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# DOPAS

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## Deliverable n°D3.22

## D3.22 DOMPLU experiment


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**ABSTRACT:**

This Deliverable shows the DOMPLU Experiment, which has been emplaced in the Äspö Hard Rock laboratory.



**RESPONSIBLE**:

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# 1 Background

The KBS-3V method is proposed by SKB and Posiva for the disposal of spent fuel packaged in copper canisters with cast iron inserts in a crystalline host rock. The long-term safety principles are based on isolation and containment of radioactive waste through the choice of a stable geological environment at depth and the use of a multi-barrier system consisting of engineered barriers (canister, buffer, backfill, and closure) and the host rock. The canisters are emplaced in vertical holes, containing pre-compacted blocks of bentonite buffer, below horizontal deposition tunnels. The deposition tunnels are backfilled with bentonite blocks and pellets, and closed with a deposition tunnel plug, see Figure 1-1.

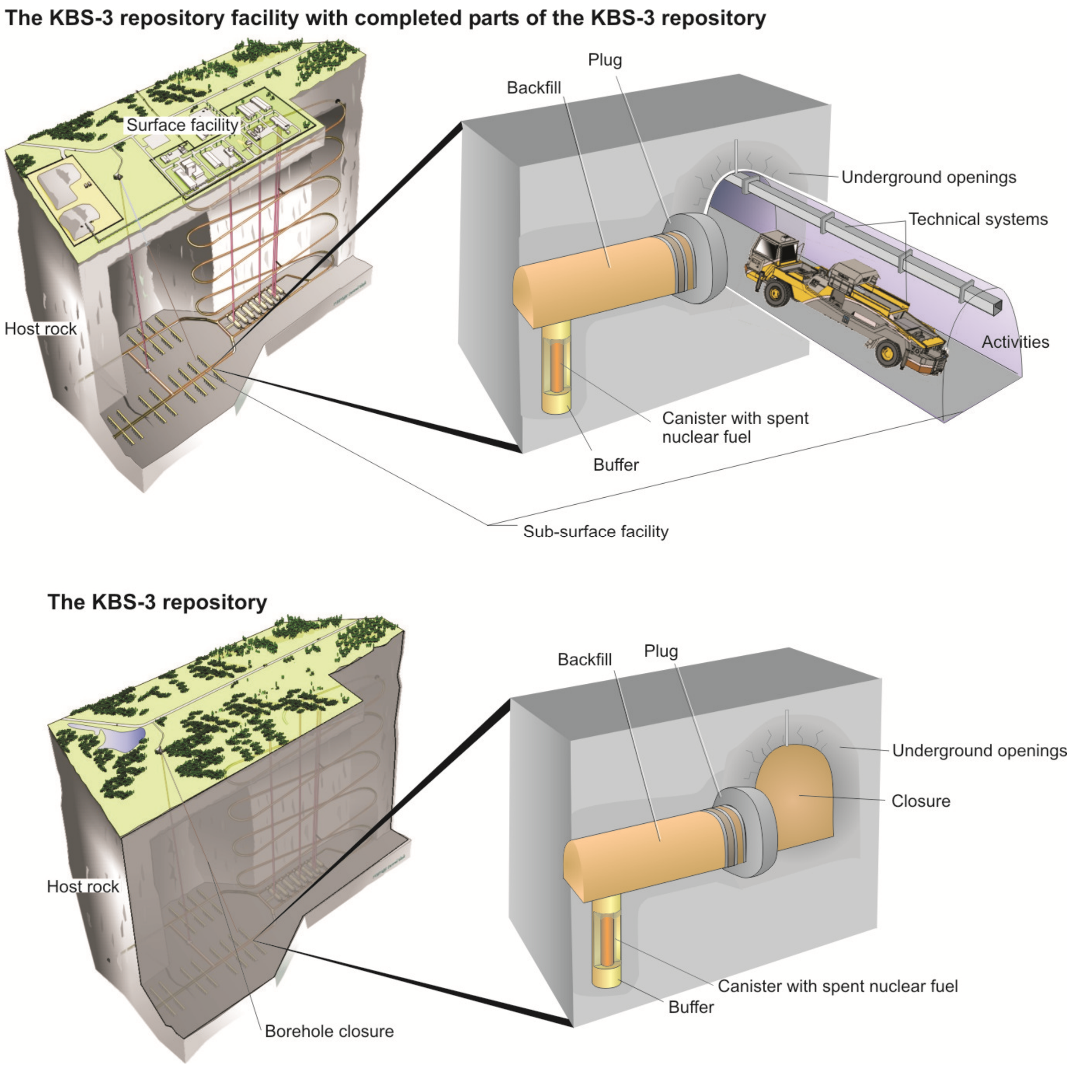


***Figure 1-1.*** *The KBS-3 repository facility and the KBS-3 repository. The KBS-3 repository is constructed within the KBS-3 repository facility (SKB, 2010a).*

Owing to the potential for water flow to erode the bentonite buffer in the deposition holes, the water flux across the plug must be low. The initial requirement on water tightness is achieved by contact grouting of the concrete dome which is completed approximately 100 days subsequent to casting. The plug design includes a filter that drains water past the structure in order to delay the pressurisation of the plug until the concrete has cured and developed sufficient strength. To assure that low hydraulic conductivity is provided for the full service life of 100 years, a watertight seal composed of swelling bentonite clay is also used in the reference design. After the bentonite seal has saturated, the leakage requirement on the concrete dome is redundant and the main purpose of the concrete dome is to act as support and carry the loads of the water and swelling pressure from the deposition tunnel.

In Sweden, a site has been selected at Forsmark for final disposal of spent nuclear fuel from the Swedish nuclear power plants. The spent fuel repository will be located approximately 470 m below the ground surface in crystalline rock. A license application for disposal of spent fuel, based on the KBS-3V method, was submitted in March 2011.

## 2 The DOMPLU experiment

System design development for deposition tunnel end plugs has been carried out in cooperation between SKB and Posiva Oy according to the KBS-3V reference disposal concept. The system design development has included verification of the dome plug design by analytical and numerical calculations, laboratory examinations and small scale tests. The main activity though, was to test a plug system in full scale (The DOMPLU experiment) with representative hydrogeological conditions at the Äspö Hard Rock Laboratory (HRL).

The DOMPLU (Dome Plug) experiment is based closely on the reference conceptual design of the SKB deposition tunnel plug, as described by SKB (2010b) in the licence application for the KBS-3V repository. Accordingly, DOMPLU represents a full-scale test of the deposition tunnel plug that is currently expected to be used in the Swedish Spent Fuel Repository. DOMPLU includes a few modifications intended to test the performance of new materials planned to be introduced in the future as part of SKB's revised reference design for a deposition tunnel plug.

One of the main objectives of the full-scale test was to demonstrate that it is feasible to build the dome plug system. This included verifying practical aspects such as logistics and arranging of parallel activities. It was also to be shown that it is possible to use an unreinforced concrete dome plug consisting of low-pH concrete mix B200 which can satisfy the design requirements. Furthermore, an advanced cooling scheme should be tested with the aims to reduce the induced stresses in the concrete dome during hydration and to cause a thermal pre-stress after contact grouting.

Another crucial purpose of the experiment was to measure the water sealing function of the plug by subjecting it to a high water pressure, potentially up to 7 MPa. To facilitate pressurisation, the experiment was to be installed 450 m below ground in the crystalline rock at the Äspö HRL. Since the available groundwater head at this depth is approximately 3 MPa, and it would take a long time to reach that pressure inside a plugged tunnel, a pressurization system was designed to inject water behind the DOMPLU structure.

In addition, a water leakage measurement system was to be installed on the downstream side of DOMPLU to verify the leakage rate of outflowing water across the plug.

A layout of the DOMPLU experimental set-up is shown by Figure 2-1.

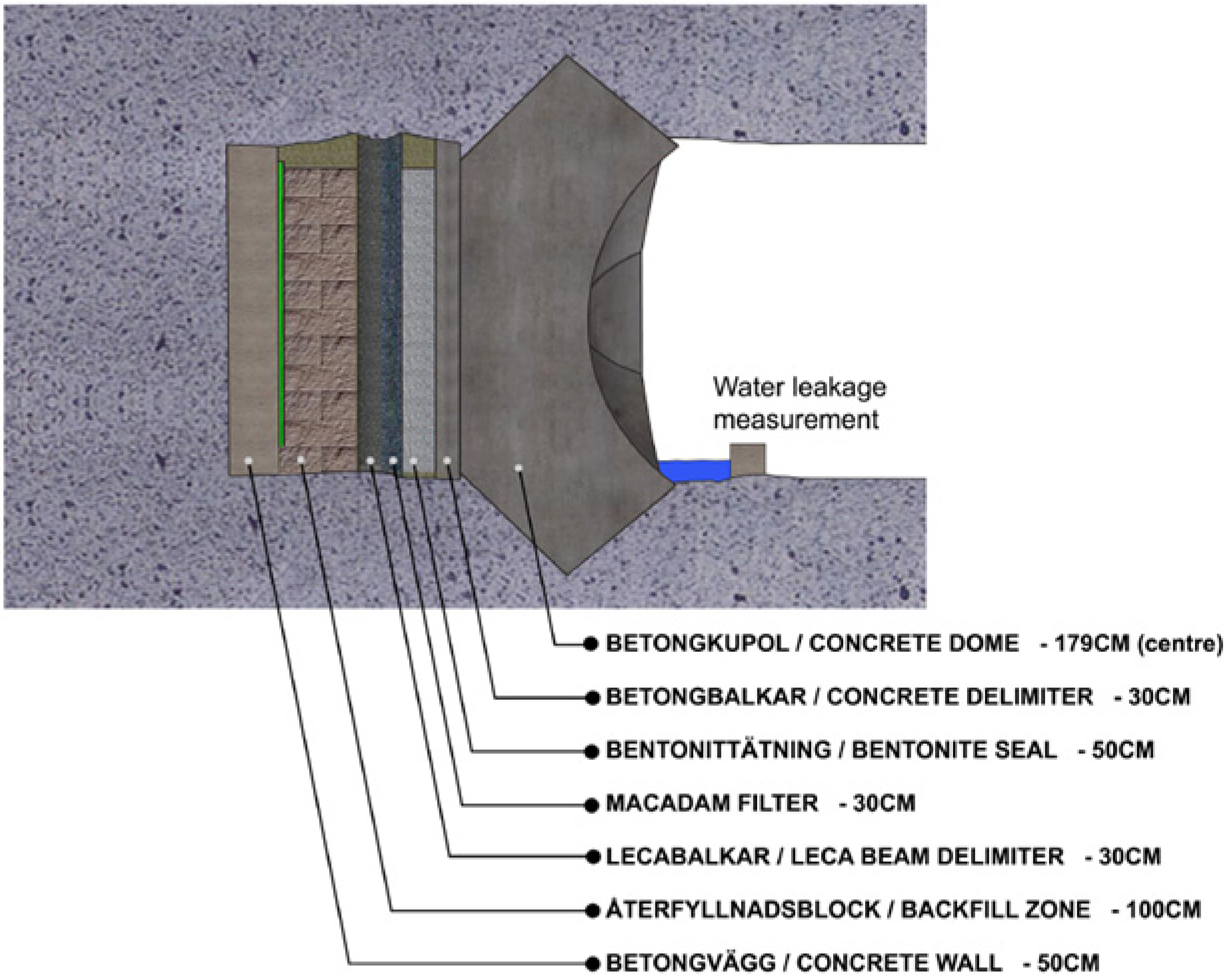


***Figure 2-1***. *SKB's design for the DOMPLU experiment, with backfill, filter layers and bentonite seal on upstream side of the concrete dome. Water is collected by a tight weir downstream of the concrete dome and the leakage rate is continuously recorded by an on-line scale connected to this weir.*

## 3 About this report

As DOMPLU was designed and construction was already underway at the start of DOPAS project, the work of DOMPLU within the DOPAS project is focused on the monitoring and performance assessment of the full-scale plug (Task 4.3). Nevertheless, this report briefly summarises the installation of the DOMPLU experiment in Äspö Hard Rock Laboratory. The extensive project summary, including full descriptions of monitoring and assessments of all available DOMPLU results until September 30, 2014, is provided by the DOPAS Deliverable D4.3.

# 4 Installation of DOMPLU

A new 14 m long experiment tunnel in Äspö HRL was dedicated exclusively for the DOMPLU full-scale test. To prepare the tunnel excavation and to decide on the plug location, a 30 m pilot hole was drilled for the purposes of core and borehole mapping and conduct of high-pressure water injection tests (up to 10 MPa). The tunnel geometry needed to conform to the reference KBS-3V deposition tunnel (SKB 2010c) and was excavated by drilling and smooth-blasting techniques. The result is a horseshoe-shaped tunnel contour according with principle dimensions, width 4,2 m and height 4,8 m.

In the summer of 2012 a concrete wall was cast at the tunnel face to provide a defined start position for installation of the plug components. In the autumn of 2012, an octagonal slot excavation for the concrete dome abutment was carried out by wire-sawing, see Figure 4-1. Technical challenges were taken into account related to minimization of Excavation Damaged Zone (EDZ) in the tunnel and smoothness of surfaces required for controlled concrete fitting. New workers safety arrangements were also developed.

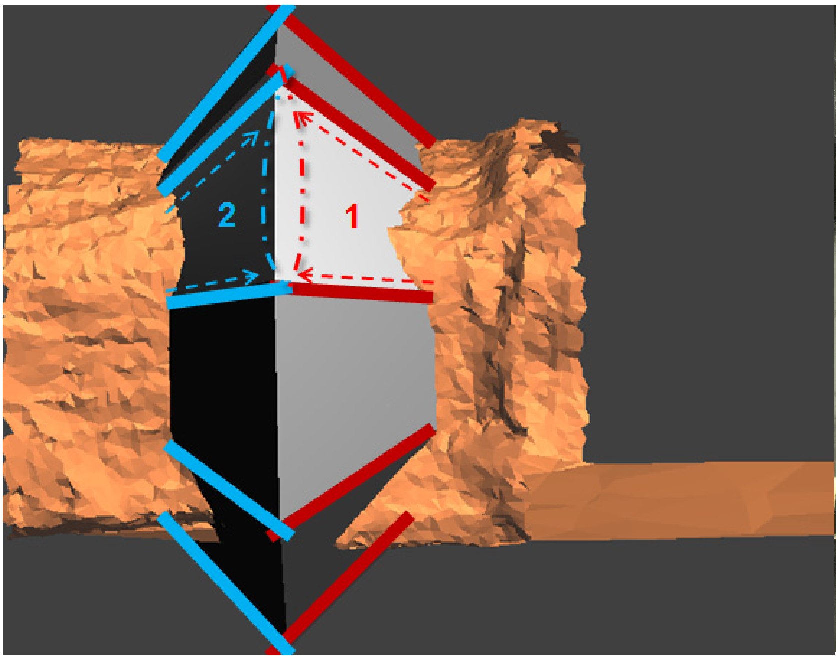


***Figure 4-1***. *Left: Principle for drilling and wire-sawing of the octagonal slot by blind cuts. Right: Part of the excavated slot after completion.*

The backfill, the bentonite seal and the filter components were installed in January 2013, see Figure 4-2. (January 30, 2013 is defined as day 1 of measurements in the DOMPLU assesment report, DOPAS D4.3).

Pipes for contact grouting and the concrete cooling system were installed during mid February directly followed by formwork assembly for the concrete dome.

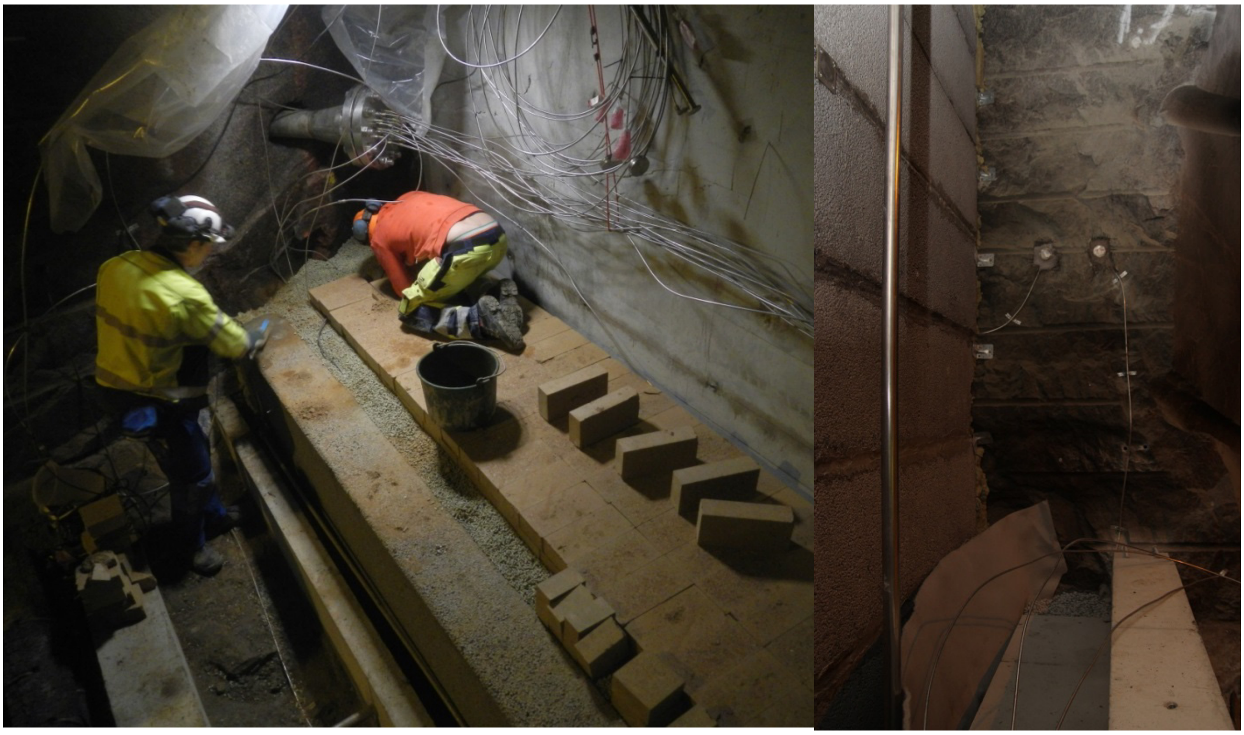

*__Figure 4-2__. Photos of the DOMPLU installation in January 2013. Left: Top view of the arrangement of bentonite blocks and pellets in the backfill transition zone. Right: Side view of the filter section (LECA beams, drainage/air pipe and gravel), geotextile delimiter, bentonite seal (MX-80 blocks and pellets) and concrete beam delimiter. All cables inside the plugged volume are led in steel tubes to protect them from being damaged due to high water pressure.*

The concrete dome was cast on March 13, 2013, see Figure 4-3. The cooling system was used to cool the structure down to +4°C at the time of casting to prevent thermal gradients. During the casting temperatures within the concrete dome were recorded as direct input to calculations of the cooling procedure. The use of a cooling machine resulted in very low concrete temperatures during hydration, reaching maximum of about the ambient rock temperature (15°C). This contributed to a gentle hardening of the unreinforced concrete dome and low risk of cracks. Furthermore, pressure on the formwork was recorded during casting. The formwork could be removed as planned after 28 days of hardening.

Finally, about three months after casting, contact grouting with ultrafine cement was performed in June 2013. At this time, the cooling system was once again activated stepwise to +1°C during two weeks to force contraction and opening of the concrete-tunnel gap to facilitate grouting of the gap between the concrete dome and the rock contact.

***Figure 4-3****. Left: Formwork by Doka used for casting of the concrete dome in March 2013. Right: The concrete dome after removal of formwork in late April 2013.The beam in front of the dome was used for positioning of displacement sensors.*

## 4.1 Monitoring systems

The backfill, filter and bentonite seal components are instrumented by 51 sensors at several positions. The properties being measured by the array of sensors includes temperature, relative humidity, displacements, pore pressures and total pressures. These were placed on-site at the same time as the components. The cables from sensors in the backfill and seal layers are lead sideward through pipes in the rock to a monitoring niche in the neighboring tunnel, a distance of about 21 meters. The main purpose with this route was to avoid penetrating the bentonite seal by sensor cables.

Monitoring of the concrete dome structure is done by 56 sensors measuring strains, temperatures, axial and radial displacements. Sensors within the concrete are lead out the front face of the concrete plug.

## 4.2 Pressurisation system

The accelerated testing is achieved by using artificial pressurization with water behind the plug, and having incremental increases in pressurizing. The pressurization system was specifically developed for the purpose of injecting water to DOMPLU. It was prefabricated by standard components at the Äspö HRL, above ground. The pumps are redundant and each one was dimensioned to be able to reach 10 MPa pressure at 10 l/min. A flowcharter of the pressurization system is seen in Figure 4-4.

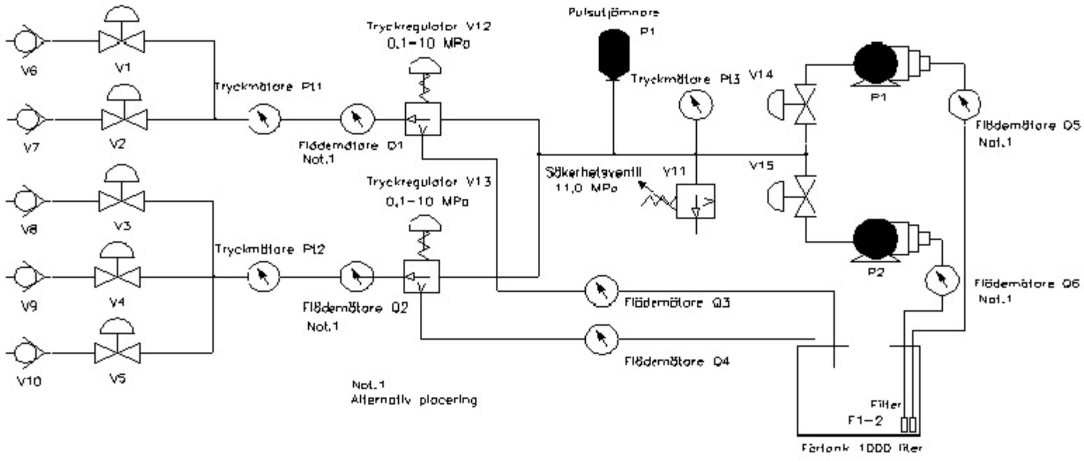


***Figure 4-4.*** *Pressurization system flowcharter. (Text in Swedish)*

The pressurization of the plug system was performed by pumping water into the backfill and filter section through pipes installed in a 21 m lead-through borehole to the experimental tunnel. In total, five pressurisation pipes with an outer diameter of 20 mm were installed in this lead-through. Three of the installed pipes end in the layer of gravel located behind the bentonite backfill, while the last two pipes end in the gravel filter of the plug system. By using the three backfill pipes, the plan was to achieve a channel through the pellet filling to the filter section, from which the water then initially should be drained.

## 4.3 Leakage measurement system

With the principal goal of monitoring water leakage though the plug over time, a water collection system was installed on downstream side of the concrete dome. A watertight weir, see Figure 4-5, was cast to collect all leakage water passing the plug. The water in the weir is then transported via a steel pipe into a basin, also seen in Figure 4-5, where the water is automatically weighed, providing an on-line record of the leakage rate.

A plastic sheet cover, as shown by the photo in Figure 4-6, was installed on the downstream side of the concrete dome in order to prevent leakage from evaporating and to allow condensation to drip into the weir.

***Figure 4-5.*** *Left: The watertight weir. Right: Basin for weighing of leakage water outflow from the weir*

***Figure 4-6.*** *Installed plastic sheet, which encloses the concrete dome plug to prevent evaporative water loss.*

## 5 Conclusion

The civil work for DOMPLU was in general successful with a few important experiences gained from construction. These experiences are highlighted and provided in DOPAS D4.3.

The pressurization of the DOMPLU experiment could successfully start in September 2013 (month 0) when the bentonite seal had been artificially wetted by flooding of the filter for the entire summer. At that time it was recognized that the experimental set-up would have good potential to provide monitoring data as expected. The monitoring results are evaluated and reported in the DOMPLU technical summary report, DOPAS D4.3.

## 6 Acknowledgements

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## 7 References

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**SKB, 2010b.** Design, Production and Initial State of the Backfill and Plug in Deposition Tunnels. SKB Technical Report TR-10-16. Svensk Kärnbränslehantering AB.

**SKB, 2010c.** Design, Construction and Initial State of the Underground Openings. SKB TR-10-18. Svensk Kärnbränslehantering AB.