R-08-137

Buffer protection in the installation phase

Hans Wimelius, Svensk Kärnbränslehantering AB

Roland Pusch, Geodevelopment International AB

December 2008

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1402-3091
SKB Rapport R-08-137

Buffer protection in the installation phase

Hans Wimelius, Svensk Kärnbränslehantering AB

Roland Pusch, Geodevelopment International AB

December 2008

Summary

The research and development of the design and construction of the SKB`s repository for final disposal of spent reactor fuel is conducted along several paths (“lines”). Issues concerning the bedrock are dealt with in the “rock line” and those related to buffer and backfill in deposition holes and tunnels are considered in the “buffer line” and “backfill line”, respectively. These lines also deal with sub-activities that are coupled to several other lines. One of them includes development of techniques for protecting buffer blocks from moisture and water in the installation phase. Techniques and methods for placement and removal of the “buffer protection sheet” are dealt with in the “buffer line”. The removal is, however, considered as being part of the backfilling sequence.

Since the performance of the sheet is of fundamental importance to the placement and function of the buffer it deserves particular attention. Thus, the removal of the rubber sheet that serves to protect the buffer blocks in the installation phase may be difficult and can cause significant problems that may require retrieval of already placed canister, buffer and backfill. These matters are in focus in the present report.

Arrangements for protecting already placed buffer blocks from moist air and water have been tested in earlier large-scale experiments, i.e. the Prototype Repository project at Äspö but the experience from them has called for more effective protection of the clay blocks as described in the present report. Focus is on the construction of foundation components at the bottom of the deposition holes required for establishing a tight seal between rock and buffer blocks, and on the protection sheet and arrangements for limiting water pressure on it. Special attention is paid to the drainage of the space between rock and protection sheet that is necessary for avoiding failure of the sheet and to systems for achieving this and for providing alarm signals if the allowed pressure is exceeded.

The major conclusions from earlier tests are that preparation of plane concrete foundations for the buffer columns is very difficult, and that more effective protection of the buffer from being wetted in the installation phase is required. The presently reported study serves as continuation of these earlier tests and it is concluded that the concept is feasible in principle. However, additional improvements and more field application, especially under more difficult conditions respecting inflow of water, are required for demonstration of its practical value.

Sammanfattning

Forskningen kring och utvecklingen av design och byggande av ett SKB-förvar av använt kärnbränsle är, representerande i ”linjer”. Frågor som rör berggrunden behandlas i ”berglinjen” och de som rör buffert och återfyllning av tunnlar och deponeringshål i ”buffert-” och ”återfyllnadslinjerna”. Arbetet som rör förslutningen av förvaret behandlas i ”förslutningslinjen”. I de olika linjearna ingår delaktiviteter som har koppling till flera andra linjer. En av dessa är utveckla teknik för att fukt– och vattenskydda buffertblock som installeras i deponeringshålen. Teknik och metod för utförande av installation samt demontaget av buffertskyddet behandlas i ”buffertlinjen”. Demontaget ingår dock i sekvensen för återfyllnaden.

Eftersom buffertskyddets funktionen är av fundamental betydelse för utförandet och funktionen hos bufferten kräver den särskild uppmärksamhet. Sålunda kan demontaget av gummiduken, som skall skydda bufferten i installationsfasen, vara svårt och bristning av duken kan orsaka betydande problem som kan innebära att anbringad kapsel, buffert och återfyllnad kan krävas. Dessa frågor är centrala i denna rapport.

Anordningar för skyddande av bufferten från fuktig luft och vatten har undersökts i tidigare storskaliga försök, t ex projektet Prototype Repository project i Äspö, men erfarenheten från dem innebär att mer effektivt skydd av buffertblocken måste åstadkommas, vilket beskrivs i rapporten. Uppmärksamheten är särskilt inriktad mot utförande av fundamentet på hålbotten och gummidukskyddet som skall ge tätning mellan buffert och berg, samt mot begränsning av vattentrycket mot duken. Särskild vikt har lagts vid dränering av utrymmet mellan duk och berg, som krävs för att undvika bristning hos duken, och vid anordningar för att åstadkomma detta och för att göra ett alarmsystem som signalerar om trycket överskrider tillåtet värde.

De viktigaste slutsatserna från tidigare försök är att utförande av ett plant betongfundament för buffertblocken är besvärligt, samt att mer effektiv tätning av bufferten mot vatten och fuktig luft krävs i installationsfasen. Den i rapporten redovisade studien är en fortsättning av tidigare experiment och visar att konceptet är tillämpligt. Det fordras dock förbättringar och ytterligare fältprovning, särskilt under besvärliga förhållanden avseende vatteninflöde, för att demonstrera dess praktiska värde.

Contents

1 Introduction

1.1 General

Preparation of KBS-3 deposition holes comprises the following activities:

1. A final inspection of the deposition holes is made before further activities in them are initiated. This includes measuring of the diameter and of the inflow for comparison with earlier obtained data. Special attention is paid to the stability of the holes with respect to rock fall and to potential spalling (acoustic measurements).
2. Preparation of the bottom of the hole by casting a bottom bed of silica concrete below the lower copper plate and installation of the upper copper plate,
3. Cleaning by flushing the walls with pressurized water,
4. Placement of pipes and alarm against the rock from the tunnel floor to the bottom of the hole for sucking up water,
5. Placement of buffer protection sheet for preventing water flowing in from the rock or from the tunnel floor to reach the buffer,
6. Placement of buffer blocks up to the top of the canister while keeping the protection sheet anchored at the tunnel floor,
7. Placement of the canister,
8. Completion of the column of buffer blocks,
9. Removal of the protection sheet by pulling it up,
10. Filling of pellets in the gap between the rock and the buffer blocks up to the lower end of the ramp at the individual deposition holes,
11. Completion of the pellet fill of the ramp and start of backfilling the tunnel.

The present report deals with activities numbered 2, 4, 5 and 9 focusing on the buffer protection sheet, particularly the manufacturing, fastening and removal, and on its performance.

1.2 Aim of study

A practical method for protection of the column of buffer blocks from being exposed to water or moisture is needed and the presently proposed procedure is to use a rubber sheet that is tightly connected to a copper plate at the bottom of the hole and draining the space between the rock and the sheet until clay pellets are filled in the space between the buffer blocks and the rock. The Prototype Repository project (Figure 1-1) (the project are described in, /Svemar and Pusch 2000, Johannesson et al. 2004/) involved placement of buffer blocks and canister in six deposition holes with shielding of the buffer blocks only from moisture using a big plastic bag (Figure 1-2). This worked because of the very small inflow of water /Pusch and Andersson 2004/ but in practice it will be required to protect the placed buffer blocks from water and very moist air for which the rubber sheet method is intended to be used as a standard procedure because it resists water pressure better than the plastic sheet. Placing and attaching the sheet to the copper plate that covers the concrete foundation is of little concern but removal of it may offer difficulties and the aim of the present report is to describe in detail how the method can be applied. It also deals with placement and removal of tools that are required for making sure that the sheet works, i.e. drainage and alarm systems.

Installation and removal of the plastic bag worked acceptably but wrinkles caused poor fitting between the sheet and the rock (Figure 1-3). A rubber bag expanded to create tight contact with the rock was therefore used in the presently described experiments.

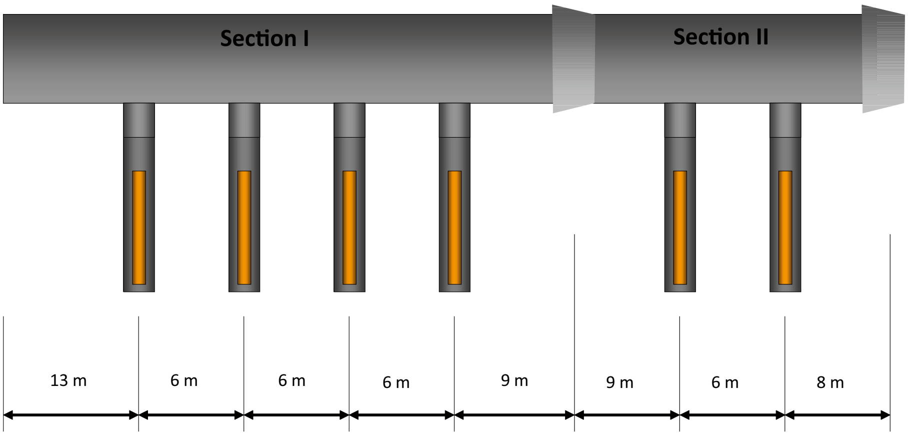


***Figure 1-1.** Longitudinal section of the Prototype Repository test drift at the Äspö URL illustrating six deposition holes with canisters embedded in buffer clay.*

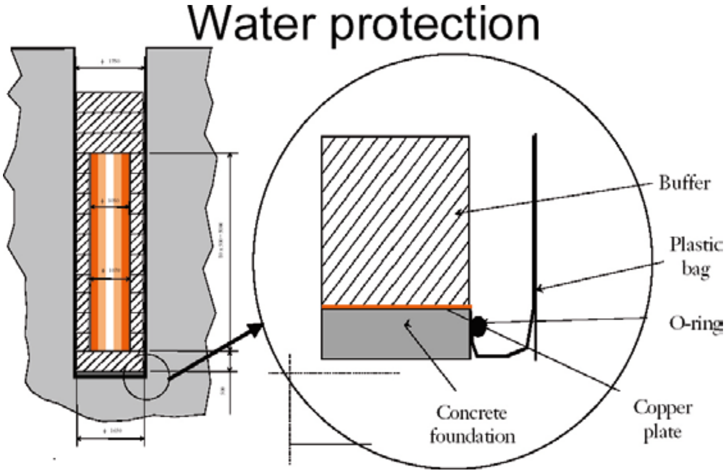


***Figure 1-2.** Schematic drawing of the moisture protection bag of plastic used in the Prototype Repository project.*

***Figure 1-3.** Photo taken after installation of the plastic sheet in the Prototype Repository project.*

1.3 Research and development

SKB's development of the KBS-3V concept has led to improvements with respect to robustness and constructability as manifested by the project which the present report is based. Further work is planned, which is summarized in Chapter 9 of the present report.

2 Buffer blocks in deposition holes

2.1 Principle of buffer protection in the installation phase

An important criterion is that the buffer must not be so affected by the environment prevailing in the deposition hole until backfilling of the tunnel has proceeded beyond it that the long-term safety is jeopardized. This requires that water and humid air are prevented from contacting the buffer blocks, for which a tight, flexible sheet termed buffer protection sheet, is proposed. The main geometrical measures of SKB's concept KBS-3V are indicated in Figure 2-1.

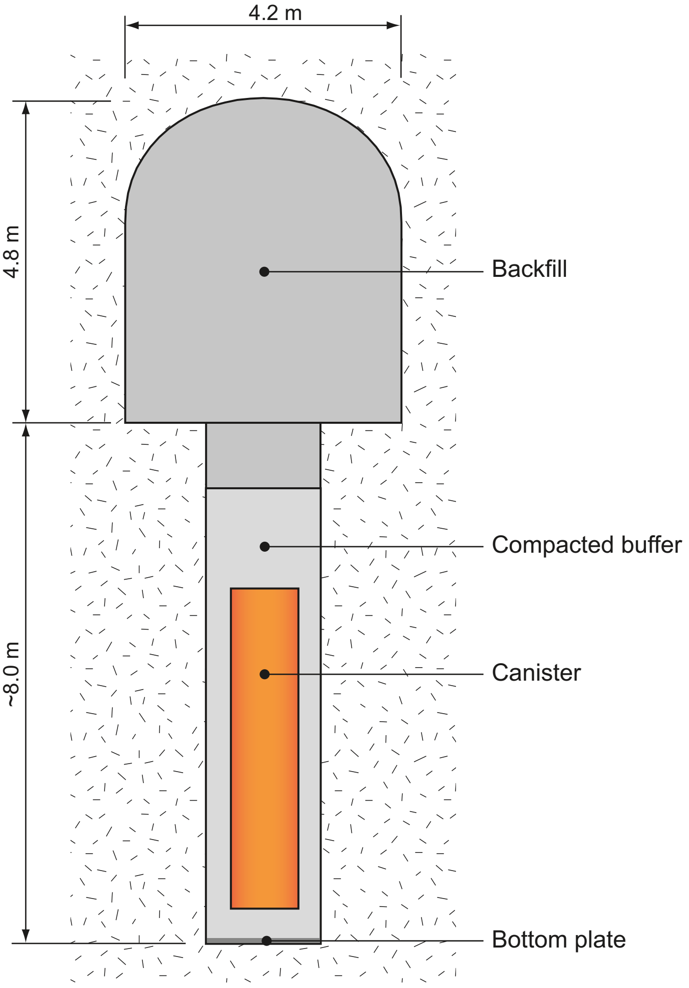


Figure 2-1. Cross section of a deposition hole bored from the floor of a deposition tunnel. The buffer consists of blocks of compacted clay granules and pellets filled in the gap between buffer and rock (not shown).

2.2 Preparation of deposition holes

The length of the period in which the buffer protection sheet needs to serve depends on how the activities in the deposition hole and the tunnel backfilling are combined. This time is estimated at about 3 months, following the presently proposed sequential procedure indicated in Figure 2-2. The sheet will be tightly attached to a bottom foundation and the space between rock and sheet kept drained by vacuum technique until the sheet is removed after which pellets can be filled into it. An alarm system is installed for signalling if the water level rises in the space until the sheet is removed.

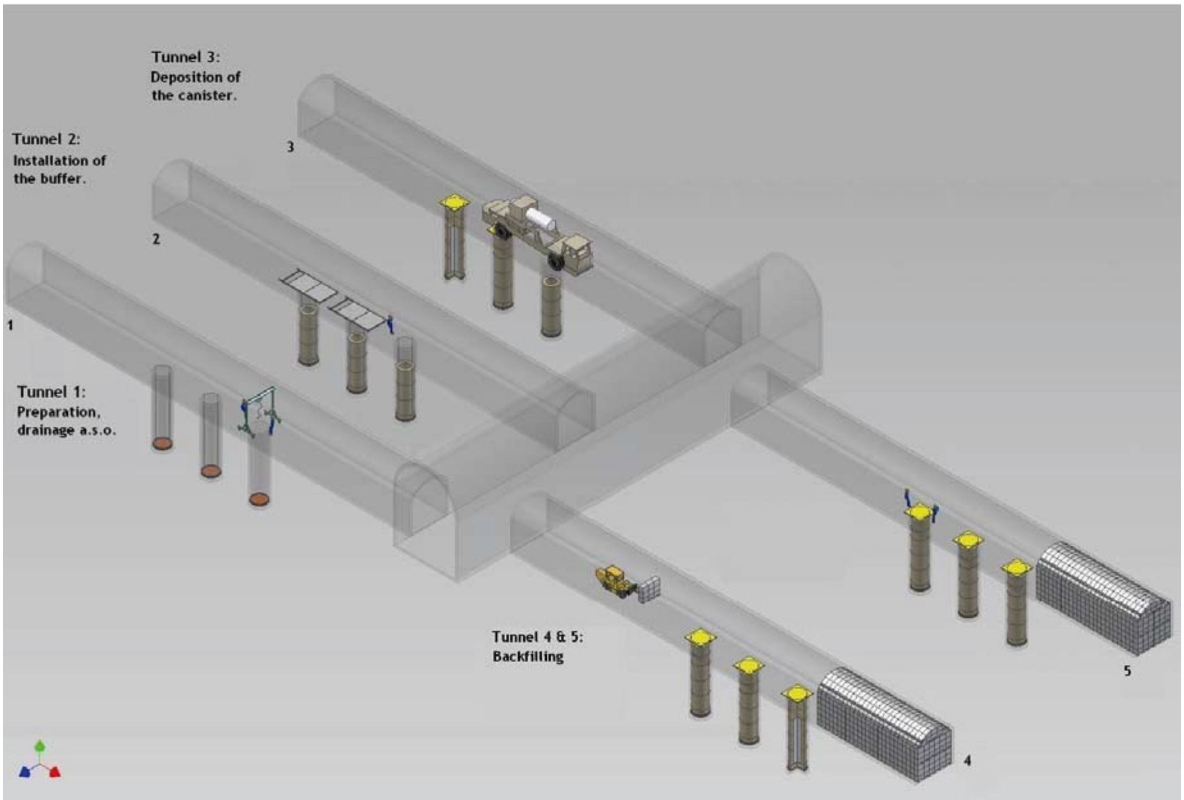


Figure 2-2. *Proposed sequence of deposition of buffers, canisters, and backfills /Wimelius and Pusch 2008/.*

The various steps in preparing the deposition holes and tunnels that we are concerned with are taken in the following order:

1. The bottom foundation is constructed followed by placement of drainage and buffer protection sheet, and alarm sensor,
2. The lowest buffer block and all six annular buffer blocks are placed,
3. The canister is installed,
4. The uppermost three buffer blocks and the clay blocks that may be used for filling the ramp[1] are placed,
5. The buffer protection sheet is pulled up and the drainage and alarm sensor removed,
6. Filling of pellets in the space between buffer and rock,
7. Placement of tunnel backfill over the hole and further to the next hole.

Figure 2-3 illustrates the geometry of a deposition hole and the clay components embedding the canister.

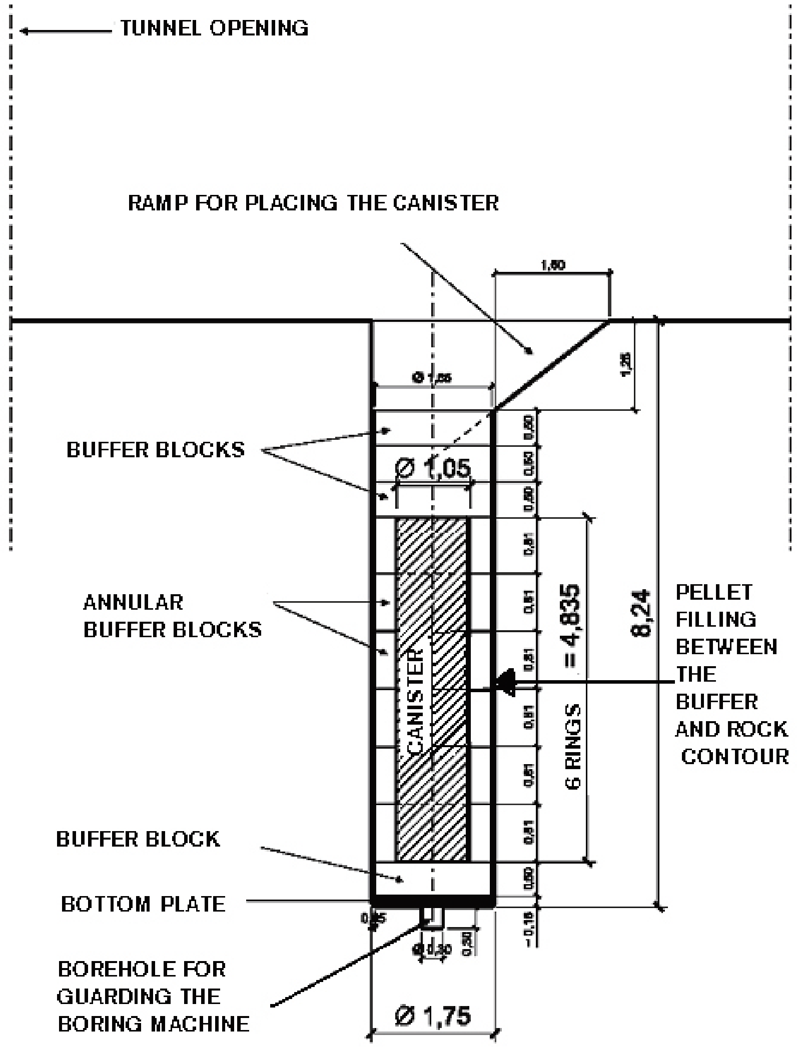


Figure 2-3. *Section of deposition hole. The pellet fillings around and above the buffer blocks are not shown.*

---

[1] No decision has yet been taken of whether pellets and blocks will be used.

3 The Buffer Protection sheet

3.1 Concept

Figure 3-1 illustrates the buffer protection sheet arrangement in a deposition hole. The components of importance are the concrete foundation covered by a copper plate, the rubber sheet and the drainage system consisting of a pump (not shown) that discharges water from the gap between the sheet and the rock.

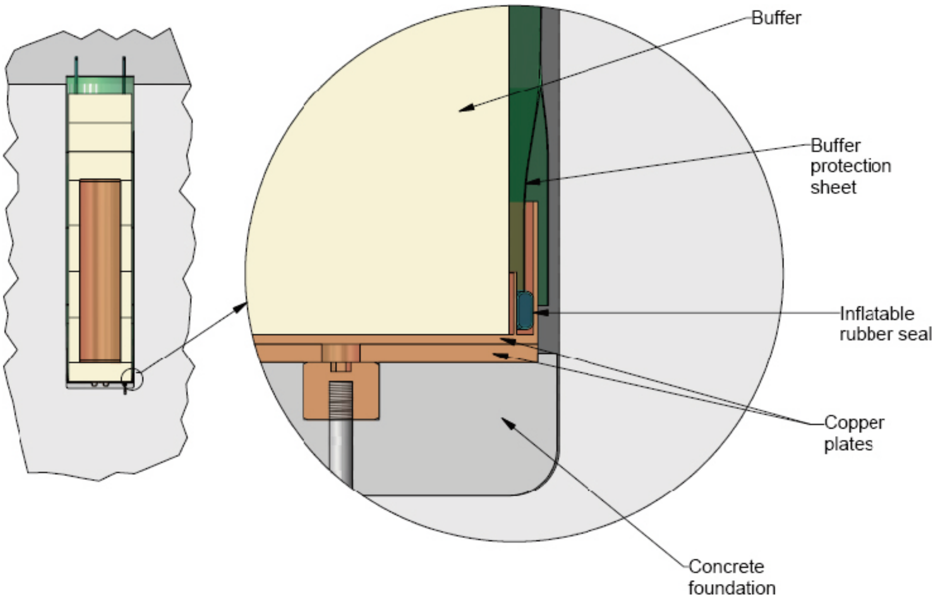


Figure 3-1. *Schematic section of deposition hole in the buffer installation phase. Water is prevented from contacting the buffer block column by a rubber sheet that is tightly fastened to the concrete foundation.*

3.2 Function

The buffer protection sheet shall isolate the buffer blocks from water and moisture for which it must be tightly connected to the bottom foundation. It must resist a certain, moderate water pressure in the case of possible malfunction of the drainage.

The deposition holes extend to about 8.0 m depth and have a diameter of 1.75 m. The outer diameter of the buffer blocks is 1.65 m leaving a 50 mm gap between rock and blocks to be filled with clay pellets. Since the pellets must be in contact with the rock the sheet has to be removed just before filling of the pellets. They are poured in without compaction to fill the space from the base of the hole to the upper end of the uppermost buffer block, i.e. at the lower end of the ramp (bevel) (cf Figure 2-3). The concept implies that the rubber sheet is pulled up at this stage. The procedure may be difficult and requires testing under realistic conditions, which has been made in a full-scale experiment described later in the report.

The detailed connection between the protection sheet and the foundation is shown in Figure 3-2. The lower end of the rubber sheet confines the vertical flange of the copper plate that is anchored to the concrete foundation. Reinforced rubber straps are vulcanized to the sheet for holding it in the hole in the block and canister placing phases, and for pulling it up prior to the pellet filling phase.

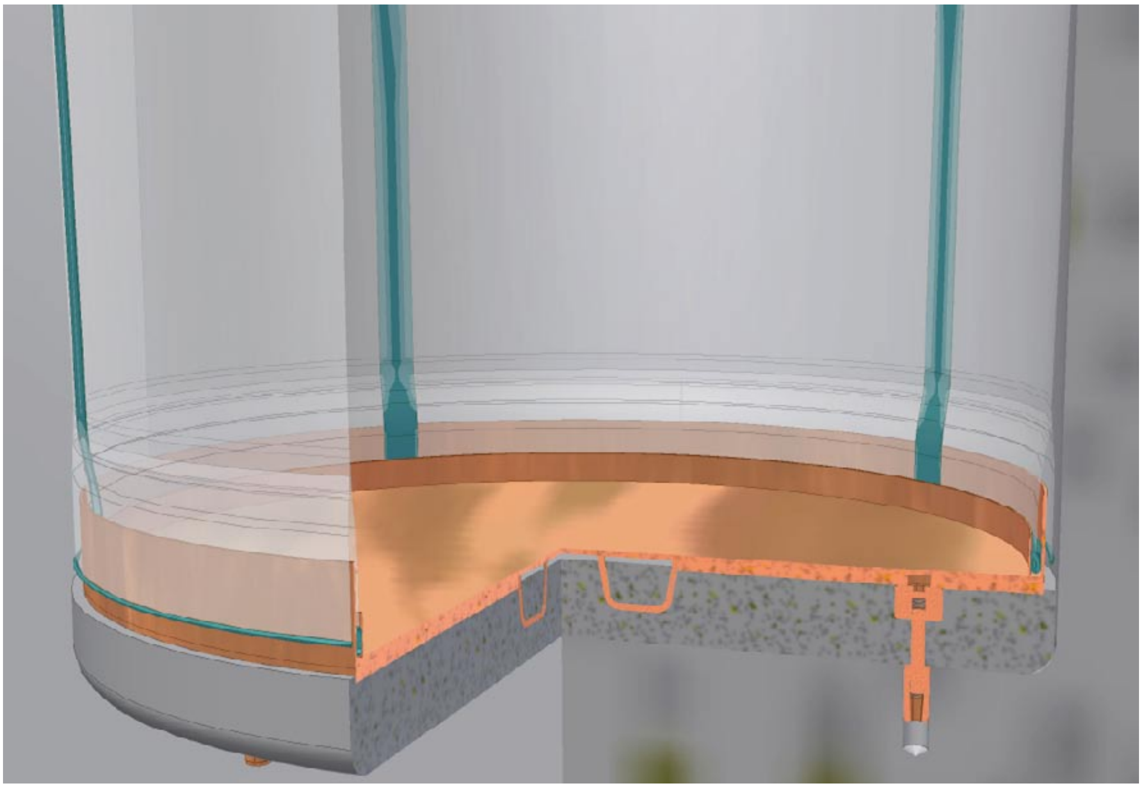


Figure 3-2. *View of buffer protection sheet and bottom foundation. The sheet is connected to the flange of the copper plate that is anchored in the concrete. The green objects are rubber straps vulcanized to the sheet.*

3.3 Conditions

3.3.1 General

Since only copper and concrete with pH < 11 will be accepted in the completed deposition holes no other metals and no organic components may remain in them. This implies that there must not be any remnants of the rubber sheet after completing the construction of the buffer. If the rubber sheet would rupture it may require replacement of it by another one, and removal of canister and placed buffer blocks as well as already placed tunnel backfill that may have softened by inflowing water.

The construction of the concrete foundation and mounting of the buffer protection sheet can be made without any time constraint. Hence, sufficient time will be available for pursuing the work and for performing the required quality control and making any necessary repair.

3.3.2 Criteria

The impact of the protection sheet and bottom bed on the homogeneity and density of the pellet fill will not be specifically discussed in the present report. Focus will be on criteria that indirectly affect the construction, placement and function of these components. The main criteria are:

- The sheet must not hinder placement of the buffer components,
- The sheet must be removed after placing the buffer blocks.

The first mentioned criterion implies that there must be no significant wrinkles or folds in the sheet and that the space between the sheet and buffer blocks must be sufficient to remove the sheet without getting stuck or affecting the buffer blocks.

A very important basic condition is that the canisters and columns of buffer blocks must be oriented vertically, which requires that the bottom bed is perfectly horizontal. A deposition hole that deviates so much from being vertical that the space between buffer and rock is too small to bring in pellets uniformly or to remove the protection sheet, has to be abandoned.

3.4 The bottom foundation

The foundation consists of two parts, a concrete plate cast on site, and a copper plate anchored in the concrete. The bottom foundation must be almost perfectly horizontal; the deviation from the horizontal must be less than 1/1,750.

3.4.1 Concrete foundation

The concrete is cast directly on the blasted and reasonably well smoothened bottom of the hole and shall have a thickness of about 150 mm. Low pH concrete is used, like the type of self-compacting silica concrete intended for borehole plugging /Pusch and Ramqvist 2004/. Such concrete has a fluid consistency and flows out to yield a horizontal surface.

3.4.2 Copper plate

The copper plate consists of two units and serves to prevent water from being transferred from the underlying concrete to the buffer block on top of the foundation. It shall be shaped so that the buffer protection sheet can be tightly attached to it.

3.5 Drainage

Drainage is required for preventing water that collects around the bottom foundation to rise up to the connection of copper plate and buffer protection sheet. It is achieved by using vacuum technique. Two pipes with 18 mm outer diameter are moved down between the sheet and the rock to about 10 mm above the copper plate. The space between the rock and the outer vertical flange of the copper plate serves as a water basin (Figure 3-3).

3.6 Alarm

The water level in the water basin is measured continuously and an alarm is activated if a critical level is reached.

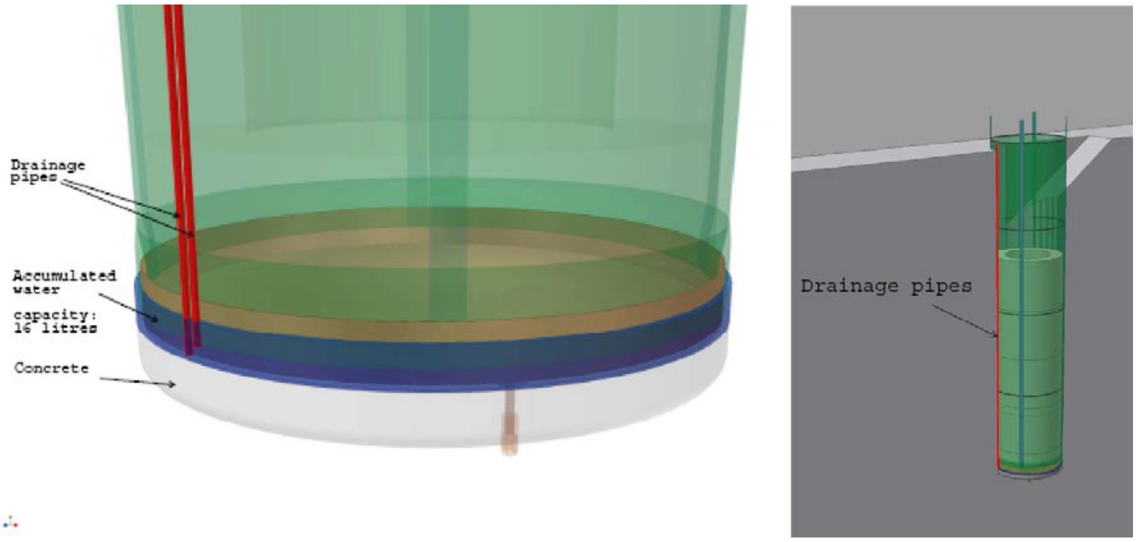


Figure 3-3. The installation for drainage. The blue colour represents water that has partly filled the basin.

4 Design of the bottom foundation and buffer protection sheet

4.1 Bottom foundation

Experience from the Prototype Repository Project /Pusch et al. 2004/ shows that casting of the concrete and subsequent trimming of the surface to become almost horizontal and sufficiently plane is time-consuming and impractical. A way of avoiding the trimming, is to use the copper plate as upper form that is left in the hole. The strength of the copper plate is defined by the selection of copper material with 95% Cu. The design including stress/strain calculations have been made in cooperation with SWECO.

4.1.1 The copper plate

The copper plate consists of two parts, a lower plate anchored to the rock (Figure 4-1) and an upper plate connected to it (Figure 4-2). The buffer protection sheet will be clamped in the U-shaped recess in the upper plate.

The position of the lower plate is carefully adjusted to fit the required co-ordinates, after which concrete is cast below it to establish tight contact with the plate. The second, upper plate is then placed upon and connected to it.

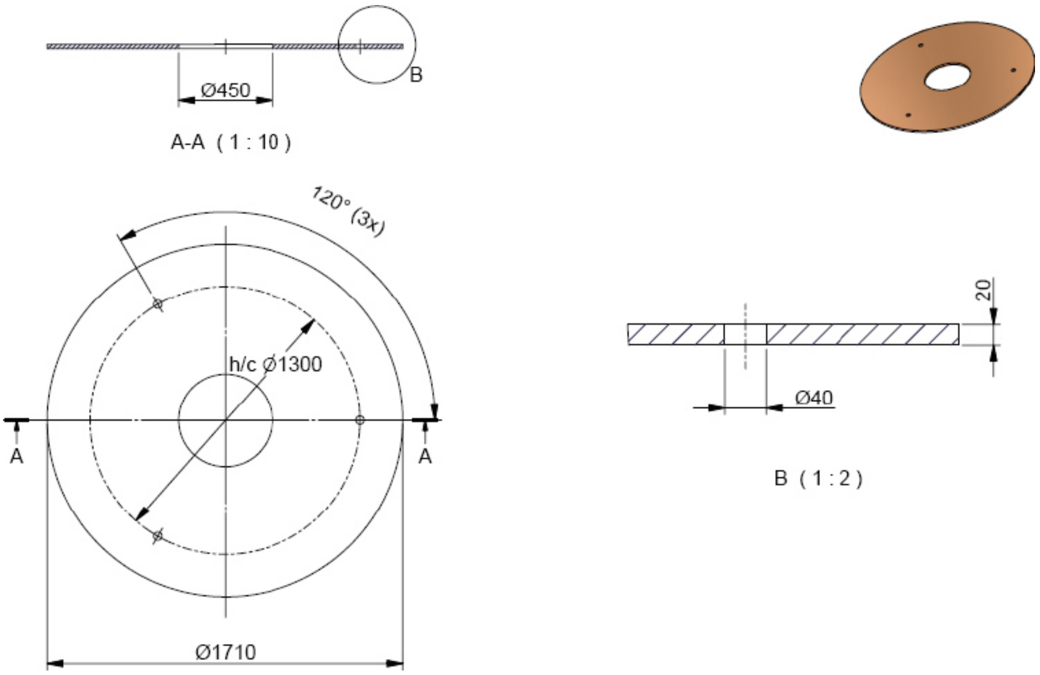


Figure 4-1. *The lower copper plate for fixation of the upper plate. The central circle is a hole for casting concrete below the plate.*

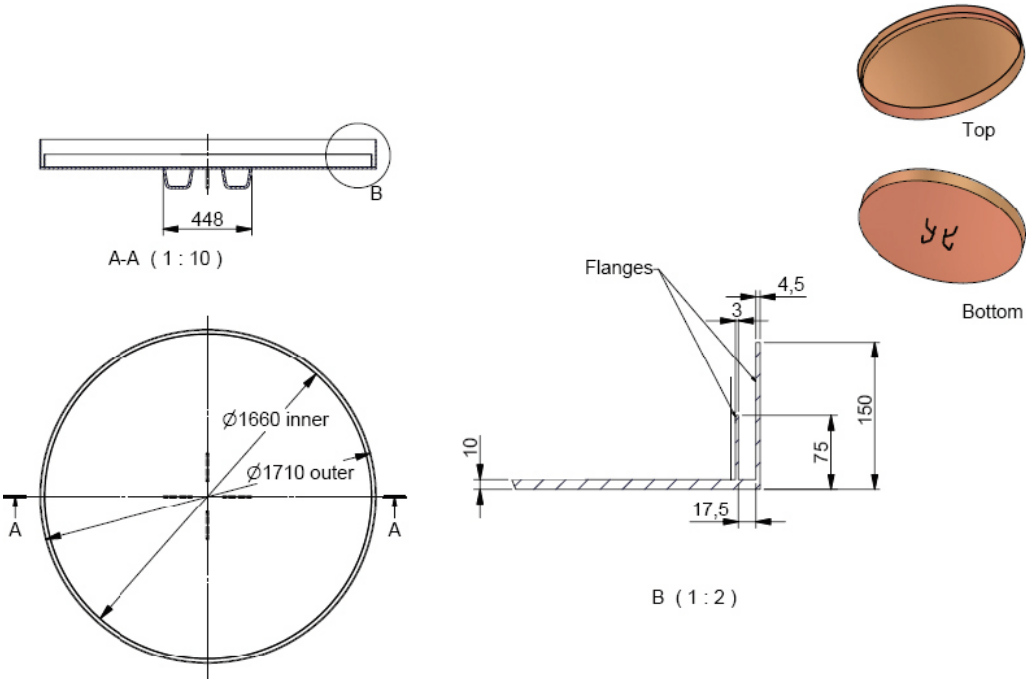


Figure 4-2. The upper copper plate.

4.1.2 The concrete slab

The concrete slab is cast on site after mounting the lower copper plate. The concrete is poured through the hole of the hoisted copper plate and allowed to fill the bottom all the way to the walls of the deposition hole.

4.2 The Buffer Protection Sheet

The sheet consists of 1.2 mm thick rubber (”EPDM”). Four rubber straps are vulcanized to the sheet along its entire height. The shape of the sheet is maintained by supporting rings that pass through loops that are vulcanized to the sheet with a regular spacing of 500 mm, radially. The role of the rings is to maintain the shape of the sheet so that the edges of the stacked buffer blocks will not damage it. The rings, which may consist of two parts, will be made of stainless steel but copper may also be considered. The technique has not yet been fully tested but the experience so far is that it may be sufficient with only one ring to make sure that the sheet will not be squeezed and stuck between the copper plate and the lowermost buffer block (Figure 4-3). The experience from the tests is in fact that the sheet maintains its shape even without steel supports.

An inflatable tube of 2 mm rubber is vulcanized to the lower end of the sheet for pressing it against the flanges of the copper plate so that water is prevented from flowing down along the walls of the holes and into to the space where the sheet is connected to the copper plate and further to the buffer blocks. It can be expanded or emptied from the tunnel floor. Figure 4-4 shows the design of the components at the bottom of the deposition holes.

Figure 4-3. *The buffer protection sheet with supporting rings mounted in a deposition hole.*

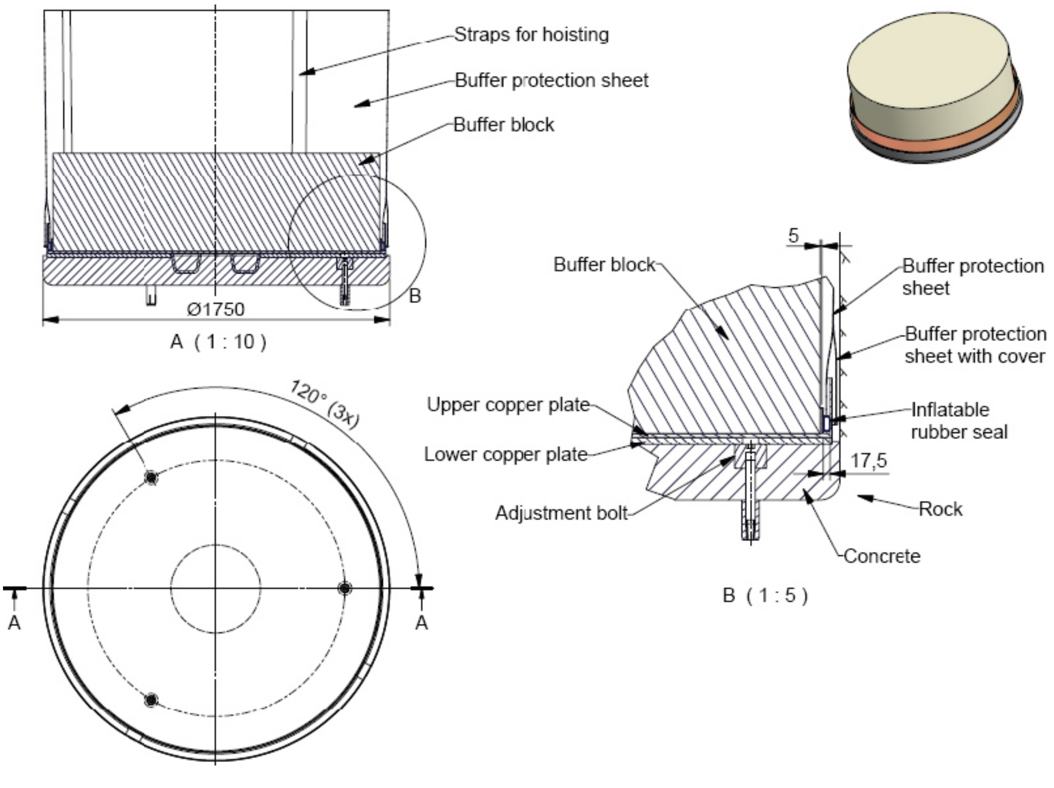


Figure 4-4. *The design of the components at the bottom of the deposition holes.*

5 Drainage system

5.1 General

Drainage is required for keeping the water level in the deposition holes low enough to prevent leakage through the buffer protection sheet. The bottom plate is so designed that 16 litres of water can be stored in the space between the vertical flange of the upper copper plate and the rock.

The condition on which the design work was based was that the inflow into the deposition holes will not exceed 0.1 lit/min, meaning that it will take 160 minutes until water reaches up to the connection between the buffer protection sheet and the copper plate if the drainage system would fail. Since tests have shown that the sheet can resist a pressure of 25 kPa (2.5 m water head) without leaking, problems with malfunctioning drainage units are deemed small.

Water is sucked up from the water basin by using vacuum technique, which is preferred to pumping it up because of simplicity and safety. For this purpose ejector technique is proposed. It is commonly used for extracting ballast from ships and can be applied also to the present case of draining deep holes. The principle is that the water column in the pipe is disintegrated by the air sucked by the pump. By this technique water can be drained from at least 15 m depth.

5.2 Procedure

Ejector technique is effective and simple but the capacity is limited since there is only room for pipes with 18 mm outer diameter in the deposition holes. The equipment, tanks and pump, are placed at the outer end of the deposition tunnel for space reasons. Tubes with 6 m length are tightly connected and placed on cable ladders mounted on the tunnel walls. The tubes extend to the inner end of the deposition tunnel.

Connection to the pipes in each deposition hole is made via valves. The risk of damaging the tubes by vehicles moving in the tunnel requires that they are located below steel plates along the entire tunnel length. Figure 5-1 illustrates the arrangement for drainage.

It is important that the tube connection to each deposition hole and the pipes placed in them are removed immediately after completing the drainage for eliminating any risk of damage to the vacuum system. Frequent use of valves and checking of the function of the entire system will be necessary since any delay caused by malfunctioning will affect the whole series of backfilling operations.

Two exploratory tests have been made in the Bentonite Laboratory at Äspö URL for investigating the applicability of the drainage concept. One of them was made with two pipes with 15 mm inner diameter giving a flow of about 6 l/min. The other, which was performed with only one pipe with 20 mm inner diameter, gave a discharge rate of about 20 lit/min.

Both tests were made by use of a Norclean ejector operated with pressurized air (Figure 5-2). It had a maximum suction, i.e. negative pressure, of 78 kPa and a maximum air flow capacity of 318 m^3/h. The working principle of the equipment, which has no moving parts, is that vacuum is formed when compressed air expands after passing a venturi tube. The simple and safe working principle makes the technique very attractive and makes it possible to suck up water from 15 m depth. Application of ordinary vacuum methods can not bring up water from more than 9.8 m depth but adding air to the vacuum pipes above the bottom plate can raise this measure to at least 15 m.

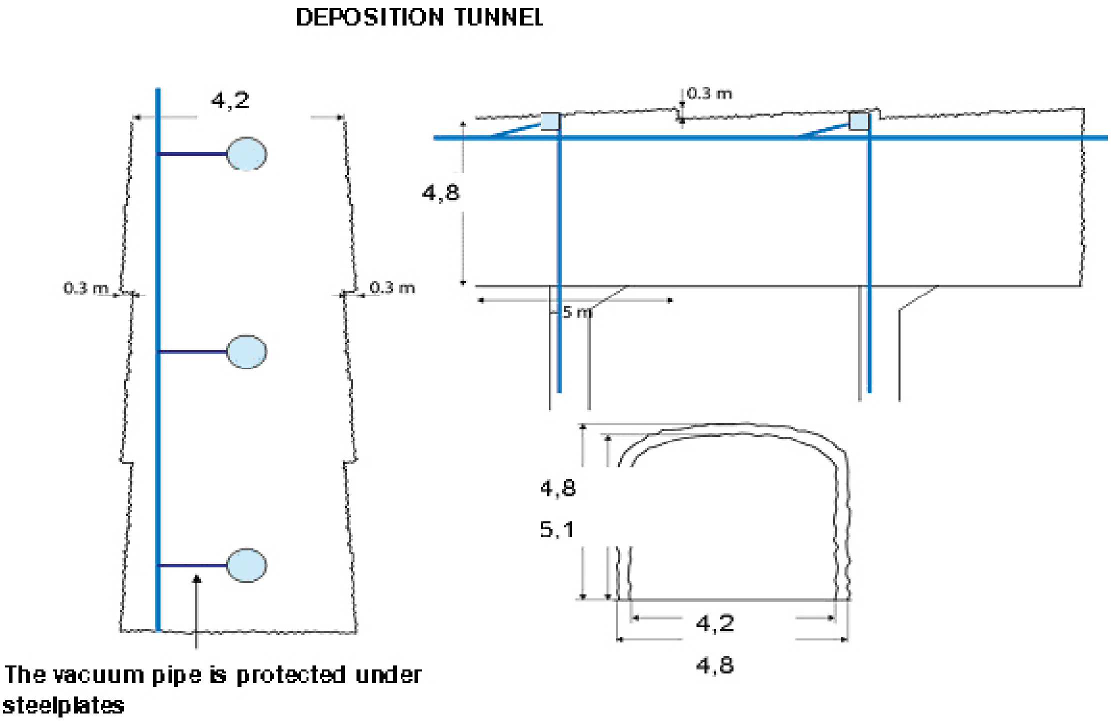


Figure 5-1. Schematic picture of the drainage arrangement.

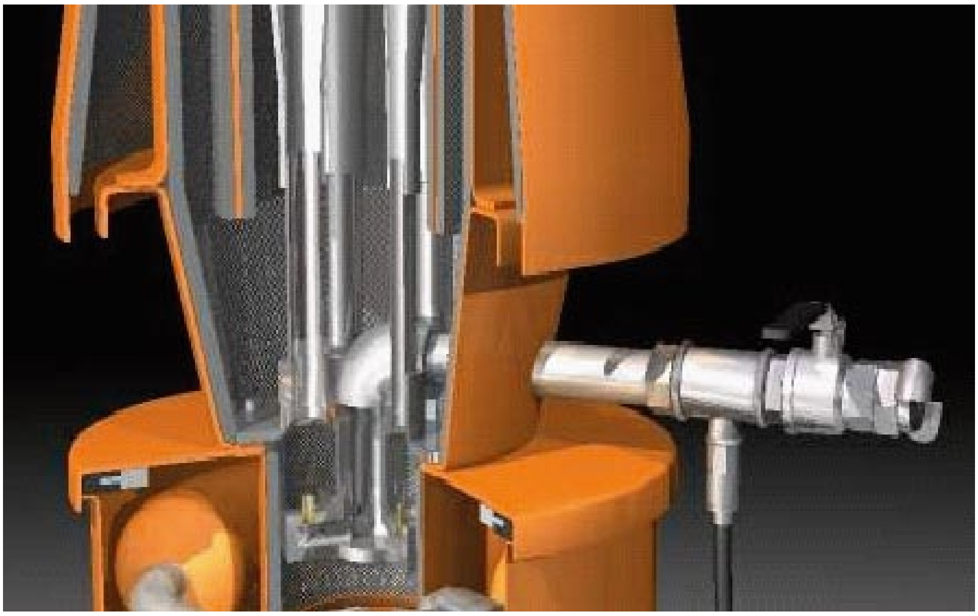


Figure 5-2. Norclean ejector, equipment.

5.3 Capacity

It is estimated that a system that can provide suction of 1 hole per minute is sufficient, which implies that one series of treatment would require 50 minutes for a tunnel with 50 deposition holes. However, considering the need for a well performing drainage system and for back-up of the vacuum system it is separated in two parts, one serving 25 of the 50 holes and the other the remaining ones (Figure 5-3). This makes it possible to detach one of the systems when 25 holes have been completed.

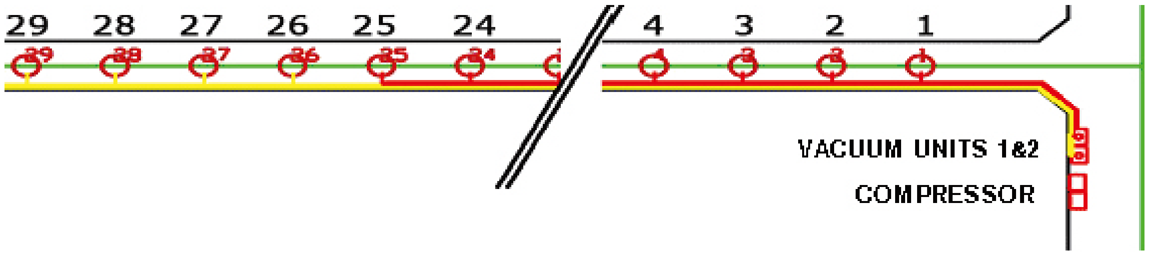


Figure 5-3. *Schematic drawing of the drainage system in a tunnel with 50 deposition holes.*

Drainage of each hole for 1 minute per hour will be sufficient for preventing water to rise up the lower end of the buffer protection sheet provided that the rate of inflowing water to the hole does not exceed 0.1 l/min. The operation time for each of the vacuum systems in a tunnel with 50 deposition holes will hence be 25 minutes per hour. If they are used interchangeably just one compressor will be required in most of the time while the capacity to produce compressed air must be doubled if two holes have to be drained at the same time. This may be required if the alarm system indicates need for it.

Each of the vacuum systems has a tank with a volume of 950 litres. It is emptied at the end of the respective suction operation by opening a bottom plug and discharging collected water, and they can also be drained by a pump in the course of the operations.

The drainage system is so designed that the deposition holes are discharged in the order 1 to 50 in a tunnel with 50 holes and that the discharge rate does not exceed about 5 l/min.

5.4 Controls

The electrical system that controls and watches the drainage is based on a PLC-system (Programmable Logic Controller-system) with five boxes mounted in the tunnel (Figure 5-4). This system is computer-controlled and provides electric power to the valves of each deposition hole. A PLC consists of connections for receiving and transmitting electrical signals. A processor compares the signals with those of an installed code, after which the outputs are adjusted to be in agreement with the code. A PLC also has space for storing information.

The PLC-system controls the adjustable suction periods and also reacts on alarm signals given by the sensors in the deposition holes. If vacuum is on, the alarm function has the highest priority while the controlling functions are returned to normal function. The control system reacts on disconnection of local parts of the vacuum system and therefore ignores signals from the valves that have been detached.

If additional safety measures are wanted arrangements for weighing water that is transported to the tanks can be made for certifying that the drainage system works.

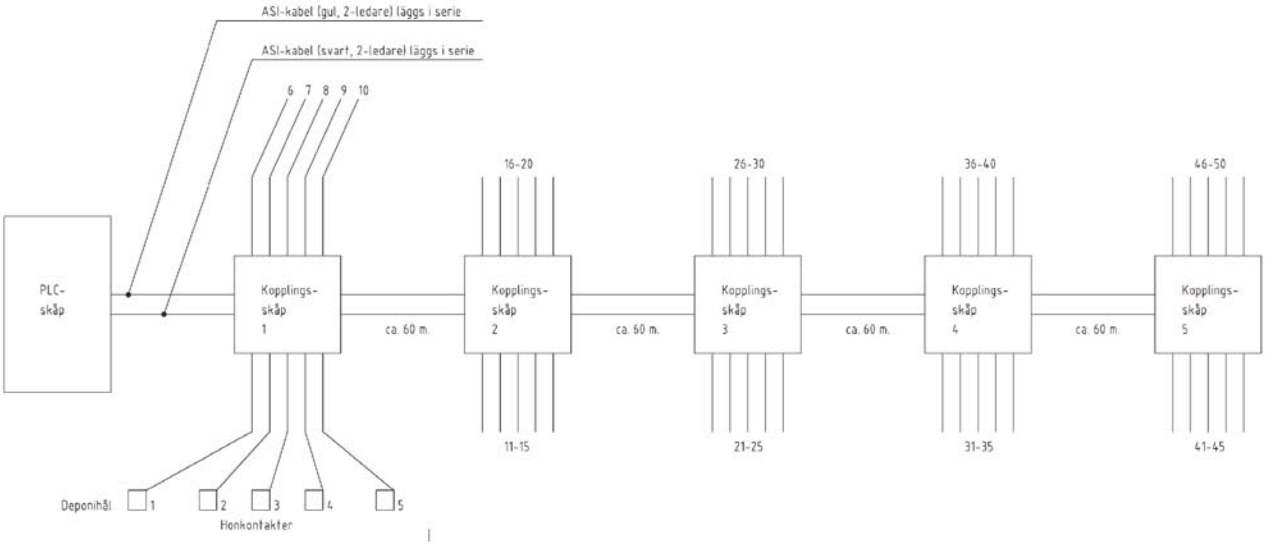


Figure 5-4. *System for controlling drainage.*

6 Alarm system

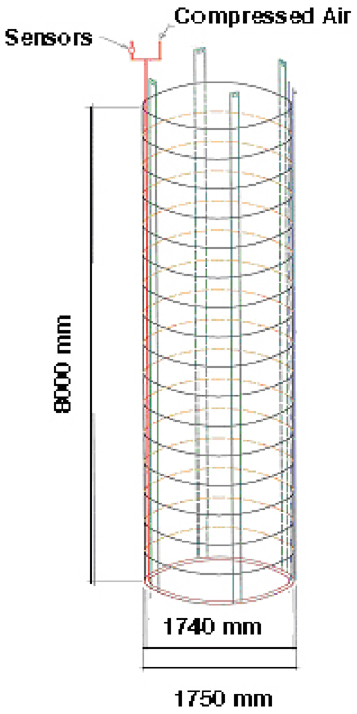
A simple and reliable alarm system for recording the water level in the deposition holes has been worked out and tested by SKB (Mats Lundqvist). Signals are provided if the water level exceeds the lower ends of the drainage tubes. The system also makes it possible to determine the free water level in the space between rock and protection sheet.

6.1 Principle

The alarm system makes use of a pipe with 10 mm outer diameter that is placed in the space between the buffer protection sheet and the rock with its lower end about 10 mm above the upper copper plate (Figure 6-1). The pipe, which is in the same space as the drainage pipes, is equipped with a pressure sensor in its upper part together with a nozzle connected to a tank with pressurized air. The signal provided by the sensor represents the water pressure, and hence the water level, and is recorded by a National Instruments USB-module. The computer program is Labview-coded. The output signal activates the alarm and vacuum systems. The alarm system consists of a recording instrument working according the bubble-pipe principle, meaning that it measures the pressure difference (or the counter pressure) in the pipe and gives the water level in the pipe.

6.2 Performance and maintenance

The pressurized air required for the alarm system is provided by the compressor used for drainage of the deposition holes. The accuracy of the pressure regulator must be high for guaranteeing safe performance of the alarm system. As for the drainage system a major tube is placed in the tunnel with tube connections to the individual deposition holes. In a real repository, PLC control will be utilized for handling alarms and supervision.



Figur 6-1. The alarm arrangement. Diameter of deposition hole is 1,750 mm and diameter of bufferprotection is 1,740 mm.

7 Construction and mounting

7.1 Activities

The work described here is based on a tentative activity plan that works acceptably but is deemed to require further development. The descriptions of activities 7.2 to 7.4 have not yet been applied in practice. It comprises the following activities:

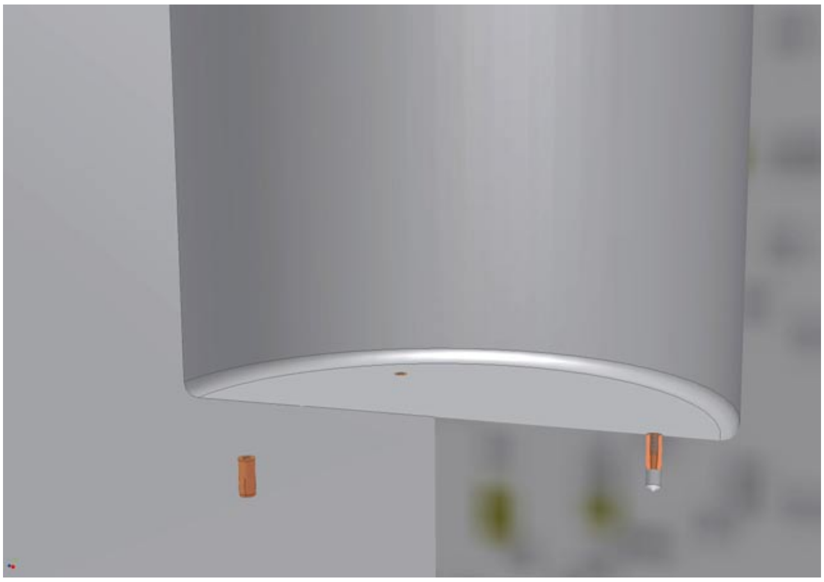
- Mounting of "HKD" tube, (a threaded tube that is put in a drilled hole in the rock and expands and becomes anchored when the bolt fitting in it is turned),
- Mounting of copper bolts for anchoring the bottom copper plate,
- Mounting of bottom copper plate,
- Casting of concrete up to the bottom copper plate,
- Mounting of upper copper plate,
- Mounting of drainage and alarm tubes,
- Mounting of buffer protection sheet.

7.2 Bottom copper plate

7.2.1 Mounting of "HKD" tube

The exact position of the bottom plate and ring, vertically and laterally, is determined on the basis of precision measurements made in characterization of the respective deposition holes. The plate is mounted so that the distance between the lowermost buffer block and the rock will be as close to 50 mm as possible.

Three holes for bolt sockets are bored in the rock below each deposition hole, the location being determined by a jig. The co-ordinates of the bottom plate are not determinants of the construction of the bottom parts or their performance, but the position of the bolts for the HKD tubes must fit the holes in the ring (Figure 7-1).



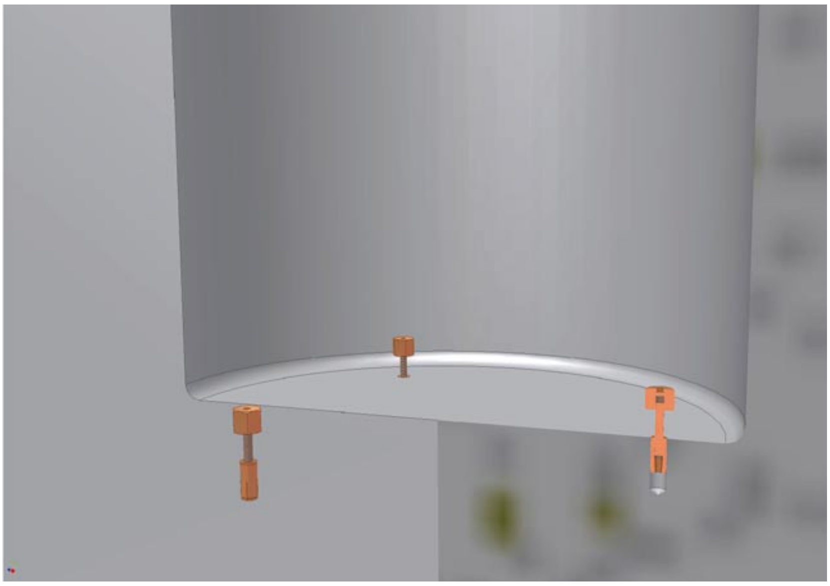
Figur 7-1. *Sockets for mounting of HKD tube. Half the bottom of a deposition hole viewed in section.*

7.2.2 Anchoring of copper bolts

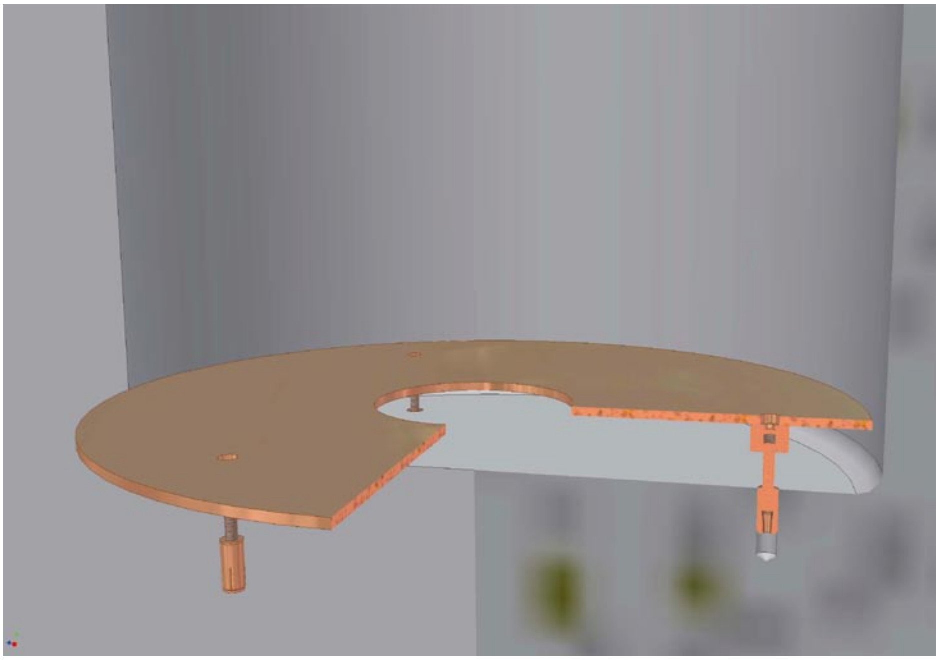
Copper bolts (M24) and nuts are screwed in the sockets and the vertical position of the nuts done in two steps, the first preliminary with no plates in place (Figure 7-2), followed by adjusting the height by an insex key reaching down through the holes in the plate (Figure 7-3).

7.2.3 Mounting of lower copper plate (fixation ring)

The plate is adjusted to fulfil the requirements concerning lateral and vertical positions by moving the height of the three nuts, which are available through holes in the plate (Figure 7-3). Their vertical positions are checked by using a precision water gauge. For fixation of the plate before starting casting of concrete below it the nuts are clinched or secured by additional nuts.



Figur 7-2. *Mounting of copper bolts and adjustable copper nuts. Half the bottom of a deposition hole viewed in section.*



Figur 7-3. *Mounting of lower copper plate in elevated form before casting of the concrete.*

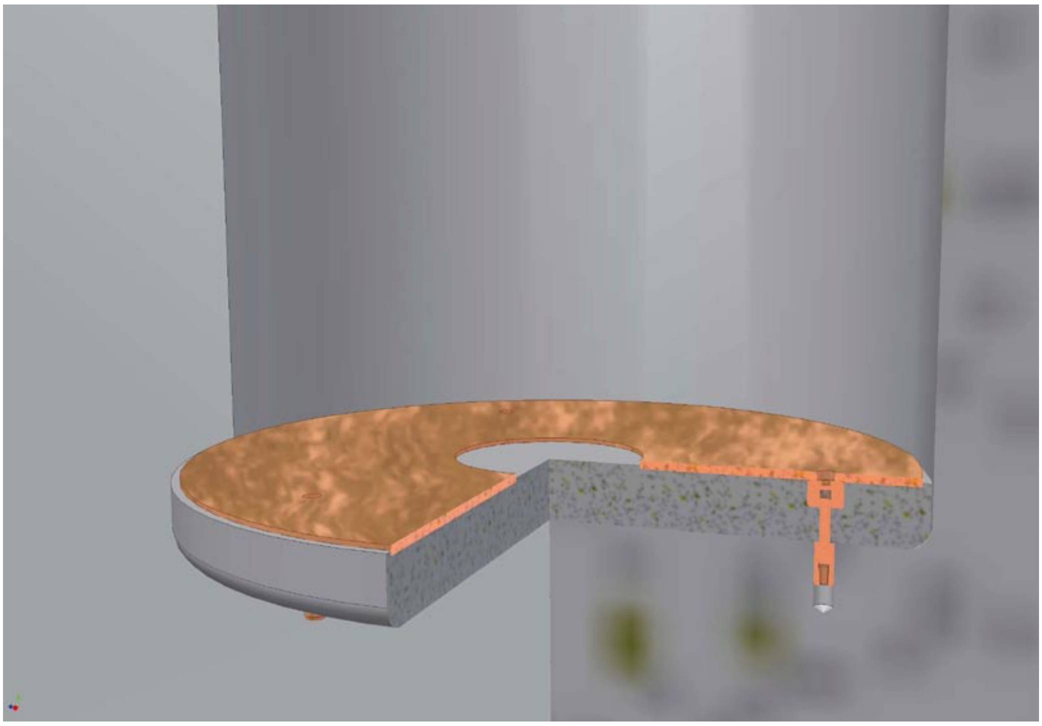
7.3 Casting of concrete foundation

Low-pH silica concrete composed according to CBI's recipe /Pusch and Ramqvist 2007/ will be cast to fill the deposition holes up to the bottom plates to form a concrete plate with a thickness of about 150 mm (Figure 7-4). The concrete is in fluid form and is filled through the central hole in the lower copper plate up to slightly less than half the thickness of the lower plate.

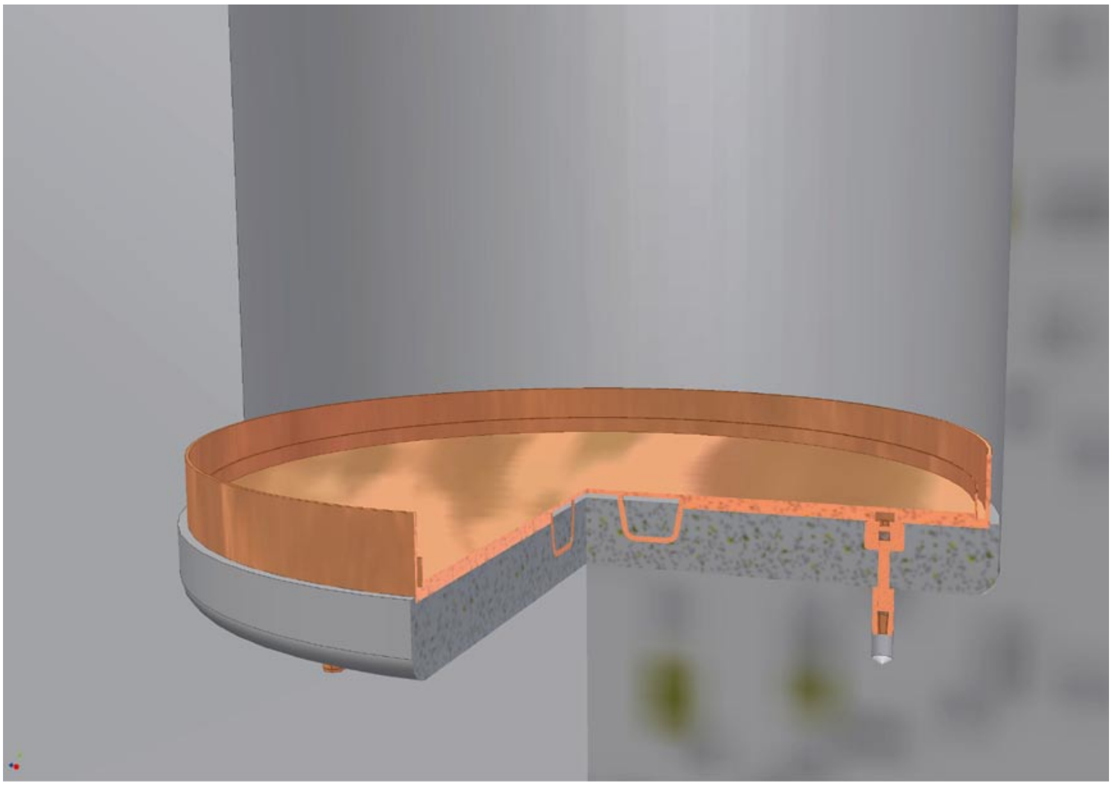
7.4 Mounting of upper plate

The upper level of the concrete in the central hole is checked before installing the upper plate. This operation is made by visual inspection or camera technique

The plate is pressed down into the fresh concrete and is anchored by U-bent reinforcement extending into the concrete. The objective is that the vacuum-operated tool for lifting buffer blocks shall be utilized also for installing the upper plate. This tool has been manufactured and is being tested at Äspö in 2008 and 2009. It is equipped with facilities for placing the plate in the desired position.



Figur 7-4. *Concrete plate filling the space below the bottom of the lower copper plate.*



Figur 7-5. *Complete system of concrete plate, lower and upper copper plates with flanges.*

7.5 Installation of drainage and alarm tubes

The two tubes for drainage and the pipe for the alarm function are placed with their lower ends in the space between the flange of the upper copper plate and the rock (Figure 7-6).

7.6 Installation of buffer protection sheet

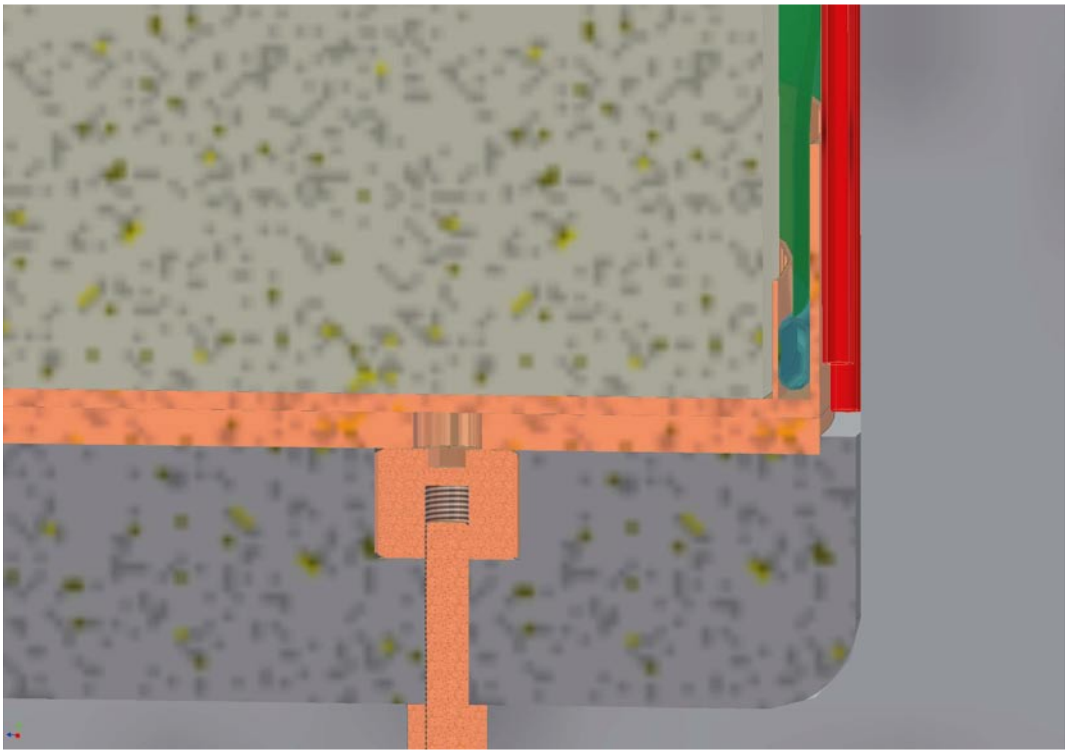
The buffer protection sheet is lowered in the hole, The inflatable sealing is fitted between the flanges and fixed while being expanded under an air pressure of about 150 kPa. The tube must not move inwards over the flange of the upper copper plate after having been expanded.

The tightness of the sheet is checked by applying water pressure in the space between the sheet and the rock, after which the water is sucked up. The arrangements at the bottom of the holes then appear as in Figure 7-7.

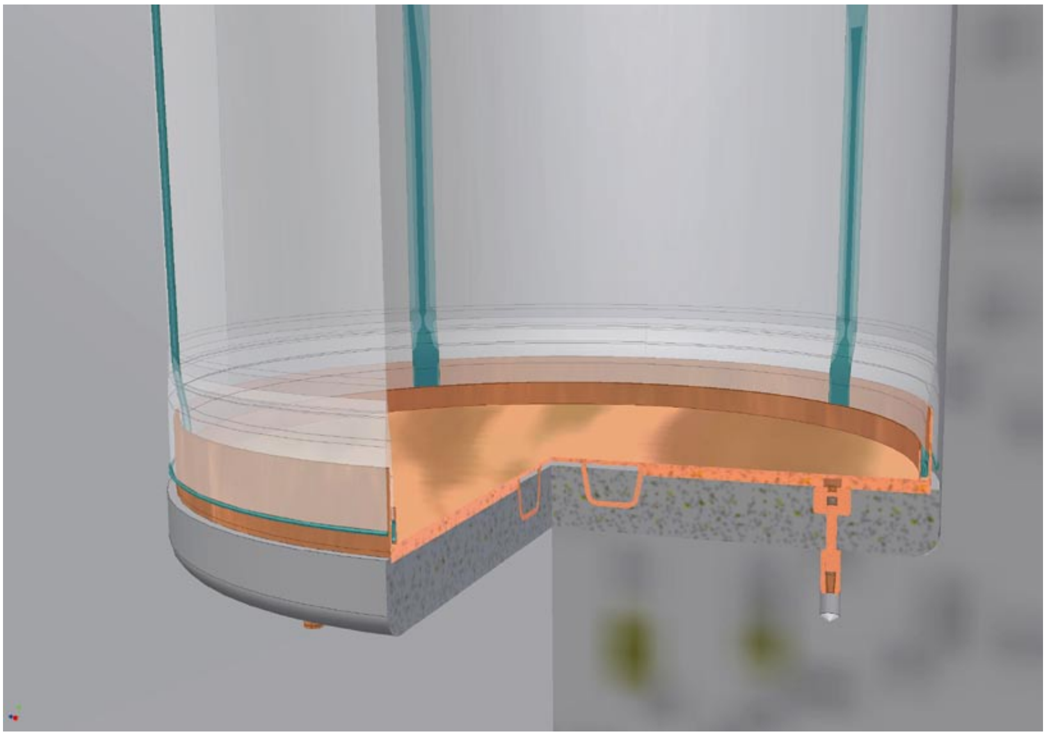
Before the protection sheet is hoisted in the deposition hole a stabilizing ring is put in the lowest set of loops just above the flange of the upper copper plate for avoiding folding and squeezing of the sheet at the installation of the lowest buffer block.

7.7 Installation of buffer blocks and canister

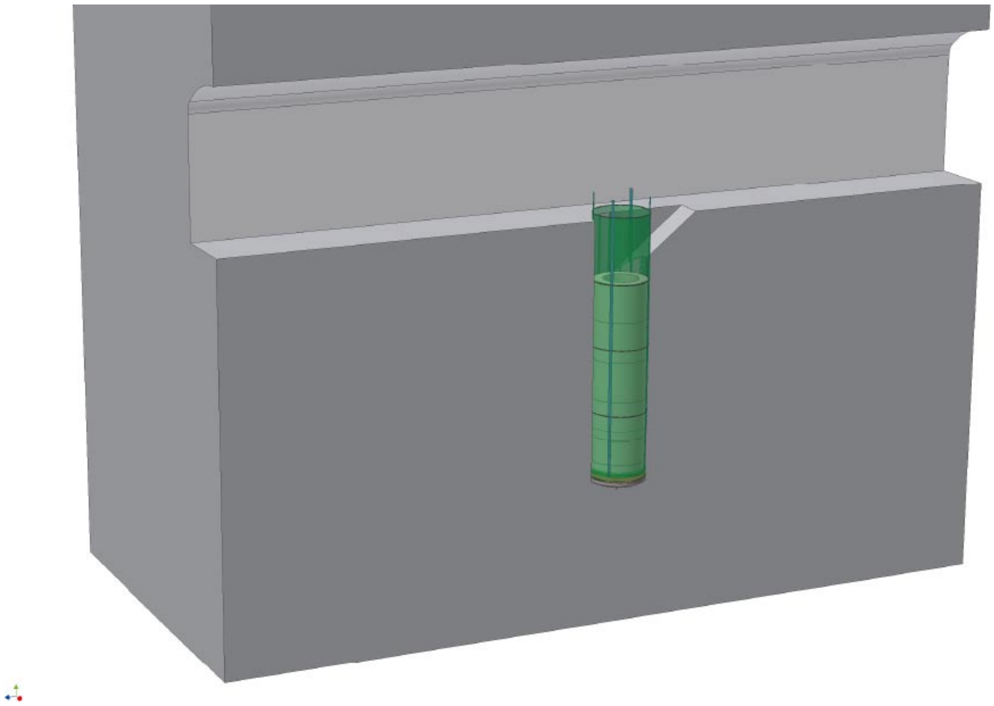
The bottom block is placed and a defined number of buffer blocks are stacked on it before the canister and remaining blocks are installed (Figure 7-8). The protective steel plate covering the deposition hole and associated ramp are temporarily replaced by a “gammagate” when the canister and upper buffer blocks are being installed in the deposition hole.



Figur 7-6. *Details of concrete plate and the copper plates with flanges. The longest red stripes represent the drainage tubes and the shortest the alarm pipe. The green stripe is the buffer protection sheet. The blue stripe is the inflatable rubber seal that is vulcanized to the rubber sheet and clamped between the flanges of the plates.*



Figur 7-7. *The completed arrangement at the bottom of a deposition with the buffer protection sheet surrounding the sheet clamped between the flanges of the upper copper plates.*



Figur 7-8. Deposition hole with ramp and bottom plates, protection sheet and buffer blocks before deposition of canister.

7.8 Connection of buffer protection sheet to the steel plate at the tunnel floor

When the buffer blocks have been installed inside the protection sheet it has to be closed for preventing possible inflow of water and exposure of the buffer to moist air. The closure and necessary mechanical details for this have not yet been defined or designed but these matters are not believed to cause difficulties. In principle, a flange is required that is tightly connected to the sheet and protection plate at the tunnel floor. Cables to sensors for RH measurement in the sheet-isolated space containing buffer blocks extend through the flange.

The ramps from the tunnel floor down into the deposition holes affect the design of all this and must be considered in the forthcoming project planning.

7.9 Detachment of alarms and drainages

The tubes for drainage and alarm are released from their connections at the tunnel floor and pulled up after installation of canister and upper buffer blocks. At this stage the front of the tunnel backfill approaches the hole.

7.10 Detachment of buffer protection sheet montage

The air pressure in the closed buffer protection sheet is lowered and the sheet then lifted up by use of the loops that are vulcanized to the sheet. It is expected that the axial, vulcanized reinforcements will provide the strength required in this phase.

8 Tests performed

8.1 General

The various components have been tested individually after which a full-scale experiment of the integrated system was made. The applied strategy has primarily been to make sure that the buffer protection sheet works and secondarily to work out and perform design, construction and tests the components of the bottom part.

8.2 Conditions

The tests were performed in the Bentonite Laboratory at the Äspö URL where a deposition-type borehole had been prepared in concrete with an inner cylinder of stainless steel for providing the required dimensions of a true deposition hole (Figure 8-1).

A bottom plate of steel was prepared as illustrated by Figure 8-2 with the dimensions according to Figure 4-2. No installations of the aforementioned types were made since the purpose of the experiments was only to investigate the performance of the buffer protection sheet with special respect to the integrated function of sheet and bottom plate.

Figure 8-1. *The artificial deposition hole at Äspö URL.*

Figure 8-2. *Bottom plate of ordinary iron.*

8.3 Requirements

The following requirements had been defined for the project:

- The bottom plate shall have the same dimensions as specified for a real plate (cf Figure 4-2),
- The bottom plate shall serve as a tight seal between buffer blocks and the base of the holes,
- The bottom plate must be placeable with an accuracy of better than 1/1,750 mm in the horizontal plane,
- The buffer protection sheet must resist a water pressure of 10 kPa without leaking,
- The buffer protection sheet must remain tight over a sufficiently long period (i.e. about 3 months),
- It must be possible to place the buffer blocks within the protection sheet,
- It must be demonstrated that the buffer protection sheet can be detached from a narrow space with 25 to 50 mm width after installing the buffer blocks,
- A system for drainage with a suction power of at least 110 kPa must be installed,
- An alarm system for warning of too high water level in the space between rock and protection sheet must be installed,
- No material except buffer must remain in the deposition holes after removal of drainage, alarm, and buffer protection sheet.

8.4 Test of drainage system

8.4.1 Description

Two sets of tests of individual components have been performed followed by experiments using the integrated systems. Relevant suction conditions were arranged by use of a crane as indicated by Figure 8-3. The arrangement made it possible to suck up water by vacuum, the effect of which could be increased by drilling holes in the suction tube for letting extra air in (ejector technique). This resulted in an increase in hoisting water from the theoretical maximal level 9.8 m up to 12 m. Different size and spacing of the drilled holes were tested to find the optimal pattern. The 12 m suction height will make it possible to place the drain tubes in the deposition tunnel a few meters above the tunnel floor. The holes in the drainage tubes must be located above the water level since the ejector effect is otherwise lost. The experience from the pilot tests at Äspö indicated that the holes should be drilled about 1 m above the lower end of the tubes.

Figure 8-3. *The vacuum pump (orange) with flexible tube (blue) connected to a tube (black) down to the bottom of the test hole.*

8.4.2 Test results

Three tests, which were conducted using the same vacuum pump, can be characterized as follows:

Test I. Inner diameter of the drainage tube in the hole 20 mm; Several small holes drilled in its lowest part. Suction capacity 20 l/min at 12 m suction height.

Test II. Two copper pipes with 15 mm inner diameter and one 10 mm drillhole in them at 1 m distance above the lower ends. Suction capacity 6 l/min at 12 m suction height.

Test III. Co-ordinated installation, testing and detachment of the whole system. This worked out satisfactorily.

The lower capacity of the system achieved in Test II than in Test I was probably caused by the smaller diameter of the drainage tubes and optimal conditions have not yet been found with respect to their dimensions and to the size and location of the holes drilled for letting extra air in. It is self-evident that the latter holes should not be located below the water surface.

A general conclusion of the test series was that there is enough understanding and experience to work out a complete drainage system for the KBS3-V concept.

8.5 Test of the alarm system

8.5.1 Description

The test arrangement was that described in Section 6.1, designed and built by SKB (Mats Lundqvist) that was responsible for design and performance of the tests of the alarm system. As for the drainage tests access to pressurized air was required.

The aim of the tests was to find out if the alarm system works with required accuracy, which made it necessary to calibrate the system by performing manual measurements. Figure 8-4 illustrates the recording of the water level in the space between the buffer protection sheet and the wall at the bottom of the hole.

Tests were made specifically for finding the best measurement techniques and also, in conjunction with integrated tests, for identifying the most suitable method for placement of the buffer protection sheet and alarm system. Determination of the function of the respective systems was of course an important task as well.

The measuring principle is described in detail in Ch. 6.1.

8.5.2 Test results

The outcome of the water level measurements was that the accuracy was very good and that the deviation from manual, direct measurement of the level was within +/–1%. Installation and detachment could be made without difficulties and the techniques worked out appear to be applicable with limited further development.

***Figure 8-4.** Calibration of the alarm system with recording of the water level between the buffer protection sheet and the wall at the bottom of the hole.*

8.6 Test of bottom plate and buffer protection sheet

8.6.1 Description

Several pilot experiments were made for finding suitable design and construction principles, particularly respecting the connection of the bottom plate and the sheet. The final versions have been described in Section 7.

Figure 8-5 shows the lower part of the buffer protection sheet with the tube for air pressurization attached. Vulcanized loops for lifting the sheet are seen at mid height. The folded lower part is the inflatable tube for directing water that flows along the sheet down into the basin with 16 l storage capacity.

The buffer protection sheet had to be reconstructed and adjusted a few times before it worked properly and could be used for large scale testing, which focused on determining whether the sheet remained tight for 45 days under a water pressure of 6 kPa on the connection of bottom plate and sheet. A large-scale experiment of the integrated system of protection sheet, drainage and alarm units was ultimately performed.

8.6.2 Test results

The handling and placement of the buffer protection sheet were successful. Thus, the sheet retained its shape even without supporting rings, and it remained tight for 45 days under 6 kPa pressure. The tightness of its connection to the bottom plate was very good, it resisted a pressure of 25 kPa (2.5 m water column) with only very slight intrusion of water, which was concluded to be caused by folding of the inflatable tube.

Figure 8-5. *The buffer protection sheet with the tube for expanding it and the folded inflatable ring seal (held by the investigator).*

8.7 Integrated testing

The full-scale experiment at the Bentonite Laboratory ended with an integrated experiment of all components, i.e. placement of the bottom plate, buffer protection sheet and buffer blocks, and installation of drainage and alarm systems, including also detachment of all the units.

8.7.1 Placement of bottom plate

The bottom plate was put on site by the aid of a crane and mounted according the earlier described design and construction principles without problems and fulfilling the required precision demands.

8.7.2 Mounting of drainage and alarm

The tubes for drainage and alarm were inserted and anchored in the water basin. They were then connected to the systems on the tunnel floor for drainage and pressurization, respectively, and finally tested.

8.7.3 Installation av buffer protection sheet

The sheet was lowered into the hole by use of a crane (Figure 8-6) and the seal carefully pressed down in the gap between the flanges of the upper plate.

The sheet was stretched axially after having been tightly connected to the bottom plate and after mounting of the lowermost supporting ring, following inflation of the seal.

8.7.4 Installation av buffer blocks

Eight buffer blocks of concrete, simulating real bentonite blocks, were installed using the crane, the column reaching up 4 m from the bottom of the hole (Figure 8-7). The rings occasionally came in contact with the sheet but caused no damage. The blocks could be placed so that the distance between them and the concrete wall was at least 35 mm.

8.7.5 Detachment of alarm and drainage

The alarm and drainage tubes could be detached without difficulties.

Figure 8-6. *Installation of the buffer protection sheet.*

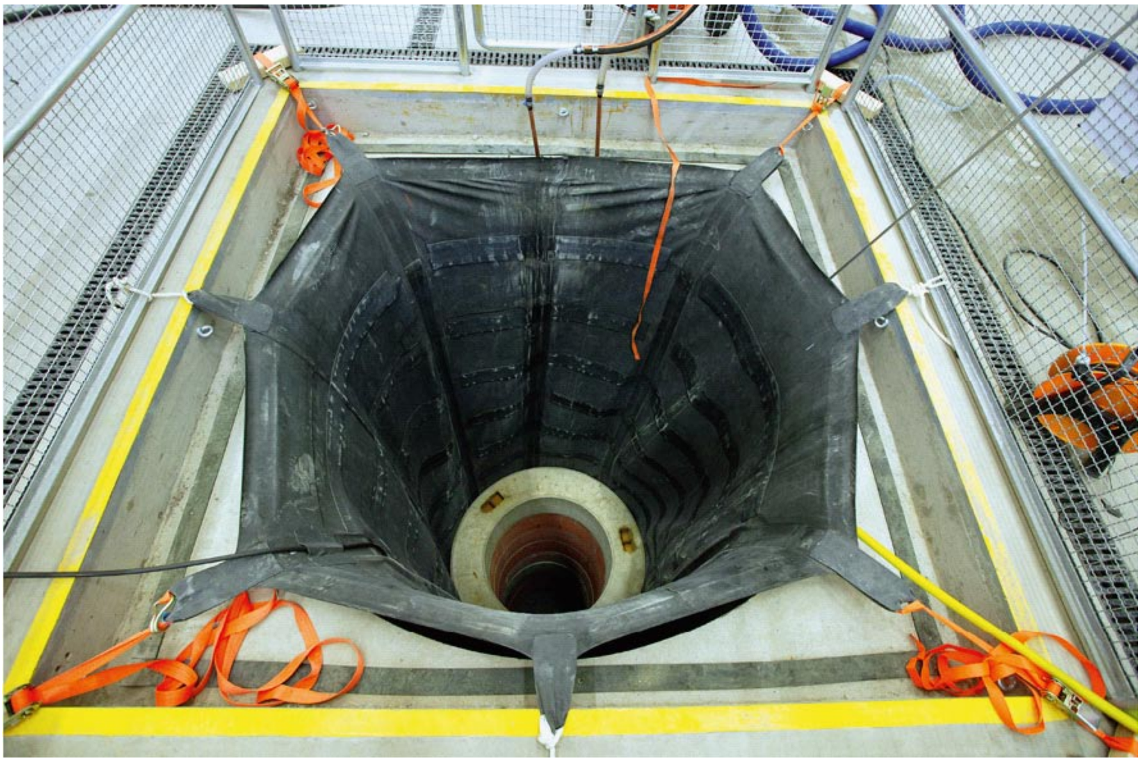


Figure 8-7. *Installed buffer column.*

8.7.6 Detachment of buffer protection sheet

The air pressure in the seal at the upper end of the hole was decreased to ambient (Figure 8-8) and a yoke attached to the sheet coupled to a balance for checking that the pulling force was uniformly distributed over the periphery.

The buffer protection sheet could be brought up with very slight variation in pulling force, which demonstrated that the sheet was not stuck (Figure 8-9). The difference between the test conditions and those in a real deposition tunnel is that the limited tunnel height requires that hoisting must be made in two steps.

Figure 8-8. *Detachment of the buffer protection sheet. It is being hoisted from the test hole in the picture.*

Figure 8-9. The ”deposition hole” with buffer block column after completing the integrated experiment.

8.8 Experience from tests

8.8.1 Preparation an placement of the buffer protection sheet

The overall conclusion from the tests was that the buffer protection sheet works well but that it is important that the vulcanized loops and other accessories are tightly and strongly attached to the sheet since folds are easily formed which can cause problems both in the installation and detachment stages. It is suggested that 8 equally spaced axial reinforcements are vulcanized to the sheet. Also, it is recommended that the loops for the rings are maintained even if no rings are used since they will be of assistance in the detachment phase.

The confining ring that keeps the protection sheet pressed against the rock just above the bottom plate should be further developed since the one used in the tests, i.e. the 3 mm thick steel plate, was concluded to be too thick and rigid.

8.8.2 Connection of buffer protection sheet and bottom plate

It is important that no folds are formed in the buffer protection sheet at and after inflating the sealing rubber tube that is contacting the upper copper plate (cf figure 7-6) When pressurized it must not expand inwards over the inner flange. A suitable air overpressure is estimated to be 150 kPa. A sheet-supporting ring is suitably placed just above the upper flanges for certifying that the sheet is in contact with the rock. Using rings with joints the pipes for drainage, alarm and air should be placed in these discontinuities. In practice one must take irregularities in the walls of the deposition holes into consideration; they may have to be smoothened by low-pH cement for avoiding that the sheet gets stuck.

8.8.3 Installation of buffer blocks in holes with protection sheets

The following comments are relevant:

- The protection sheet with supporting rings is assumed to slide down easily without being deformed. However, if necessary one can equip the sheet with rings with 0.5 m spacing along its entire length, but the principle to be followed is that as few rings as possible should be used.
- The space between the lowest buffer block and the flange of the upper copper plate is 5 mm and the required precision in moving the block on site will be provided by the positioning system. There is a risk that the sheet will be squeezed between the flange and the buffer but it can be reduced by equipping the sheet with a ring as described in the preceding paragraph.
- The limited height of a real deposition tunnel will make all operations of handling, installation and detaching of buffer protection sheets significantly more difficult and demanding than in the large-scale experiment.

8.8.4 Detachment of the buffer protection sheet

Since damage and failure of the buffer protection sheet is the most riskful activity in the entire backfilling operation all possible effort must be taken to make the detachment of the sheet safe and an important task is to bring it up by uniformly distributed pulling forces. For this purpose a yoke is necessary as demonstrated by the large-scale experiment and a further requirement is that the space between buffer block and the wall of the hole should be uniform and at least 35 mm as in the experiment.

9 Further development

Development of the concepts for the bottom plate and buffer protection sheet is ongoing and for the latter an alternative sealing technique is being proposed that does not require double flanges (Figure 9-1). This means that other production techniques can be considered, like pressure lathing, according to which the plate is quickly rotated while pressing a suitably shaped tool against it. The plate is thereby shaped according to the design and at the same time gets it thickness reduced.

If a thin copper plate is used the concrete foundation must be cast and evened before placing it. Alternatively, the rock at the bottom of the hole be smoothened and the copper plate be placed directly on it. A study on these matters is ongoing with the conditions that it must 1) be possible to make the rock bottom of the hole even and smooth, 2) that the concrete foundation can be cast with a perfectly horizontal upper surface with great smoothness, and 3) that a technique must be found for achieving these goals. Figure 9-2 illustrates a possible method for making the bottom of the hole and the upper surface of the concrete or rock very smooth.

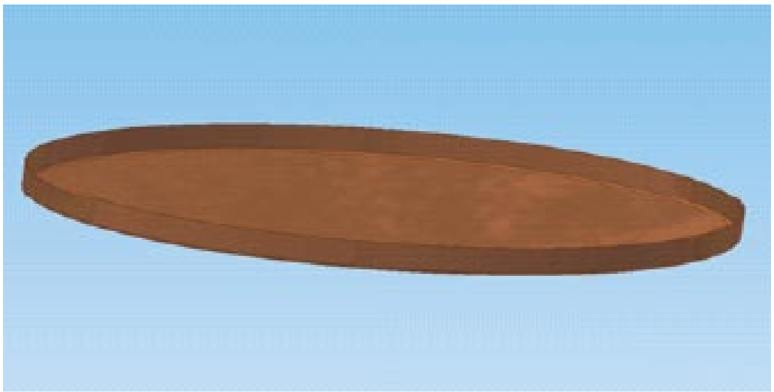


Figure 9-1. *Alternative shape of the copper plate is being considered.*

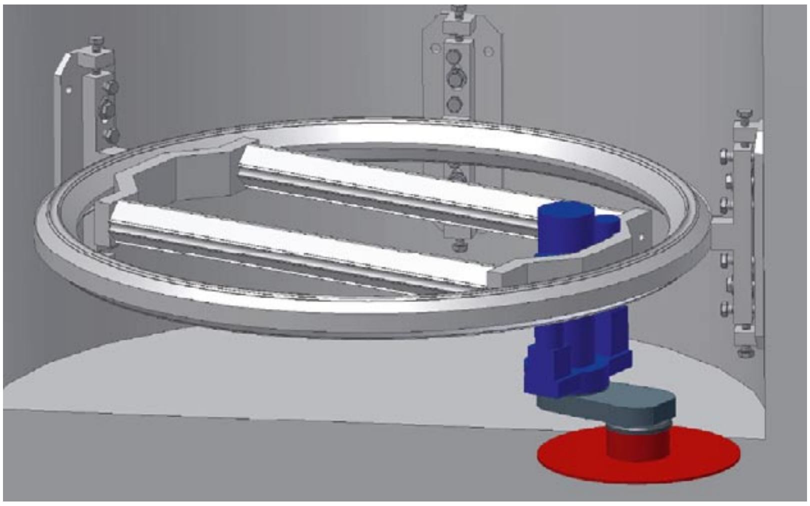


Figure 9-2. *Proposed equipment for smoothening rock and concrete.*

10 Conclusive remarks

The comprehension of the use of buffer protection sheets can not be decided at present. It primarily depends on the water inflow into the deposition holes, which may be and is in fact expected to be insignificant in many holes. Considering the experience from the Prototype Repository project at Äspö /Pusch et al. 2004/ and its predecessor, the Buffer Mass Test at Stripa /Gray 1993/, the fraction of significantly wet holes is 10–20% and if this holds for the forthcoming real repository the need for buffer protection sheets can be small depending on how canister deposition and backfilling sequences can be combined keeping in mind the expected degradation of buffer blocks by moist air.

Deposition holes that require protection sheets put a stronger demand on the inclination of the holes and on the construction of bottom plates. They also require greater accuracy in preparation and installation of the buffer blocks than holes without protection sheets.

Deviation from theoretical dimensions of the deposition holes and buffer blocks will cause difficulties at the installation and removal of the buffer sheets but has no impact on the long-term safety conditions.

For minimizing the time during which the buffer protection sheets will be exposed to water pressure etc, the backfilling of the tunnels can be made sequential, a matter that is presently being investigated /Wimelius and Pusch 2008/.

It is realized that strong demands on the buffer protection sheet and the bottom plate generate equally strong demands on the whole series of installation activities in the deposition tunnels, implying risk of delay and need for reconstruction.

11 References

Johannesson L-E, Gunnarsson D, Sandén T, Börgesson L, Karlzén R, 2004. Äspö Hard Rock Laboratory. Prototype repository. Installation of buffer, canisters, backfill, plug and instruments in Section II. SKB International Progress Report IPR-04-13. Svensk Kärnbränslehantering AB.

Gray M N, 1993. Stripa Project Overwiev Report. Vol. III; Engineered barriers. OECD/NEA International Stripa Project 1980–1992. Svensk Kärnbränslehantering AB, Stockholm, Sweden.

Pusch R, Ramqvist G, 2007. Borehole project – Final report of Phase 3. SKB R-07-58. Svensk Kärnbränslehantering AB, Stockholm, Sweden

Pusch R, Börgesson L, Svemar C, 2004. Prototype Repository Final Report (Deliverable D36). SKB International Progress Report IPR-04-27. SKB, Stockholm

Pusch R, Andersson Ch, 2004. Preparation of deposition holes prior to emplacement of buffer and canisters in Section II. SKB Int. Progr. Rep. IPR-04-21. SKB, Stockholm.

Svemar C, Pusch R, 2000. Prototype Reporsitory, Project description FIKW-CT-2000-00055. Int. Progress Report IPR-00-30, SKB, Stockholm.

Wimelius H, Pusch R, 2008. Backfilling of KBS-3V deposition tunnels-Possibilities and Limitations. SKB R-08-059. Svensk Kärnbränslehantering AB, Stockholm, Sweden. (in prep).