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Äspö Hard Rock Laboratory

Canister Retrieval Test

Retrieval phase

Project report

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May 2008

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Abstract

Main goal of the Canister Retrieval Test (CRT) at Äspö Hard Rock Laboratory is to demonstrate the ability to retrieve a deposited canister at full buffer saturation.

To show this a canister was deposited in year 2000. Since then the surrounding buffer has gradually been saturated and formed a firm grip of the canister. In this report the work done in order to free and retrieve the canister from the deposit hole is described. A number of references are given in which more detailed description of methods and analyses results can be found.

One of the goals in the project is to verify the mathematical models of the buffer saturation process. To achieve this large numbers of samples have been taken from the upper part of the buffer. These are analyzed and the result compared to computer simulations. The models are being developed within the Task Force work and are not yet finished, results can therefore not be reported in this document.

The heater system used to simulate the residual heat from the spent fuel had problems during the experiment and great effort has been taken to find the cause. The power cables outside the canister show both pressure and twisting damages from the buffer. The cables are however still fully functional at these locations. The main cause has instead been established to sections in between the canister lids, i.e. underneath the lid that should protect the cable and connectors from the buffer. Here the cable shield has severe damages. Loss of cable shield has led to water entering the cable with resulting short circuits.

The heater elements have also been investigated to find possible problems. Chemical reactions that temporarily effect the heater system are found. The phenomenon is most likely temporary and will improve over time. They cannot alone be the reason to the total failure of heaters that has been observed during the experiment.

Dissintegration of the buffer as method to free the canister from the buffer has been proven to function well. Despite some issues with the equipment the canister was successfully freed. During the test a maximum buffer removal rate of about 90 kg/h was reached. During continuous operation of the system a canister could then be freed in about 180 hours. Some system improvement possibilities have been identified. With these the efficiency of the system would lessen the needed running time of the system.

Lifting of the canister was done with the same machine as used at the deposition. The machine had to be somewhat modified to reach the site without disturbing the TBT experiment. The retrieval was straight forward and no issues were encountered. The canister has been transported to the canister laboratory in Oskarhamn for analyses.

Sammanfattning

Projekt ”Canister Retrieval Test” (CRT), återtagsprojektet, vid Äspölboratoriet har som främsta mål att visa att det går att återta en deponerad kapsel när den kringliggande bufferten vattenmättats.

För att visa detta i full skala deponerades en kapsel under hösten 2000. Sedan dess har bufferten vattenmättats och dess svälltryck format ett hårt grepp om kapseln. I denna rapport redovisas arbetet med att frilägga kapseln och lyfta den ur deponeringshålet. Ett antal referenser redovisas där detaljerade beskrivningar av arbetet och analysresultat återfinns.

Då ett av målen med projektet är att verifiera buffertens vattenmättnadsförlopp har ett stort antal prover på bentonitbufferten tagits. Dessa prover analyseras och resultatet ska kontrolleras mot gjorda simuleringar. Detta arbete är inte slutfört i dagsläget, arbete i Task Force pågår, och resultat kan därför inte redovisas i denna rapport.

Då de värmare som simulerar det använda kärnbränslets restvärme har haft problem under drifttiden har stor vikt lagts på att säkerställa orsaken till felen. Det har visat sig att strömkablarna utanför kapseln har stora skador på ytterhöljet. Kabeln har kläm och vridskador, dock har det konstaterats att dessa inte påverkar kabelns funktion. De skador som däremot har påverkat kabelns funktion återfinns på de kabeldelar som befunnit sig mellan kapsellocken, dvs. under det övre locket som skulle skydda kontaktdonen från bufferten. Här har kabelhöljet spruckit med följd att vatten har trängt in i kabeln och orsakat kortslutning.

Värmarna har också undersökts för att eventuellt hitta fel även på dem. Kemiska fenomen som temporärt påverkar värmarsystemet har påvisats. Fenomenen är med största sannolikhet av övergående karaktär och kan inte vara orsak till det bitvis totala frånfallet av värmare som observerats under drifttiden av kapseln.

Metoden att med saltlösning slamma upp bentonitbufferten och därefter pumpa den ur hålet har visat sig fungera bra. Trots flera problem med utrustningen under testet kunde kapseln friläggas med metoden. Under försöket uppnåddes en kapacitet på ca 90 kb buffert per timme. Under kontinuerlig drift av systemet skulle en kapsel helt inbäddad i bentonit kunna friläggas på ca 180 timmar. Ett antal förbättringspunkter på det befintliga systemet har identifierats, med dessa implementerade skulle effektiviteten kunna ökas och tiden att frilägga kapseln minskas.

Lyftet av kapseln ur hålet gjordes med samma maskin som deponerade den. Maskinen fick byggas som något för att kunna komma fram till deponeringshålet utan att påverka TBT försöket. Lyftet av kapseln var problemfritt. Kapseln har sedan körts till kapsellaboratoriet i Oskarshamn för analys.

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1 Introduction

1.1 General

SKB's strategy for the disposal of canisters with spent nuclear fuel is based on an initial emplacement of about 10% of the canisters followed by an evaluation of the result before any decision is made on how to proceed.

The overall objective of the Canister Retrieval Test (CRT) is to demonstrate to specialists and to the public that retrieval of canisters is technically feasible during any phase of operation.

The project consists of three phases where the first phase includes preparation of the test site, installation of instrumentation, buffer and canister and launching of the test. This first stage was completed in year 2000. The second phase is the water saturation period. The third phase will deal with the actual retrieval of the canister and evaluation of the collected test data. Heater shutdown in October 2005 initiated the third phase. Saturation phase had then been in operation for five years.

There are three main goals of the retrieval phase of the project:

- Verify the buffer saturation model through buffer samples and analyses.
- Verify the canister retrieval method with a fully saturated buffer.
- Find the cause of the canister heater malfunction.

This report is an overview of the work conducted in the retrieval phase of the project. The aim is to give a brief explanation of all activities within the project. Several references are given to reports that are written with detailed description of work and results from analyses.

1.2 Test programme

The deposition tunnel for the experiment is located on the 420-meter level in the extension of the D-tunnel, and was excavated by conventional drill and blast. The tunnel is 6 m wide and 6 m high, and the centre-to-centre distance between the two deposit holes is 6 m, which is the spacing being considered for the deep repository. In the Canister Retrieval Test, higher thermal power is needed in the canister in order to obtain a temperature of about 90°C on the surface of the canister.

The buffer was installed in the form of blocks and rings of bentonite. The full dimensions are diameter 1.65 m and height 0.5 m. When the stack of blocks was 6 m high, the canister, equipped with electrical heaters, was lowered down in the centre of the hole, cables to heaters, thermocouples and strain gauges were connected, and further blocks were emplaced until the hole was filled up to one meter from the tunnel floor. On top the hole was sealed with a retaining plug made of concrete and a steel plate. The plug is secured against heave caused by the swelling clay by a cable anchored to the rock. The tunnel will be left open for access and inspections. Water is supplied artificially around the bentonite blocks by means of permeable mats attached to the rock wall. An illustration of the set up is shown in Figure 1. A more detailed layout of the deposit hole is shown in Figure 2.

The expected saturation time for the test is two-three years in the 350 mm thick buffer along the canister and 5-10 years in the buffer below and above the canister. The decision on when to start the retrieval tests is dependent on information of the degree of saturation. Instruments are installed to monitor the process in different parts of the buffer. This instrumentation is similar to the instrumentation in the Prototype Repository and yields comparable information during the saturation period.

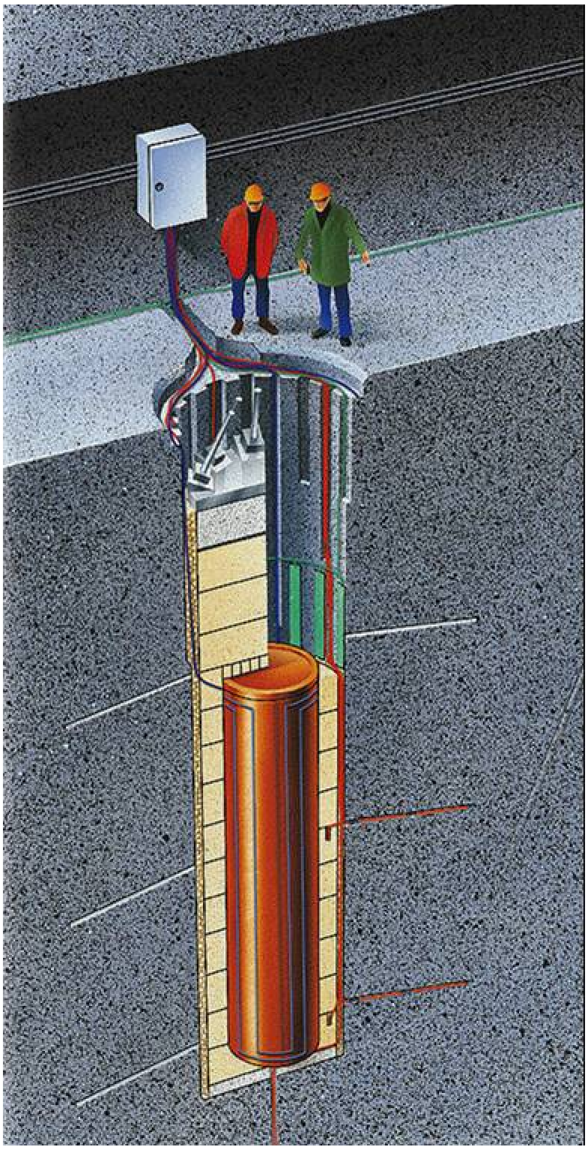

Figure 1. *Set up of the Canister Retrieval Test.*

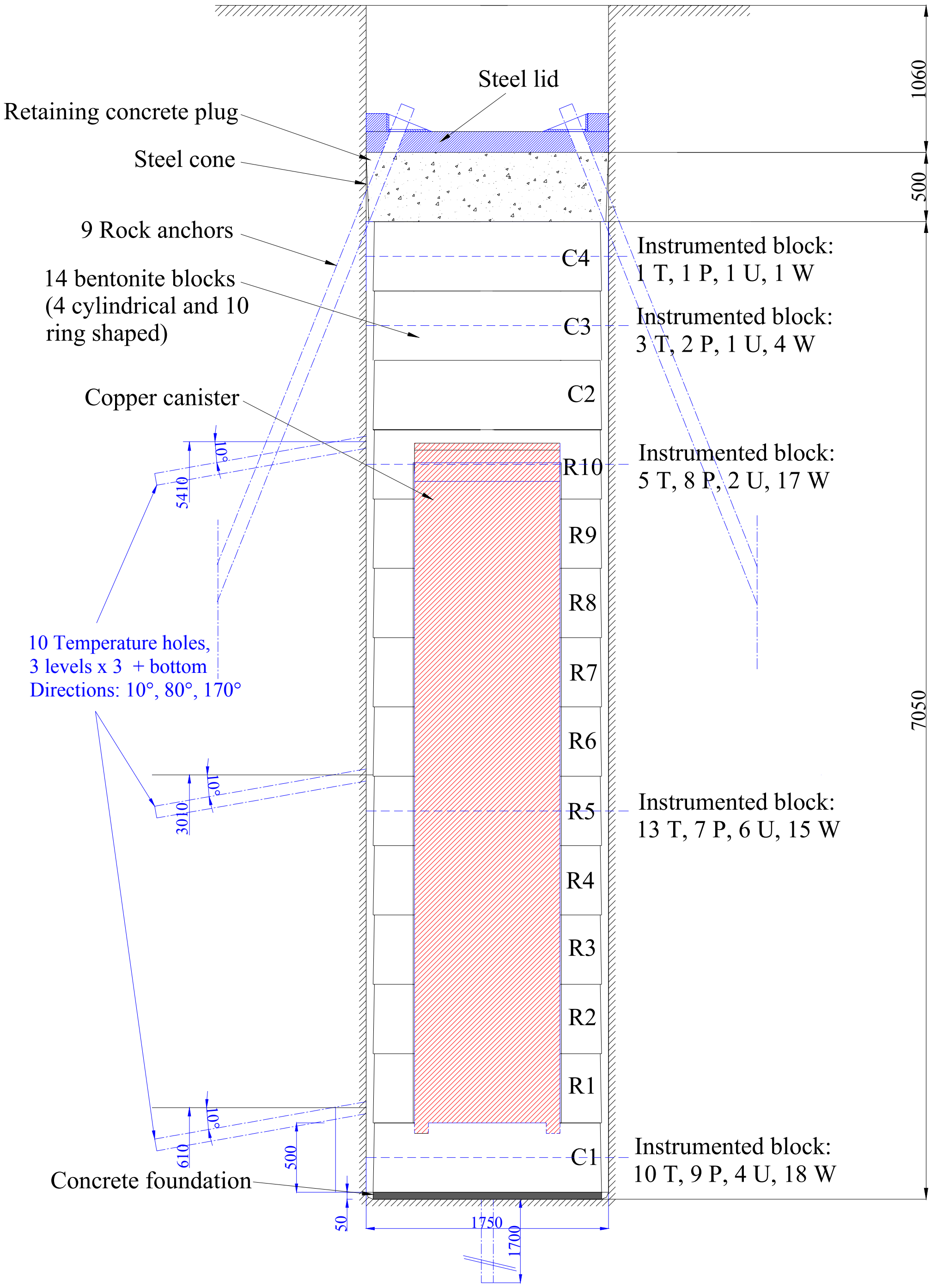

Figure 2. *Schematic layout of the experiment. Sensors have been placed in five of the bentonite blocks. For each block the number of each sensor type is described. (T=temperature, P=total pressure cell, U=pore pressure cell and W=relative humidity sensor).*

More detailed information regarding the layout and installation can be found in the CRT installation report, SKB IPR-02-30 [1].

1.3 Document outline

The content of this report is divided so that topics related to each other are also grouped in the text. This means that all activities are not necessarily reported in the order they were carried out, which unfortunately can be confusing. The reason for this is that some activities were carried out in the middle of another activity, and even spread out over a wider time span. For example the heater analyses were divided into several parts which were carried out when other activities allowed; in the middle of the buffer sampling, after the buffer sampling were completed but before the buffer disintegration test, after the canister was retrieved and even after the canister was delivered to the canister laboratory. References in the text can therefore sometimes refer forward in the report, text can also sometimes imply that activities already reported are not carried out yet.

The order in which the activities were carried out at the site is as follows: (chapter number in parenthesis)

1. Heater shut down (2.1)
2. Emptying saturation filter mats (2.2)
3. Drilling and sampling gas underneath the plug rubber mat (3.1)
4. Removing the steel lid (3.2)
5. Removing the concrete block (3.3)
6. Removing the rubber mat (3.4)
7. Sampling and excavating the buffer down to the canister top (4.1, 7.1)
8. EIS measurement #1 on entire heater system (6.1)
9. Removing the canister upper lid (5)
10. Heater power cable first test (5.1-5.3)
11. Sampling and excavating the buffer to mid height of canister (4.1, 7.1)
12. Replacing the heater power cables, restarting heaters temporarily (5.4)
13. Buffer disintegration test (7.2)
14. Canister retrieval (8)
15. Excavation of remaining buffer underneath canister (7.3)
16. Gas sampling from canister (in storage building above ground) (6.2)
17. Transporting the canister to the canister laboratory (8)
18. EIS measurement #2, only connectors and heaters (at canister laboratory) (6.1)
19. Opening the canister, cutting and sampling pieces of the heaters (at canister laboratory) (6.3)
20. Rock sampling in deposit hole (9)

This list does not include the off-site analyses that have been made.

2 Preparatory work

This chapter describes the preparatory work done in order to be able to perform the buffer sampling, test the buffer disintegration method and retrieving the canister.

2.1 Heater shutdown

To prepare for the canister retrieval process some measures had to be taken. The first of them was to turn of the power to the heaters in enough time to allow for the buffer to cool and allow manual work with the buffer. The goal was to have a buffer temperature of 25 °C at the time of buffer sampling and excavation. Power to the heaters was turned off 11th October 2005. The buffer temperature at the time of heater shutdown was approximately 50°C, three months later at the start of the buffer excavation the temperature had dropped to 26°C, Figure 3. The heater power was 1380 W at the time of shut down.

Figure 3. *Buffer temperature between October 1st and 2005 and January 31st 2006. During this time the buffer temperature dropped 24°C and was approximately 26°C degrees when the buffer excavation was initiated.T116, T117 and T118 refers to temperature sensors. They are located at mid height of the canister, in buffer block R5. T116 is located closest to the canister of the three sensors.*

The TBT experiment that is located close to the site had to increase the power to their heaters from 1500 to 1600 W to compensate for the shutdown of the CRT heaters.

2.2 Emptying saturation filter mats

To increase the saturation process of the buffer in the CRT experiment an artificial saturation system was installed. The water distributing parts in the deposit hole consists if textile filter mats. These mats have during the operation of the experiment been more or less filled with water. To avoid additional wetting of the buffer during sampling these mats had to be dry. This was accomplished by using vacuum suction. The suction was however unsuccessful in retrieving any water from the filter mats. The conclusion was that that the mats were dry when they were disconnected from the rest of the saturation system.

3 Opening the deposit hole

The deposit hole has during the experiment period been sealed to simulate the buffer backfill. This seal consists of a rubber mat, a concrete plug and a steel lid. The construction is secured with rock anchors fastened in the hole rock wall. The layout of the deposit hole seal shown in Figure 4.

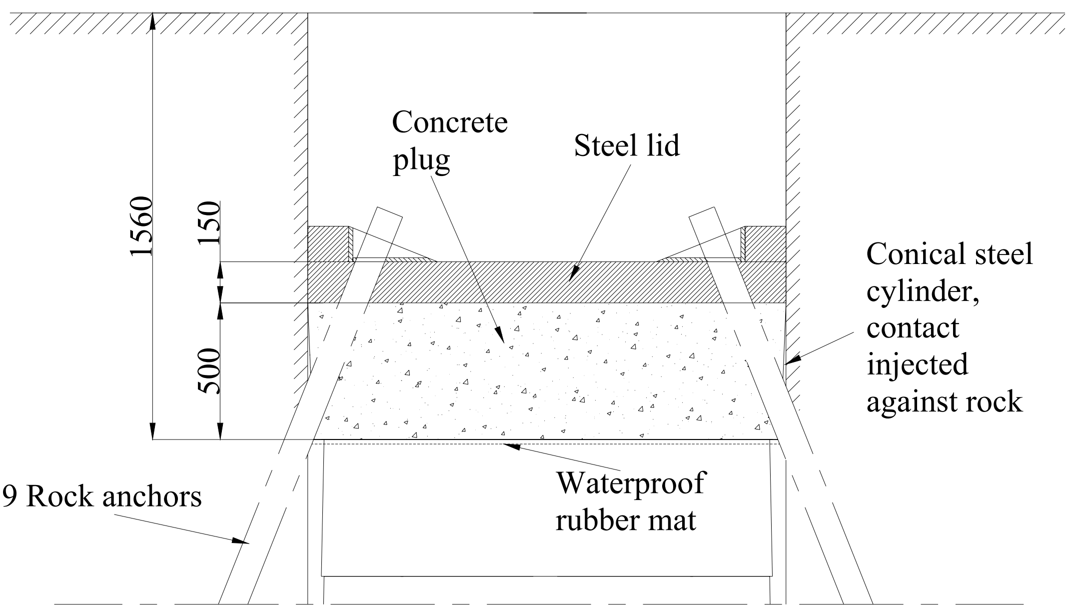

__Figure 4.__ Layout of the deposit hole seal. Right on top of the buffer is a rubber mat. On top of the rubber mat a concrete plug is cast. Above the concrete plug a steel lid is placed and secured with large rock anchors installed in the rock wall.

3.1 Deposit hole gas test

The planned activities in the deposit hole required knowledge about the conditions in the deposit hole, mainly to guarantee the working environment. Since the canister contains several gaskets, mainly to seal the cable throughput, the tightness of the canister was questioned, especially since the heaters failed. If the gaskets for some reason had failed during the experiment, gas would have leaked out in the deposit hole. This gas could eventually end up underneath the rubber mat separating the concrete plug from the bentonite buffer. To check the occurrence of gas a gas sampling test was conducted. This was done by drilling a hole through both the steel lid and concrete plug. The rubber mat was then punctured with a gas sampling needle. The test was successful and the analysis of the sampled gas showed no heightened levels of any kind.

3.2 Removing the steel lid

Removal of the steel lid was conducted in January 2006. The work was done by the same entrepreneur that fastened the lid at the time of installation. Due to high tension the cables was loosened one by one a little bit allowing the lid to rise somewhat to release the pressure.

When all cables were loosened the lid was lifted without problems. Underneath the lid some expected corrosion products were found, Figure 5.

Figure 5. *The steel lid is lifted from the deposit hole. Some corrosion is visible on the side and underneath the lid.*

3.3 Removing the concrete plug

The final building block above the buffer to remove was the concrete block. No issues were encountered during the removal of the concrete plug.

Removal of the plug was straightforward. The threaded lifting nuts casted into the block was cleaned and inspected. Since no issues with corrosion or damaged concrete were found steel loops were screwed into the nuts and lifting chains attached. Figure 6 shows the block just prior lifting and the status of the rubber mat underneath.

Figure 6. *Lifting the concrete block. The lifting was straightforward and no issues encountered. To the right the rubber mat under the concrete plug is shown.*

3.4 Rubber mat

Removal of the rubber mat was also no problem. The buffer hadn't stuck to the mat and no damage on the buffer upper surface was found. Figure 7 shows the buffer surface underneath the rubber mat.

Figure 7. *The upper buffer surface as it looked when the rubber mat was first lifted. No damage on the buffer could be found.*

To avoid buffer drying and dirt falling onto the buffer a plastic sheet was always covering the buffer when no work was being carried out in the deposit hole.

4 Buffer sampling and analyses

Analyses of the buffer will give very useful data about the buffer conditions. The results will be used for THM modeling of the buffer which is part of the Task Force work. Some 1500 samples was taken from the buffer. In this chapter the process of buffer sampling is described.

Buffer sampling and manual excavation of the buffer is performed in steps; when the sampling of one buffer block is completed the block is cut into pieces and manually lifted out of the deposit hole. This also means that "manual excavation" is tested prior the buffer disintegration test.

In this section the sampling and analyses are briefly described. No results from the analyses are however given here. Buffer sampling and analyses are extensively described with both method and results in SKB IPR-07-16 [2] and SKB IPR-08-17 [3].

4.1 Sampling

The buffer consists of 50 cm high bentonite blocks that are placed on top of each other. Along the canister the blocks are ring formed. Underneath and above the canister the buffer blocks are cylindrical.

Most of the samples were taken from the buffer by core drilling from the upper surface of each installed bentonite block. The cores had a diameter of about 50 mm and a maximum length equal to the original height of the bentonite blocks of about 500 mm. The drilling was made from the tunnel floor with a rig designed for taking geotechnical soil samples, Figure 8. In addition samples close to the canister and the rock wall were taken by picking pieces from the blocks by hand. Furthermore, samples were taken close to the installed sensors. Larger pieces (up to ¼ of a block) were also sawn out from the blocks and stored. The rest of the buffer material was removed and thrown away.

Figure 8. Rig for performing the buffer core drilling. The machine is designed for geotechnical soil sampling.

Approximately 430 cores were taken out from the buffer. From these cores some 1200 samples were extracted and analyzed. Figure 9 shows the layout of the core drilling on both a cylindrical block and a buffer ring along the canister.

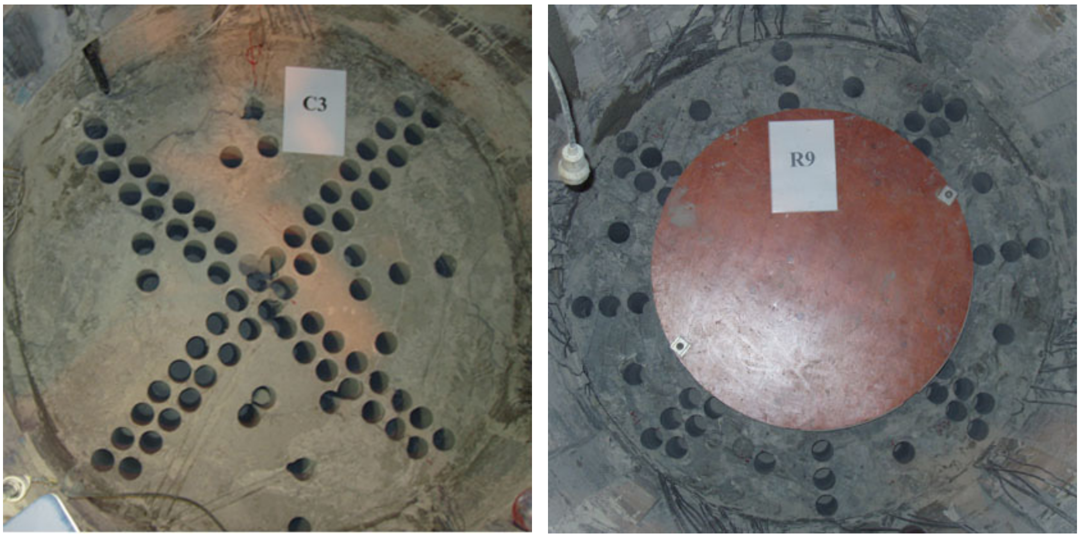

Figure 9. Core drilling pattern for a cylindrical block to the left and for a buffer ring alongside the canister to the right.

All cores and other samples were accurately numbered and stored in plastic wrapping to prevent drying and stored for future analyses.

4.2 Analyses

The analyses regarding buffer properties are done in two steps.

1. The water ratio and the density were determined at the Äspö Hard Rock Laboratory just after the samples were taken from the buffer, which minimized the risk of drying and redistribution of the water in the samples. About 1500 samples were taken from the buffer and analysed.
   Results from these analyses are found in [2].

2. More advanced investigations of the buffer will be made at Clay Technology AB in Lund, such as determination of hydraulic conductivity and swelling pressure, mineralogical changes etc. These tests do not require immediate handling of the samples and will be made in 2007/2008.
   Results from these analyses are found in [3].

The modeling work to simulate the buffer saturation process is part of the Task Force work. The works is not completed yet and no results can be included here.

Microbiological analyses are also conducted on buffer samples. These analyses have been conducted by Micans and are reported separately. No reference is available yet for the microbiology analyses report.

5 Heater power cables

When the buffer sampling and excavation reached the top of the canister the sampling was temporarily put on hold. The pause in the sampling work was used for opening the canister upper protective lid and investigating the cables going into the canister. Note that the canister had two copper lids, Figure 10, and that opening and removing the upper lid does only expose sand/buffer embedded cables and connectors underneath – the canister is still sealed.

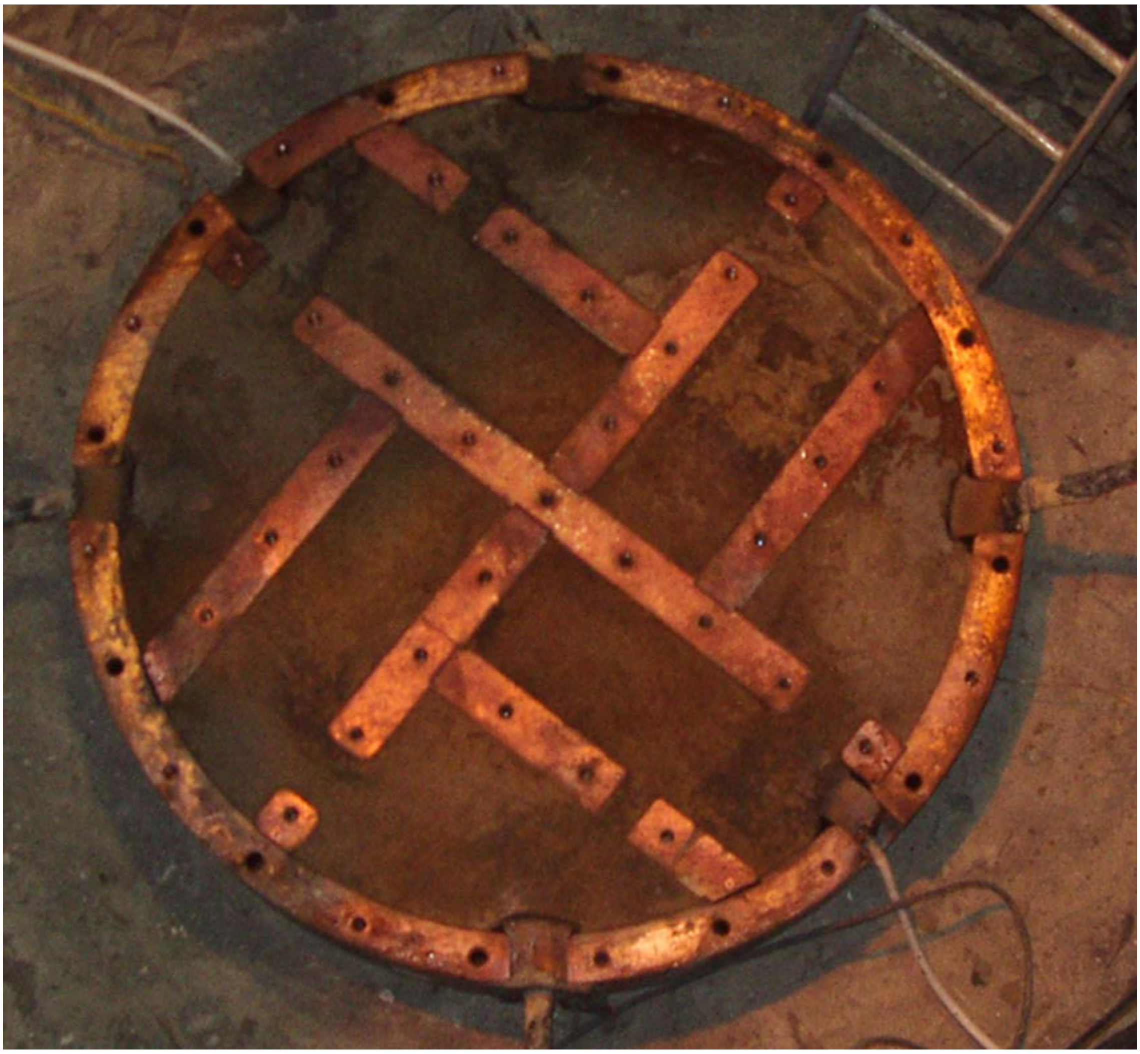

Figure 10. *The canister has two copper lids, the first is sealing the canister, the upper lid only protects the cable connectors from the buffer. Here the upper lid is just removed.*

After the upper lid was removed it was found that the mixture of bentonite and sand that filled the volume had separated. There were also pools of standing water visible.

Due to the fact that the heaters in the canister malfunctioned during operation one of the project goals was to find the reason why. The heater system consists of several parts, within the canister, outside the canister but still in the deposit hole and finally above the deposit hole. Malfunction in the system outside the deposit hole was quickly investigated and ruled out. This left only the parts within the deposit hole and the canister as sources of error for the problem.

This section describes the different damages that were found on the heater power cables.

5.1 Swelling pressure damages

During excavation of the buffer the power cables to the heaters was gradually freed. The cables show wear and tear, both pressure and twist type damages, from the buffer swelling pressure, Figure 11. The damages are found at several positions along the cables. These damages have been looked at by the cable manufacturer and it has been established that the damages are only of cosmetic type, no degradation of cable functionality can be connected to these damages.

Figure 11. *The power cables show damages from the bentonite swelling pressure at several positions.*

5.2 Cable shield damages

When the upper lid was removed and the cable underneath became visible more damaged was revealed. The cable shield close to the connector was at both cables severely damaged. As seen in Figure 12 the shield has almost completely loosened from the cable exposing the ground wiring.

The damage itself is not reason for the failure of the cable, but the moist conditions have lead to water entering the inner parts of the cable and causing short circuits. These damages have been found to be the main reason for the failures of the heaters.

The cables was analysed by the manufacturer. Comparative tests have been carried out with a unused cable as reference. The analyses have only been able to prove some crystallization of the cable shield material. It is very likely that this process have made the cable shield brittle which eventually have lead to fracturing. The fractures have been penetrated by water with short circuits as result.

Figure 12. *Damage on the heater power cable shield. The damage is located between the canister lids and close to the gisma connector.*

The cable was specified to be able to withstand the high temperatures that they were exposed to. However the heat together with the moist conditions has evidently been too much.

5.3 Connector polyurethan cast

A polyurethane cast was used to seal the connection between the Gisma connector and the cable, Figure 13 left. Also the polyurethane cast shows significant damages, the material has been completely dissolved during the experiment. Using only the thumb pressing gently on the remaining sticky material was enough to remove it, Figure 13 right.

Figure 13. *The polyurethane cast sealing the connection between the Gisma connector and the cable. The left image shows a new cast and the right image the state of the used.*

Also this part of the cable has been analyzed. The results show that the function of the cast is still intact even if the polyurethane has completely been broken down to its chemical components. The power loss can therefore not be caused by this part of the power cable.

5.4 Restarted heaters with replacement cables

A simple and quick way to find out the condition of the heaters inside the canister without open the canister was to replace the power cables and run the system for a period. This was done when the buffer sampling was completed and the buffer disintegration process was being prepared.

During the short period of time the system was running no errors were found and the system worked as designed. The deposit hole was insulated to prevent too much ventilation and temperature loss during the test. Figure 14 shows the deposit hole with insulation. Figure 15 shows the temperature increase of the buffer during this test. The power to the heaters was set at 1 kW initially and increased to 2 kW after one week. During the test the temperature of the buffer closest to the canister was raised from 23 to 32°C.

Figure 14. *New cables were fitted and the heaters restarted. No issues were encountered during this test. The deposit hole was insulated to prevent too much ventilation and temperature loss.*

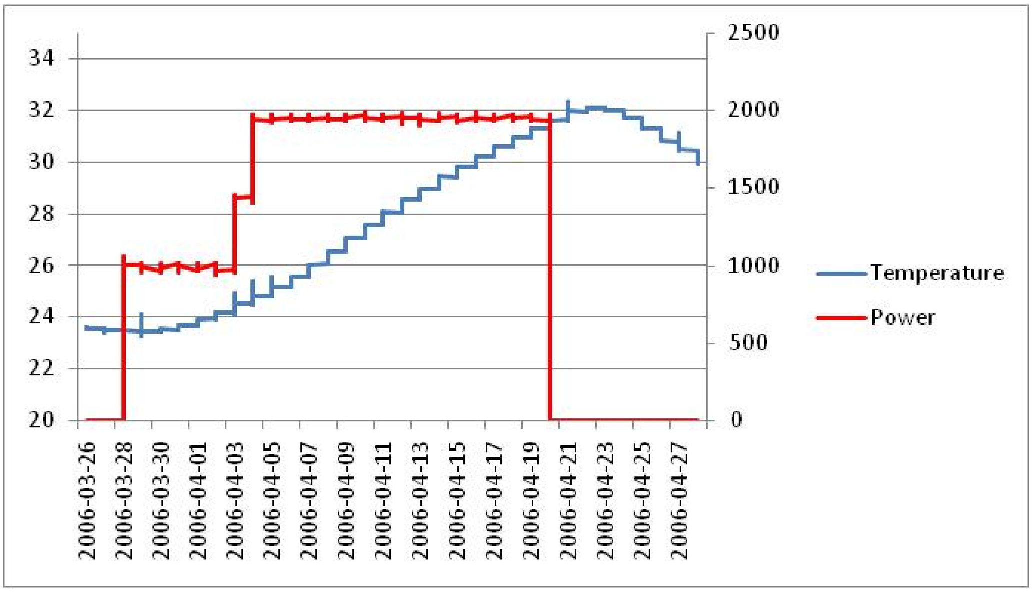

Figure 15. *Buffer temperature development during the short test of the heaters with new power cables.*

The fact that the heaters worked properly during this test period does however not rule out that there can have been issues with the heaters during the operation. The chemical processes inside the canister vary with time and these also affect the heaters. Possible problems can be temporary. For that reason the heaters were also analyzed. The analyses are described in chapter 6, Heater analyses.

6 Heater analyses

Malfunction of the heater cables may not be the only cause for the failure of the heater system. There might also be problems with the heaters inside the canister. To verify the heater functions extensive analyses work has been done.

The heater system has twice been tested with impedance spectroscopy (EIS) measurements. Once with the external power cables attached, and once without. The heaters have also been cut into smaller pieces and tested together with cables from inside the canister.

This chapter describes briefly the tests conducted and the results.

6.1 Impedance spectroscopy, EIS

Two tests with this method have been done. The first test included the entire heater system (canister and external power cables) and the second only the canister.

The first test was carried out when the canister was still in the deposit hole and the buffer sampling and excavation had just reached the canister. At this point the power cables had never been removed from the canister. Measurements concluded isolation issues in the system. Electrical resistance between the power wires and ground was low, implying short circuit issues. The measurements cannot pin point the origin of the failure, merely conclude the failure. Figure 16 shows a sample of the results from the test.

The second EIS measurement was done just prior opening the canister at the canister laboratory in Oskarshamn. At this test the power cables were removed and excluded from the test. The measurement equipment was connected to the GISMA connectors on top of the canister – the same connectors that the power cables were connected to. Results from the second test imply that the heater system inside the canister is fully operational. Isolation values are good and no other problems can be found. This verifies the earlier findings that the main problem is outside the canister (brief test of the heaters with new power cables that was conducted in the deposit hole, chapter 5.4). Figure 17 shows the isolation values from the second EIS test. Values in the right graph are significantly better than in the left.

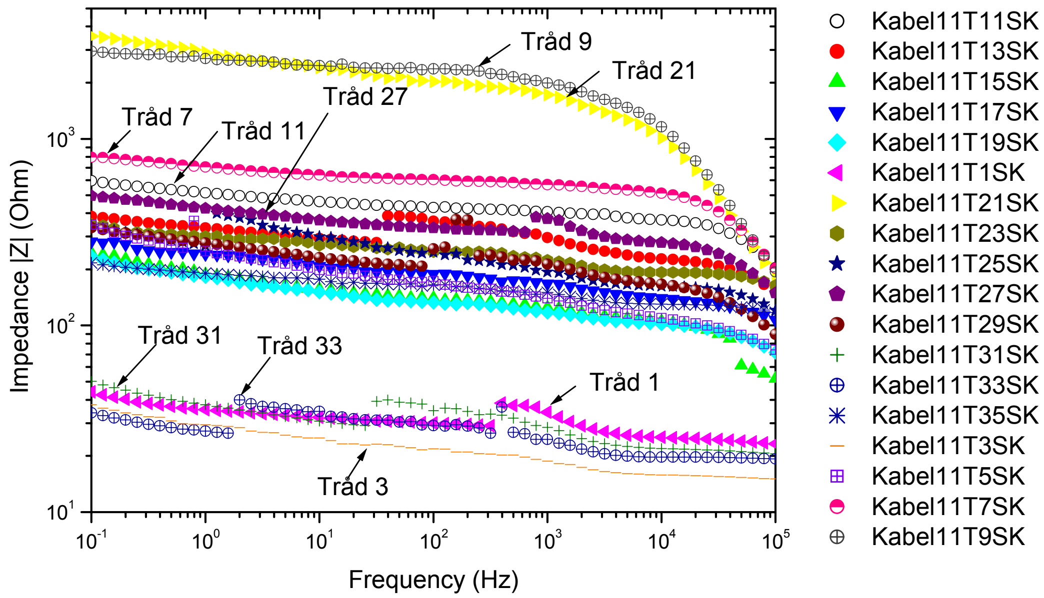

Figure 16. *Results from the EIS measurements. The low resistances in the system is clearly visible. Values as low as 10^1 to 10^2 are measured. ("Tråd"and "kabel" are Swedish words for wire and cable.)*

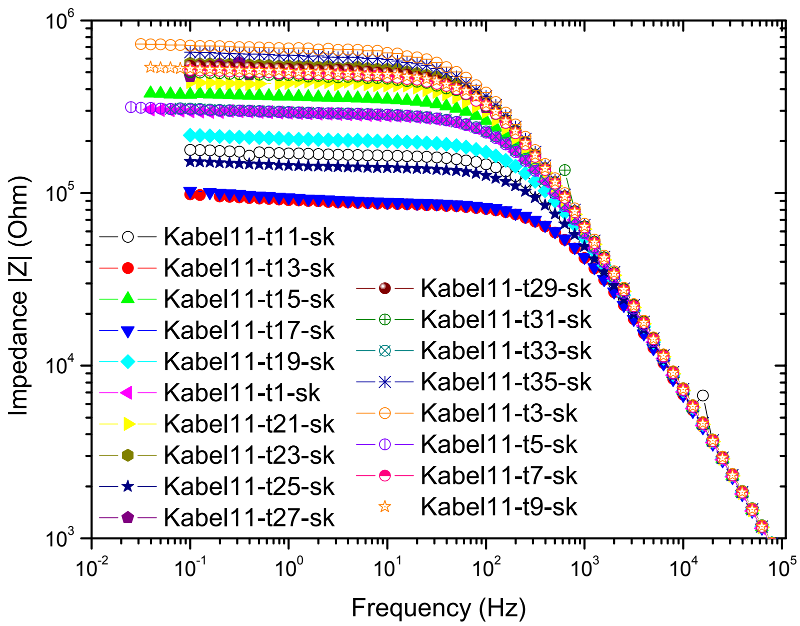

Figure 17. *The right graph are from the second measurement, without the power cables. In the right graph the isolation values are greatly improved over the earlier measurement. This indicates that the problem is within the power cables. ("Kabel" is a Swedish word cable.)*

6.2 Canister gas sampling

Before the canister could be opened and the heaters retrieved some samples of the gas within the canister were taken. The gas content is important since it gives important information about the chemical processes inside the canister during the operation. The gas sampling was carried out when the canister was located in a storage building above ground.

6.2.1 Puncturing the canister

The canister is a completely sealed cylinder, no gas valves or any other device allows for ventilating the canister or sampling gas directly. One way to drill a hole and mount a valve in a pressurized container without leakages is by the use of a “hot tap” device. Hot taps are usually used when installing valves in gas or gasoline pipes without the need to stop the flow inside the pipe.

The hot tap device is basically a pipe with a valve. The pipe is mounted in a pre drilled and threaded hole (not penetrating the material). A drill is then inserted in the pipe and the final drilling through the canister can be done. Above the valve and on the inside of the pipe is an o-ring that maintains a seal between the drill bit and the hot tap pipe. Once the canister is penetrated the drill bit can be raised above the valve – but not above the o-ring. Finally the valve is closed and the drill bit can be completely removed. The process is completed and the valve is mounted on the canister without pressure drop or leakages. Figure 18 shows a schematic image of a hot tap.

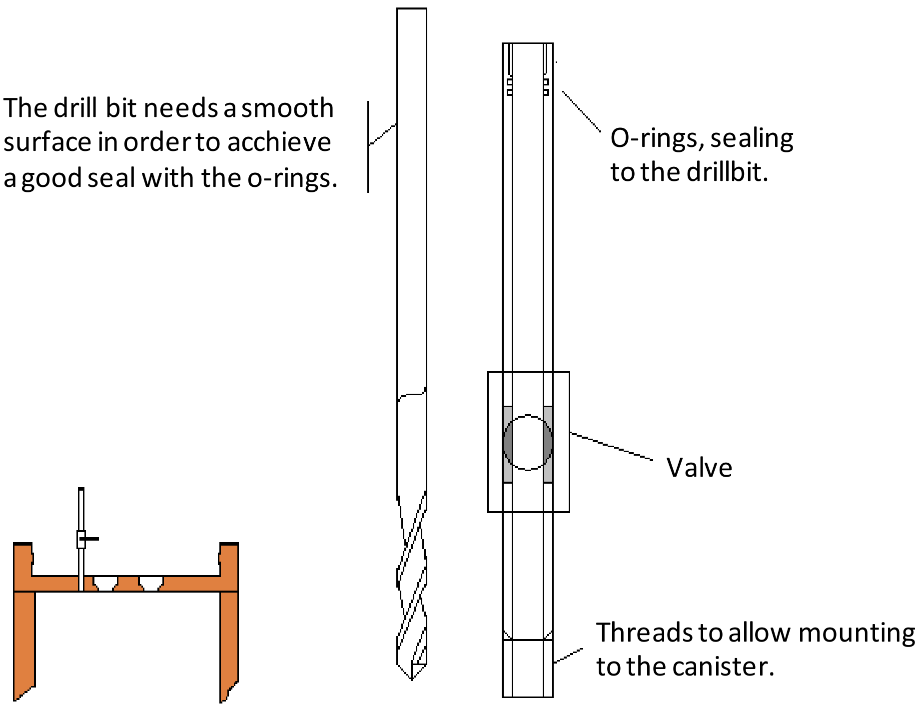

Figure 18. *A schematic image of a ”hot tap” device. The device is used when installing a valve without risking leakages in a pressurized pipe or container.*

A previous tested canister (opened at Kockums in 2002/2003) had quite high hydrogen content, 6,4-6,6 %. A level that high means that the gas would be explosive. Since the CRT canister had been in operation for a longer period of time than this reference canister, the levels of hydrogen was anticipated to be even higher. Special measures were taken to ensure a safe working environment during this work. For instance no electrical machines were allowed in the working area, an air powered and remote controlled drilling machine was used, gas sniffers were monitoring the area for possible leakages etc.

The hot tap was positioned right next to a GISMA connector so that the drill bit would not hit the steel lid underneath the copper. Drilling in copper with a steel drill bit is spark free.

When the valve was finally mounted the gas sampling could be performed. The additional equipment on the hot tap is pressure sensors and additional valves for adding additional sensors or equipment. Figure 19 shows the set up just prior puncturing the canister. In the picture the air-driven drill is visible as well as the remote controlled drill height adjusters (the two vertical steel bars).

Figure 19. *Mounting of the valve with the hot tap equipment. The picture is taken just prior the process of puncturing the canister.*

6.2.2 Gas sampling

Once the valve was mounted the sampling of the gas could be performed. The canister was expected to hold a slight overpressure. After unsuccessful tries to sample gas by simply opening the valve and fill small gas tanks the canister was actually found to have a slight underpressure.

To overcome the underpressure gas pumps were used. The pumps were also unsuccessful, mostly due to a too small pump capacity. Since no other certified pumps could be found with short notice another solution was chosen; raising the pressure to 1.1 – 1.2 bar inside the canister by inserting argon gas. This would mean that the simple "open the vale and sample the gas" method could be used after all. Argon would not be present in the canister and can easily be compensated for and identified in the gas analyses.

After the argon gas was inserted into the canister the sampling was straight forward. The analyses show that the hydrogen level in the canister was less than 2.5 %, which is below the reference canister and also below the explosive level. The level of oxygen in the canister was almost zero.

6.3 Heater analyses

Deeper analyses of the heaters have been done to investigate how they have been affected by the 5 years running time. This is important information even if it has been concluded that the heaters are in working condition. Chemical reactions in the heaters, and in other parts such as cables etc in the canister, can affect the stability of the heater system and also affect the corrosion process of connectors etc. Information regarding this is of interest for other project running similar systems at Äspö, such as the prototype repository project.

Moisture content, distribution and possible gas release from the magnesium oxide in the heaters have been discussed quite extensively. These have been tested by sampling the heaters. Six heaters were sampled at different positions and analyzed. Figure 20 shows the position of the sampled heaters and a schematic image of the sample positions within each heater.

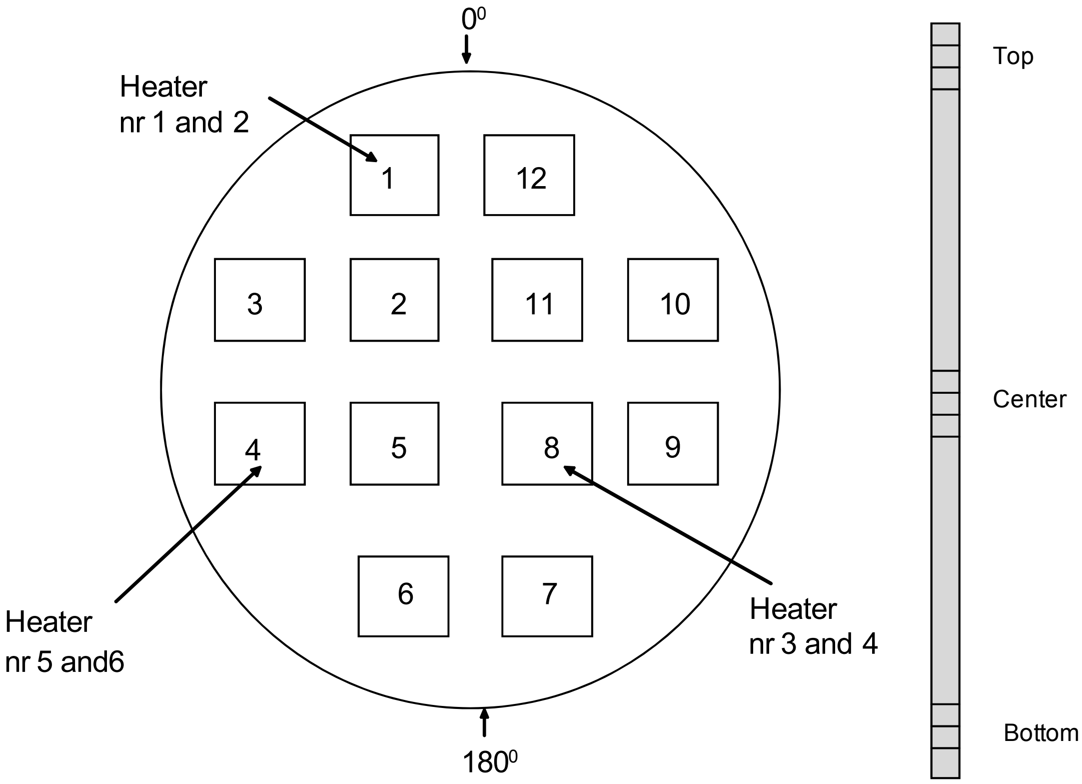

Figure 20. *Sampled heaters. Six heater were tested from the canister, two from each marked position. To the right a schematic image of the sample positions within each heater is shown.*

The analyses conclude that the difference in moisture levels inside the heaters were significant, four of the heaters had the highest levels in the upper part and the remaining two in the middle. In the most extreme case one heater element had 0.29% moisture in the bottom and 0.91% in the top. Earlier studies have shown that the average value for a used heater of this type (Backer) has a moisture content of 0.58%, Studsvik/N(K)-03-026 [4]. The study further concludes that chemical substances, mainly acetic acid that are originating from the heaters can have a negative effect on the leader-ground isolation in the electrical system. These issues will most likely improve over time, and eventually be nonexistent. Early problems with the heaters might have been caused by this issue, the main reason for the total heater failure is however still considered to be the damages of the external power cables.

7 Freeing the canister from the buffer

One of the main goals of the project was to test and verify the ability to free a canister by the use of the previous developed buffer disintegration method. During the buffer sampling the buffer was also manually excavated. Observations regarding the possibility to manually excavate buffer has for that reason also been done and is briefly reported in this section.

7.1 Manual buffer excavation

The manual excavation conducted at the time of buffer sampling was successful in the aspect that the buffer was removed. However the work was heavy, difficult and time consuming. It took at least one day for two persons to remove one buffer cylinder manually. When the work started when the buffer sampling of the buffer block was completed – in other words the buffer cylinder was at that point already divided into four quarters by the core drilling process, Figure 9. If the manual excavation have had to start with an undivided block the process would have been even harder.

The manual excavation was only performed down to half the canister height. Since the distance between the canister and rock wall is only about 30 cm the work became more and more difficult to perform the further down the work progressed. It can be concluded that manual excavation below half the canister height will be very difficult and time consuming.

7.2 Buffer disintegration

The method to disintegrate, or slurrying, the buffer has previously been tested in smaller scale by SKB. The purpose of this test is to verify the method with a full scale in situ test. In this section the method is briefly described as well as the results from the test. Extensive description and complete results are reported in SKB IPR-08-04 [5].

Disintegration of the buffer is done by using a 4% (weight) salt solution ($CaCl_2$). The solution is pumped into the deposit hole and stirred by mixers. The top of the buffer will be dissolved by the solution. The mixture can then be pumped out of the deposit hole. The process is continuous given that new salt solution is added when saturated solution is pumped out of the hole.

Figure 21 shows a schematic image of the system used for the process. The main parts of the system are pumps, mixers, the centrifuge – also called a decanter - used to separate the dissolved buffer from the salt solution making the solution reusable, holding tanks and finally the computer based automatic control system. SKB has developed the system and purchased the needed equipment, except for the decanter which is rented for the test.

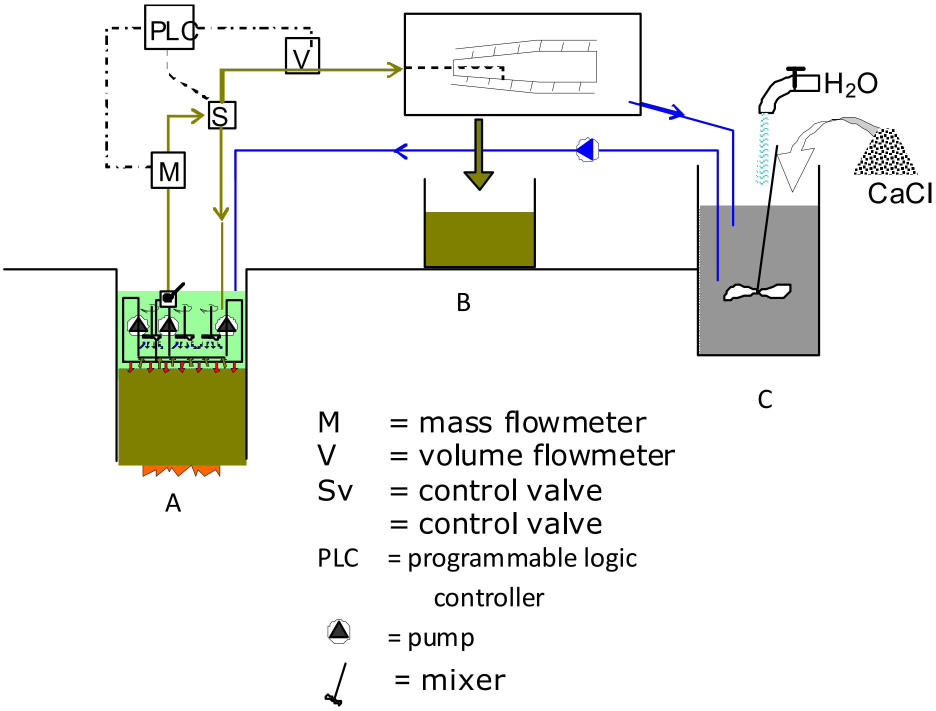

Figure 21. *Schematic illustration of the disintegration system Part "A" corresponds to the deposit hole with a given volume of salt solution above the bentonite buffer and with the slurrying equipment in the working position. Part "B" corresponds to the decanter with discharge of dewatered bentonite and clarified liquid. Part "C" corresponds to the blending vessel for preparation of salt solution and checking of the clarified liquid.*

After installation and fine adjustment of the freeing equipment in the Äspö HRL's retrieval tunnel, remaining buffer around the deposited copper canister was to be removed using the hydrodynamic technique. In trouble-free operation, the hydrodynamic technique worked very well for dissolution and removal of bentonite. Figure 22 shows the system in the deposit hole as it is seen from above during operation.

Figure 22. *The buffer disintegration system in operation. The canister is visible in the center.*

Unfortunately a number of disturbances occurred during the operation of the disintegration process. Pumps were clogged and damaged by sensor wiring and garbage, valves malfunctioned and the controlling computer system didn't always function according to specifications. Due to this a correct assessment of the efficiency of the process is not possible. Some idea of its efficiency in one day of trouble-free operation can be deduced, however. Within a data collection time of 7 hours and 2 minutes some 656 kg of bentonite was slurried and dewatered. This gives a slurrying efficiency of about 93.3 kg of bentonite/hour. With this efficiency, it should be possible to free a copper canister embedded in a bentonite buffer (2 blocks above the canister and 10 rings covering the entire canister height) of about 16.5 tonnes in just under 180 hours.

Compared with the predicted result of 200–220 hours obtained from the full-scale laboratory trials of freeing of a copper canister, a slightly better result was achieved.

In trouble-free freeing of a copper canister in an authentic environment, there are great opportunities for improving the process and the equipment. With a well developed process and efficient equipment, the freeing time can approach the theoretical maximum capacity of the chemistry for disintegrating the bentonite. The time to free a canister completely embedded in a bentonite buffer can probably be reduced considerably.

In the completed freeing trial, is has been shown that the method works, which was the main purpose of the project.

7.3 Removing remaining buffer

After the canister was retrieved from the deposit hole the buffer underneath the canister position had to be removed in order to allow retrieval of the remaining measurement equipment in the buffer. It was decided not to use the disintegration equipment to do this, mainly because the amount of sensors and sensor wiring that was positioned underneath the canister. Instead the buffer was manually removed. The sensors remaining in the buffer was retrieved as carefully as possible. The condition of most of the sensors was in spite that too poor to allow post experiment calibration.

8 Canister retrieval

Once all buffer surrounding the canister had been removed the canister could be retrieved from the deposit hole. The same machine that performed the deposit of the canister was used for the retrieval. The machine had to be somewhat modified to suit the conditions in the tunnel. This mainly consisted of moving the legs of the machine to make it wider. This was necessary to be able to push the machine over the TBT experiment located at the CRT experiment site. These modifications did not alter the lifting structure or mechanics of the machine in any way. Figure 23 shows the canister during retrieval.

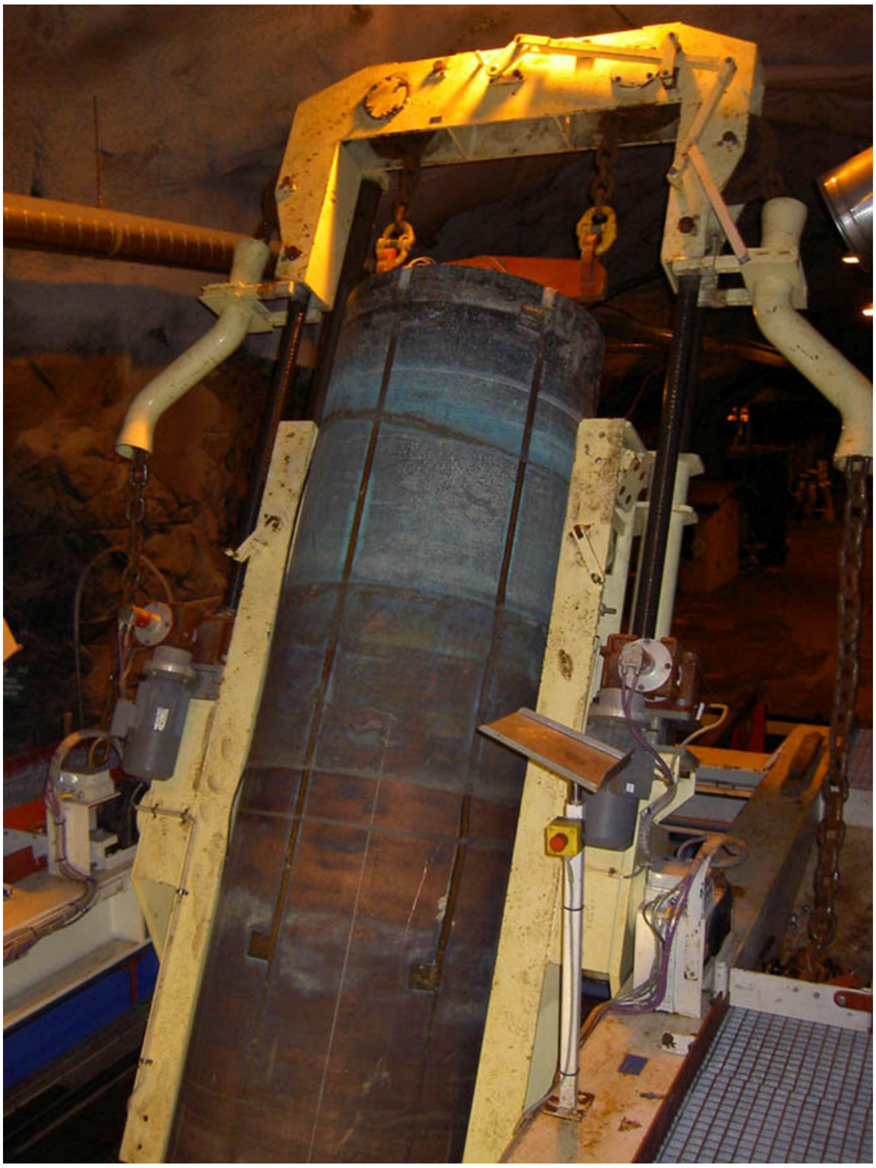

Figure 23. *The canister being retrieved from the deposit hole with the same machine as performed the deposit some 5 years ago.*

Since the disintegration of the buffer was somewhat uneven around the sides of the canister the process was discontinued when the canister bottom was visible at a section of the canister. Even though the canister was secured with jacks at the top the removal of the bentonite at sections underneath it could make it unstable and fall against the rock wall. This resulted in the fact that there was still bentonite about 100 cm up on sections of the side of the canister at the time of retrieval, Figure 24.

Figure 24. *Some remaining bentonite on the canister. The uneven levels of buffer around the canister after the disintegration forced the disintegration to be stopped before the entire canister was freed from the buffer. Despite this it was no problem to lift the canister from the deposit hole.*

The fact that there was some buffer left around the canister was not an issue, it loosened easily from the remaining buffer and could be retrieved from the deposit hole.

The canister was left in the deposit machine at the -420 meter level for about one month before it was transported out of the tunnel and placed in a storage building next to the tunnel entrance.

The canister has been delivered to the canister laboratory for analyses. Analyses are not part of the CRT retrieval phase project and thus not reported here. At present date there is yet no analyses report written for the CRT canister.

9 Rock samples

To study possible changes in rock properties six cores was taken extracted from the deposit hole. The identity of the core holes are KD0092G17 – KD0092G22.

The cores have been analyzed and the result compared to cores taken prior the installation of the canister. The analyses are not a part of this project, but of the SKB rock mechanics program. The result is therefore reported within that program and can be found in SKB IPR-06-37 [6].

10 Conclusion

The three project goals were:

1. Verify the buffer saturation model through buffer samples and analyses.
2. Verify the canister retrieval method with a fully saturated buffer.
3. Find the cause of the canister heater malfunction.

All three project goals have been addressed and are mainly reached.

The first goal is not yet fully achieved. The final analyses are underway and the modeling work is being carried out within the TaskForce program. Within approximately one year all work should be completed and the goal reached.

The second goal has been reached. The method has been shown to work. The canister was freed by the use of buffer slurrying and retrieved from the deposit hole. Some improvement possibilities have been identified during the work.

The third goal is also reached. Heater malfunctions is found to be caused by power cable damages. These damages are due to chemical reactions caused by high temperature and moist conditions, mainly between the two copped lids of the canister.

The work done in the retrieval phase of the canister retrieval test has progressed smoothly. Only minor delays in the time schedule appeared, mainly because of the difficulties to find a suitable decanter machine to rent. During the project time a shift in overall resource priorities was initiated which caused some analyses to be postponed somewhat.

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