started 2014 in ONKALO area test hall and continued 2015 in ONKALO demonstration tunnel.

Fig. 4 Container for bentonite buffer transportation.

The installation of buffer blocks was tested first in a test hall, which is located at the ONKALO site. In the floor of test hall is a full scale disposal hole made of transparent Plexiglas to allow for visual inspection of the installations.

The installation tests in the test hall were preceded by testing of the automation components of the BIM and BTD. The whole buffer block and pellet installation cycle was tested first in the test hall before moving to ONKALO URCF. Some improvements for the BIM and BTD were made before the moving to ONKALO URCF.

Fig. 5 Bentonite buffer installation in Onkalo URCF.

The sequencing of the installation tests were as follows:

- At the beginning of the demonstration, the BIM is positioned over the deposition hole, and buffer blocks are ready in containers at the mouth of the demonstration tunnel.
- The BTD transports the blocks to the BIM and the BIM's crane fetches a buffer block from the BTD located in the front part of the BIM.
- The crane lifts the block out of the container and moves it above the hole.
- The crane then lowers the block into the hole, with the final part of lowering controlled by a laser tracker.
- The vacuum is released and the container top is removed from the block.
- The crane then lifts the container top from the hole and onto the shelf of the BTD.

Requirements of precision in buffer block positioning are very demanding. Performed demonstrations showed that the chosen technology can fulfil requirements. Ability to install the blocks with laser tracker to within millimetre accuracy was confirmed.

Results from the buffer installation demonstrations were encouraging and suggested that continuing the development of this installation concept would be appropriate. Although successful, the installation process required more time than expected/allocated for this activity. Achieving the targeted installation speed, installation time for the buffer as a whole – not more than two (2) hours – requires further improvements to the machine and more installation test cycles to optimize process timing.

Fig. 6 Buffer installation demonstration in Onkalo URCF.

Dealing with installation problems: block and stray items removal

During the installation of buffer blocks with a vacuum lifter, there is a risk of dropping the block into the deposition hole. In this situation the remedial actions required can be separated into two scenarios – before and after canister installation. Before installation of the canister, it is possible to use conventional methods to lift the pieces of block out of the deposition hole. After installation of a radiating canister into the disposal hole only remote-handling methods can be used.

In WP5, two approaches to removing a damaged or otherwise unsuitable buffer block from a placement hole were considered. The first is drilling anchors into large segments to allow for hoisting from the hole. The second approach was water-jet cutting of the block so as to allow for its removal by a suction device.

The conduct of recovery trials for a situation where there is no canister present and the block is substantially damaged (the vacuum lifter cannot be used to lift large fragments), began with use of manually-installed anchors and then hoisting the large fragments from the deposition hole. This approach was not found to be reliable due to a tendency for the lifting anchors to pull out of the blocks. It was determined that in many situations it would be easier to manually reduce the damaged block(s) into pieces that could be cleared by use of a suction device or other suitable lifting means. Careful evaluation of the mechanical state and surface condition of any underlying blocks will need to be completed since the subsequent installation of overlying blocks is very sensitive to surface levelness.

Problem handling related to a damaged buffer block after canister installation requires that the work be performed remotely because of the radiation field from the canister. Additionally, extra care has to be taken not to damage (breach) the installed canister.

A number of options for use in removing a damaged buffer segment from a placement hole where a canister is already present were considered. Of these, hydrodemolition was identified as a method with considerable potential for use in removing bentonite from deposition hole. A hydrodemolition machine cuts the bentonite into small pieces using a very high water pressure and has an attached vacuum suction line to remove the bentonite fragments and slurry. This type of equipment can be used in all situations involving complete bentonite removal from deposition hole; both before canister is installed, or by remote control after canister installation.

A prototype water jet excavation machine was designed with a combined suction pipe and 3000 bar water pressure hose lines. Tests were successfully performed on the surface in December, 2014 and in the ONKALO demonstration tunnel in May, 2015. In the underground trials, the mist from the high pressure water was far less

problematic than expected based on the ground level test. The bentonite sludge generated during cutting remained almost entirely inside the test deposition hole, where it was picked up and removed by the vacuum line. Based on the test in ONKALO, the removal time for one disc block using this method is approximately one hour.
In order to evaluate any potential for this high-energy cutting device to damage a spent fuel canister a further trial was completed. During the ground level test, the water jet was intentionally directed onto a copper canister lid (of the type that would be present on an actual canister) for several minutes. It caused some polishing on the copper and it was possible to feel a slight edge to the polished area where the jet had been active for a prolonged period. The lid had not been perforated or otherwise mechanically compromised. For production use it would be relatively easy to design different pressure and suction nozzle variations for operation on bentonite buffer between canister and host rock. By mechanically limiting the water jet direction it would be possible to avoid copper canister damage.

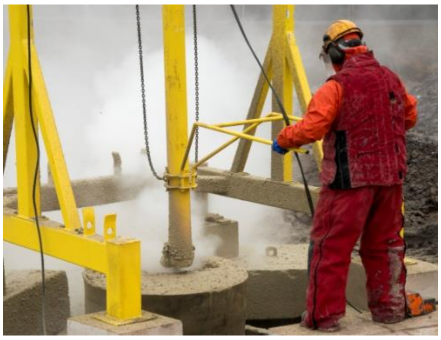

Fig. 7 Testing of water jet excavation on the surface.

The major drawback to using hydrodemolition is that the whole of the buffer and the canister need to be removed. Introduction of water into the deposition hole, means it is not possible to leave underlying bentonite usable. Other options for removing bentonite parts accurately enough in the presence of a radiation field would be very time consuming, if practical at all. On completion of the buffer excavation to the point where the canister has been recovered, a decision would need to be made regarding reuse of the deposition hole. It is expected that any canister involved in a recovery would be returned to the surface for repackaging of the spent fuel into a new canister.

For incidents involving other stray materials entering the deposition hole (e.g. rock fragments, stray bentonite pellets, nuts or bolts) after canister installation, a simple vacuum suction device can remove almost all particles in centimetre size range (also useable before canister installation). Larger items would need a remote operated device, similar to a commercial concrete demolition machine. Evaluation of the surface following this removal will need to be completed before additional buffer segments are installed.

Conclusions

LUCOEX WP5's activities have led to the development of handling and placement equipment and methods that are potentially suitable for use in the installation of buffer in a KBS-3V placement option for spent nuclear fuel. Additionally, approaches and methods to accomplish removal of defected buffer blocks after their installation have been identified and tested. Further technological optimization is required in order to reduce the time needed to accomplish buffer installation

As a result of this work, the technical viability of this repository method has been further demonstrated, providing further confidence in the KBS-3V concept.

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Video of bentonite buffer installation machine:
https://www.youtube.com/watch?v=e-CG0dJ0ZWM

Pictures:

1. KBS-3V buffer
2. BIM
3. BTD
4. container
5. ONKALO
6. emplacement test
7. problem handling test