International
Progress Report

IPR-02-30

Äspö Hard Rock Laboratory

Canister Retrieval Test

Report on installation

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September 2002

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Report no.	No.
IPR-02-30	F69K
Author	Date
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Checked by	Date
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Christer Svemar	December 2005
Approved	Date
Christer Svemar	December 2005

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Keywords: Buffer, Bentonite, Rock, Temperature, Stress, Strain, Test, Measurements, Swelling, Full scale, Retrieval, Artificial saturation, Installation

Summary

The Canister Retrieval Test was started to demonstrate the capability to retrieve deposited nuclear waste if a better disposal solution is found. The overall objective of the Canister Retrieval Test is to demonstrate to specialists and to the public that retrieval of canisters is technically feasible at any stage of the operating phase.

The test was installed in autumn 2000. This report describes the test layout and the installation procedure. The deposition tunnel for the experiment is located on the 420-metre level and is excavated by conventional drill and blast. The centre-to-centre distance between the two deposition holes is 6 metres, which is the spacing being considered for the deep repository, but only one of the holes has been used for this test. A maximum temperature of 100°C on the surface of the canister is aimed at for the Canister Retrieval Test.

The bentonite buffer was installed in form of blocks and rings of bentonite. The blocks have a diameter of 1.65 m and a height of 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 and the cables to the heaters and instruments were connected. Additional blocks were emplaced until the hole was filled to a distance of one metre from the tunnel floor. The top of the hole was sealed with a retaining plug made of concrete and a steel plate. The plug was secured against heave caused by the swelling clay with nine cables anchored in the rock. Water was supplied artificially for saturation around the bentonite blocks.

Saturation is predicted to take two-three years in the buffer alongside the canister and 5-10 years in the buffer below and above the canister. The decision on when to start retrieval is dependent on the degree of saturation.

A pilot test, Test of Deposition Process, was performed as a preparatory exercise prior to the Canister Retrieval Test and the Prototype Repository Test. The purpose of the test was to try out and practice with equipment, technique and methods developed for the installation of buffer and canisters.

The deposition hole for the Canister Retrieval Test was bored with a full-face tunnel boring machine modified for boring vertical holes. The deposition hole is 8.55 metres deep and has a diameter of 1.76 metres. The surrounding rock at the upper part of the hole consists mainly of greenstone and the lower part of Äspö diorite.

A 0.15 metre high concrete foundation was built to prevent water leaking from the rock from reaching the bentonite blocks and to reduce the risk of tilting the stack of bentonite rings.

Slots were cut in the rock wall for cables to prevent them from being damaged.

A canister obtained from SKB’s Encapsulation Project was used for the Canister Retrieval Test. The outside diameter of the canister is 1,050 mm. The height of the canister is 4.83 m and the weight 21.4 tonnes.

The bentonite used as buffer material is SKB’s reference material, named MX-80. The buffer consists of highly compacted bentonite blocks and rings with an initial density of 1,710 and 1,790 kg/m^3, respectively. The initial water content of the bentonite was 17%.

An artificial pressurised saturation system was built because the supply of water from the rock was judged to be insufficient for saturating the buffer. At the end of the test period, a high water pressure will speed up the saturation process. It will also provide a defined hydraulic boundary. The water is evenly distributed through a number of filter mats attached to the wall of the deposition hole.

A climate control system was used during installation to prevent the bentonite from being damaged by excessively high or low relative humidity.

A retaining structure is used to simulate a real storage situation. The aim of the structure is to prevent the blocks of bentonite from swelling uncontrollably. It consists of a concrete cone plug placed on top of the buffer and a steel lid which is pre-stressed by rock ties.

A large number of instruments are installed to monitor the test as follows:

- Canister – temperature and strain
- Rock mass – temperature and stress
- Retaining system – force and displacement
- Buffer – temperature, relative humidity, pore pressure and total pressure

The data acquisition system consists of a measurement computer and dataloggers. The monitored values are transferred via a serial link from the dataloggers to the measurement computer. The computer is connected to Äspö data network.

Test installation was carried out in the following sequence:

1. Preparations on site – concrete foundation, cutting of slots in the rock wall, drilling for rock anchors and instruments, installation of rock anchors, filter mats for saturation, installation of formwork for plug
2. Emplacement of bentonite blocks and rings including installation of instruments
3. Deposition of canister
4. Continuation of 2.
5. Filling of void between rock and bentonite rings with bentonite pellets and water
6. Casting of concrete plug and placement of steel lid
7. Pre-stressing of retaining system

Heating was started with an initially applied constant power of 700 W on October 27, 2000, one day after casting the plug. The displacements and forces on the plug were carefully checked and followed during the initial phase when the plug was only fixed by three anchors. When the total force exceeded 1500 kN, the remaining anchors were fixed in the prescribed manner. This took place 12-14 December, that is 46-48 days after test start.

The canister heating power was raised twice: to 1700 W on November 13 and to 2600 W on February 13.

Sammanfattning

Canister Retrival Test (Återtagsförsöket) tillkom för att tillmötesgå behovet av att kunna visa att det är möjligt att återta redan deponerat kärnbränsle om en bättre lösning skulle komma till stånd. Den övergripande målet med Återtagsförsöket är att påvisa för specialister och för allmänheten att återtag av kapslar är tekniskt möjligt under alla faser av operationen.

Återtagsförsöket installerades hösten 2000. Denna rapport beskriver försöksuppställningen och installationsprocessen. Deponeringstunneln för detta test (Återtagstunneln) är belägen på 420 meters djup och har blivit uttagen med borrning och sprängning. Centrumavståndet mellan de två depositionshålen är 6 meter, vilket motsvarar planerat utförande för djupförvaret, men endast ett av hålen har använts till detta försök.

Yttemperaturen för kapslarna kommer att vara maximalt 100° C under utförande av försöket. Bentonitbufferten installerades i form av block och ringar. Dimensionen på block och ringar är diametern 1,65 m och höjden 0,5 m.

När bentonitstapeln var 6 meter hög sänktes den simulerade kapseln som är försedd med elektriska värmare ner i mitten av bufferten. Kablar till värmare och instrument var då redan inkopplade. Ytterligare block lades på till dess att hålet var fyllt upp till en meter under tunnelns golv. Toppen av hålet förseglades med en plugg tillverkad av betong och en stålplatta. Pluggen är säkrad mot svällning, orsakad av den svällande leran, genom nio kablar förankrade i berget. Vatten tillförs artificiellt runt bentonitbufferten för att säkerställa vattenmättnaden av bentoniten.

Vattenmättnadstiden för testet är beräknad till två till tre år i bufferten längs kapseln och 5-10 år i bufferten nedanför och ovanför kapseln. Beslut om när man ska inleda återtag av kapslarna är avhängigt av information om mättnadsgraden.

Ett förförsök, Test of Deposition Process (Test av deponeringsprocessen), utfördes som förberedelse till Återtagsförsöket och Prototypförvaret. Detta inledande försök skulle särskilt prova, testa och utvärdera utrustning, teknik och metoder som utvecklats för installationsprocessen avseende bentonitbuffert och kapsel.

Deponeringshålet för Återtagsförsöket borrades med en tunnelborrningsmaskin (TBM) ombyggd för att borra vertikala hål. Deponeringshålet är 8,55 meter djupt och har en diameter på 1,76 meter. Det omgivande berget kring övre delen av hålet består till största delen av grönsten och den nedre delen av Äspödiorit.

Ett 0,15 meter högt betongfundament byggdes för att förebygga att läckande vatten från berget når bentonitblocken och för att minska risken att stapeln med bentonitringar tippar. Spår togs ut i bergväggen för att kunna leda kablar utan risk för skada från yttre tryck.

Kapseln erhölls från Inkapslingsprojektet som genomförs i SKB:s regi. Kapselns totala diameter är 1050 mm. Höjden på kapseln är 4,83 meter och vikten är 21,4 ton.

Bentoniten som används som buffert i Canister Retrieval Test är SKB:s referensmaterial benämnt MX-80. Bufferten består av högkompakterade bentonitblock och ringar med densiteten 1710 kg/m^3 och 1790 kg/m^3 vardera. Det ursprungliga vatteninnehållet i bentoniten var 17 %.

Ett system för artificiell tillförsel av trycksatt vatten byggdes på grund av att vattnet som kom från berget bedömdes otillräckligt. Under slutet av testperioden kommer ett högt vattentryck att läggas på för att minska tiden det normalt skulle ta för att nå full vattenmättnad. Vattentillförseln sker jämnt fördelat genom ett antal filtermattor fästa på bergväggen i deponeringshålet.

En klimatanläggning användes under installationsskedet för att undvika att bentoniten skulle komma till skada på grund av för hög eller för låg luftfuktighet.

En konstruktion som håller försöksinstallationen på plats används för att simulera de verkliga lagringsförhållandena med avsikten att förhindra bentonitblocken att svälla okontrollerat. Konstruktionen består av en koniskt formad betongplugg, som placerats ovanpå bufferten samt ett stållock. Hela konstruktionen är förspänd genom bergförankring.

Ett stort antal instrument installerades för att fortlöpande kunna mäta testresultaten:

- Kapsel – mätning av temperatur och töjning
- Bergmassa – mätning av temperatur och bergspänning
- Förslutningspluggen – mätning av totaltryck och förskjutning
- Buffert – mätning av temperatur, relativ fuktighet, portryck och total tryck

Datainsamlingssystemet består av en mätdator och dataloggar. De registrerade värdena överförs via en seriell länk från dataloggarna till mätdatorn. Datorn är sammankopplad med Äspölaboratoriets datanätverk.

Installationen gjordes i denna ordningsföljd:

1. Förberedelser på plats: betongfundament, uttagning av spår i bergväggen, borrning för bergförankring och instrument, installation av bergförankringar, filtermattor för vattentillförsel, placering av gjutform för plugg
2. Placering av bentonitblock och ringar, inklusive installation av instrument
3. Deponering av kapseln
4. Fortsättning på punkt 2
5. Fyllning av tomrummet mellan berget och bentonitringarna med bentonitpellets och vatten
6. Gjutning av betongplugg och placering av stållock
7. Förspänning av förslutningsplugg

Uppvärmningen startade med en tillförd konstant effekt på 700 W den 27 oktober 2000, en dag efter gjutning av förslutningspluggen. Förskjutning av och krafter verkande på pluggen kontrollerades noggrant och följdes under inledningsskedet, då pluggen tilläts att röra sig uppåt. När den totala kraften översteg 1500 kN, fixerades förankringarna enligt föreskrivet schema. Detta utfördes den 12-14 december 2000, dvs 46-48 dagar efter teststart.

Effekten till kapselvärmarna ökades till 1700W den 13 november 2000 och till 2600 W den 13 februari 2001.

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1 Background

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. One outcome may be that the canisters have to be recovered.

The Canister Retrieval Test was started to demonstrate the capability to retrieve deposited nuclear waste if a better disposal solution is found.

The first project decision document was issued on 22 April 1997 and later superseded by the project decision document issued on 21 December 1999. The Test Plan /1-1/ outlines the concept of the Canister Retrieval Test, Part I.

The Canister Retrieval Test 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. 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.

In order to try out the planned deposition process and equipment, a separate pilot test was performed, the Deposition Process Test.

This report is limited to describing the actual test installation; auxiliary equipment such as the deposition machine is not included.

1.2 Purpose and layout

1.2.1 Objectives

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

In order to provide the test conditions necessary for actual retrieval tests the test set-up has to achieve the following objectives:

- Two vertically bored test holes on full repository scale which fulfil the quality requirements deemed necessary for the real repository
- Careful and documented characterisation of the properties of these holes including the boring disturbed zone
- Emplacement of bentonite blocks, bentonite pellets and canisters with heaters, and artificial water supply under conditions planned for the real repository
- Saturation and swelling of the buffer under controlled conditions, which are monitored
- Preparations for testing of canister retrieval

Boring of full-scale deposition holes and geometrical/geotechnical characterisation of holes as well as emplacement of bentonite and canisters with heaters are carried out in sub-projects that include other tests as well in the Äspö HRL.

1.2.2 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 meters wide and 6 meters high, and the centre-to-centre distance between the two deposition holes is 6 meters, 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.

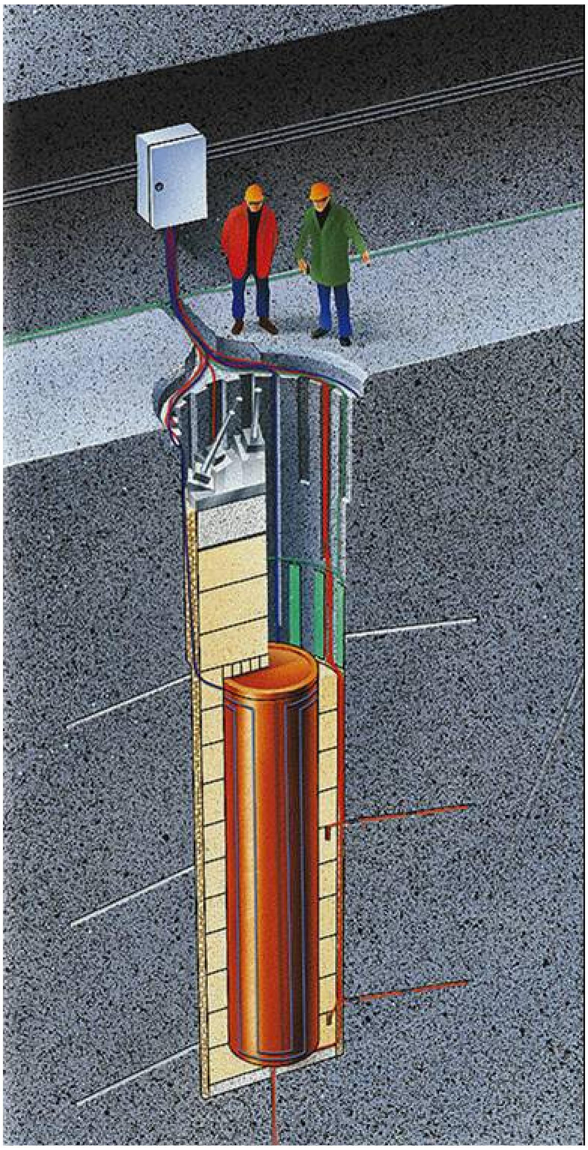


Figure 1-1. Schematic layout of the experimental set-up

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 metre 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.

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.

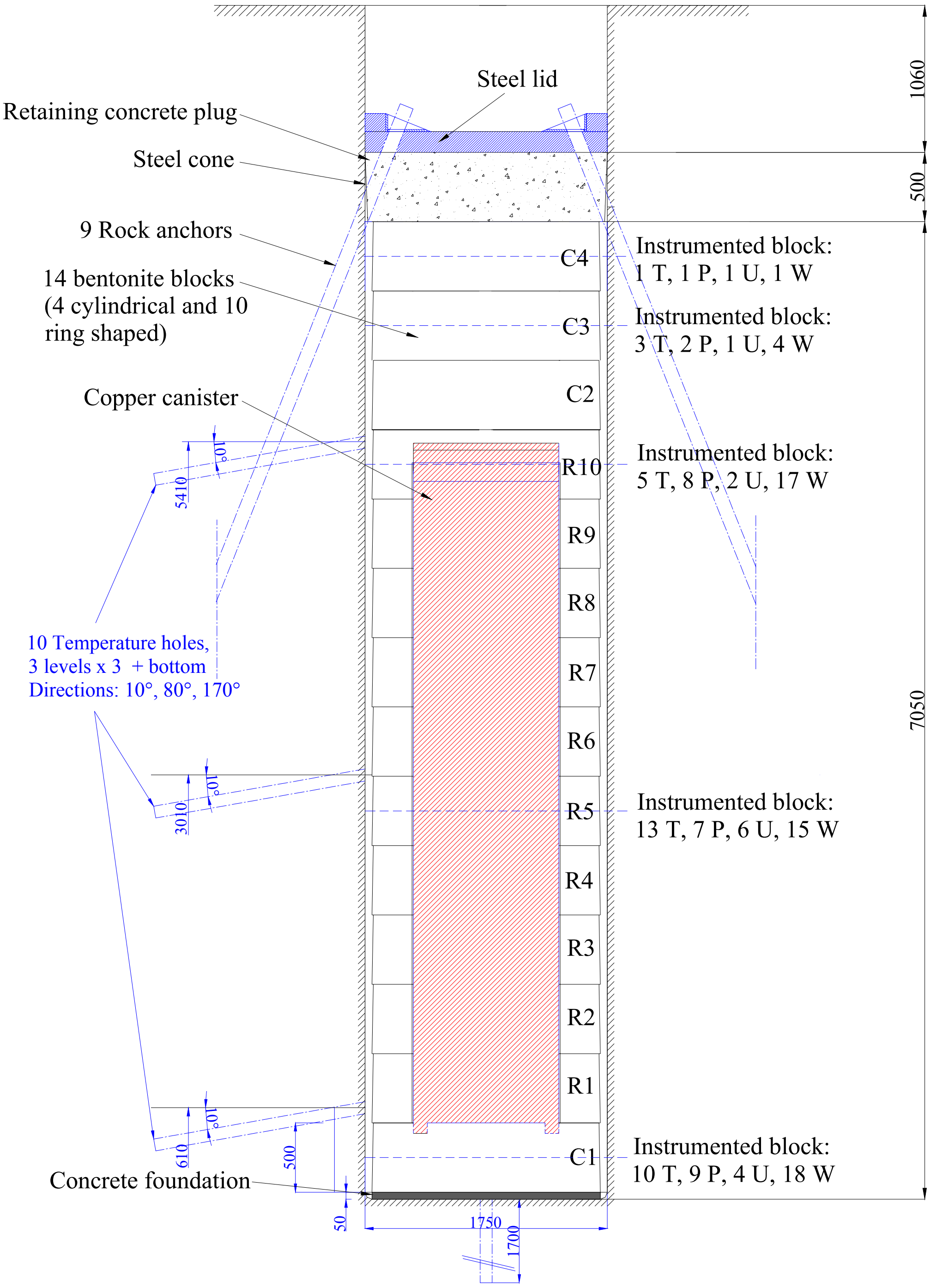


__Figure 1-2.__ Schematic view showing the experiment layout. Sensors have been placed in five of the bentonite blocks. For each block the number of each sensor type is described. (T=temperature, P=total pressure cell, U=pore pressure cell and W=relative humidity sensor).

2 Pilot test of the deposition process

2.1 General

The pilot test project, Test of Deposition Process, was a preparatory exercise prior to the Canister Retrieval Test and the Prototype Repository Test. Specifically, the test was supposed to provide an opportunity to try out and practice with equipment, technique and methods developed for the installation process for buffer and canisters. The purpose was also to improve or change equipment, technique or methods based on the experience gained. The test will only be briefly described here since the details will be given in the forthcoming description of the Canister Retrieval Test. Only those results of the pilot test that lead to a change of the original plans are described in section 2.4.

2.2 Test site

The Deposition Process Test is situated in the TBM assembly hall at the –420 level at the Äspö Hard Rock Laboratory. The hall is an expansion of the main ramp tunnel. The floor is levelled with concrete. One full-scale deposition hole, DA3147G01, is used in the test. The estimated natural water inflow to the deposition hole is approximately 5 litres/hour, which is comparable to the wettest deposition hole in the Prototype Test.

2.3 Test programme

The test was set up in the same fashion as planned for the Canister Retrieval Test and the Prototype Repository Test.

Preparations
The deposition hole was prepared for deposition of buffer and canister by boring a pump sump and draining the hole of water.

Concrete blocks and rings were cast to serve as buffer dummies in place of compacted bentonite.

A large tent was erected over the deposition hole in order to limit the air volume to be treated to achieve preferred relative humidity.

Foundation
A concrete foundation was cast in-situ at the bottom of the deposition hole to get a levelled surface for the buffer column. A fine steel mesh was placed between the rock and the foundation to create an artificial, draining fracture.

Alignment and positioning of buffer and canister
Apart from the deposition machine, the gantry crane and the lifting device, methods for alignment and positioning of the equipment were also tested. Positions for the deposition machine and the gantry crane were set out and marked on the floor. The positions of the canister and buffer were adjusted before they were lowered into the hole. A positioning device, consisting of two perpendicular sliding rulers on top of the deposition hole, gave the correct position when the block or canister was in contact with the edges. During emplacement of the concrete blocks, the rings and the canister, the technique and method for alignment and positioning could be reviewed and practised.

Climate control

Climate control equipment was installed to ensure a stable relative humidity of 70-80% in the air close to the bentonite blocks. The general idea was to dehumidify the air inside the tent and to ventilate the deposition hole with the treated air through four tubes down the hole, in order to minimize fluctuations in the relative humidity. The humidity level was monitored by gauges placed in the deposition hole that control the dehumidifier and airflow. However, the concept was modified even before installation since the actual conditions in terms of air temperature and local inflow were not as anticipated. It was considered necessary to blow treated air, with low relative humidity, directly into the deposition hole.

Performance of bentonite buffer

Performance of the compacted bentonite was tested during a month for a worst case environment in the deposition hole. A bentonite block was placed on the concrete foundation and loaded with concrete blocks to full column height. The intention was to measure water content in the bentonite and block dimensions and also to perform an ocular inspection of the block before and after the test. The relative air humidity was logged at different locations in the deposition hole during the test.

Deviations from Canister Retrieval Test set-up

For economical and practical reasons not all components in the test were the same as in subsequent tests. The following components were different:

- Slots for cables in the deposition hole and buffer were not made
- Dummies were used instead of cables
- A steel mesh was used instead of a copper mesh for the artificial fracture
- The only instruments used were for measurement of relative humidity and temperature
- The bentonite blocks and rings were replaced with concrete blocks and rings
- A system for artificial watering of the buffer through filter mats was not installed
- Filling with bentonite pellets in the void between the deposition hole wall and the buffer blocks was not tested
- Closing and sealing of the deposition hole with a retaining plug was not tested

Results

The only results reported are those where the outcome of the Deposition Process Test was not as expected. A number of problems were found in the equipment used for deposition of buffer and canister. That equipment consists of tools used in the test and is not a part of the test. Therefore, details on the equipment are not dealt with in this report.

Preparations

After casting of concrete blocks and rings and subsequent treatment of the surface, a small deviation in dimensions remained, compared to the original bentonite blocks and rings. The inner diameter of the rings was a few millimetres larger than intended and was not perfectly circular. The surface friction of the concrete was also higher compared to bentonite, which was important when the lifting bands were loosened.

Foundation
The formwork including the steel mesh leaked into the pump sump.

Protection against water leakage through the concrete foundation was deemed unsatisfactory.

Alignment and positioning of buffer and canister
The method was based on alignment using a tool with two arms at a right angle that could be adjusted along graduated rulers for positioning before lowering of buffer and canister into the deposition hole. The proposed positioning method for emplacement of the buffer did not work properly due to swinging movements of bentonite blocks and canister during lifting.

Climate control
The installed climate control equipment was not able to maintain a steady relative humidity at 70-80% in the whole deposition hole. The reason was judged to be that the distribution of the ventilation air was insufficient for maintaining acceptable conditions.

Performance of bentonite buffer
The test was not carried out as planned since it was found that trying to control relative humidity alone is not effective when free water is present in a deposition hole. It was found at the ocular inspection that the bentonite block had been damaged at one side due to contact with water running along cables. However, it was deemed that controlling relative humidity alone would be sufficient for the Canister Retrieval Test since the deposition hole used is very dry.

2.4 Corrective measures

The corrective measures correspond to the results in chapter 2.4. The corrections were not made for the pilot test.

Preparations
No corrections could be made for the forthcoming. It was judged that the lower friction on the bentonite blocks would facilitate handling with the lifting tool.

Foundation
The steel mesh was enlarged and folded over the formwork brim to prevent leakage during casting of the foundation.

The foundation was completed with a copper plate barrier on top in the forthcoming tests.

Alignment and positioning of buffer and canister
The proposed method had to be abandoned in favour of a more direct method. The first block and ring had to be carefully put in place down the hole by hand while an optical instrument monitored the position. The subsequent rings were positioned with the aid of a guiding device attached by three spring-loaded arms to the preceding ring. Measurements checked alignment and levelling of the buffer.

Climate control
Two measures were taken to attain the target interval for relative humidity in the deposition hole. The first measure was to increase the number of ventilation hoses from four to six down the hole. The second was to use a more flexible fabric for the hoses to facilitate positioning of the hose mouths.

3 Test site

3.1 General

The Canister Retrieval Test is situated on the –420 level at Äspö Hard Rock Laboratory. The tunnel is approximate 5.6 metres high and the floor is levelled off with concrete in order to support the boring machine during boring of the deposition hole. There are two bored deposition holes in the tunnel, DD0086G01 and DD0092G01. The centre-to-centre distance between the holes is 6 metres. The deposition hole DD0092G01 was used for the Canister Retrieval Test while the other hole DD0086G01 was left empty without filling.

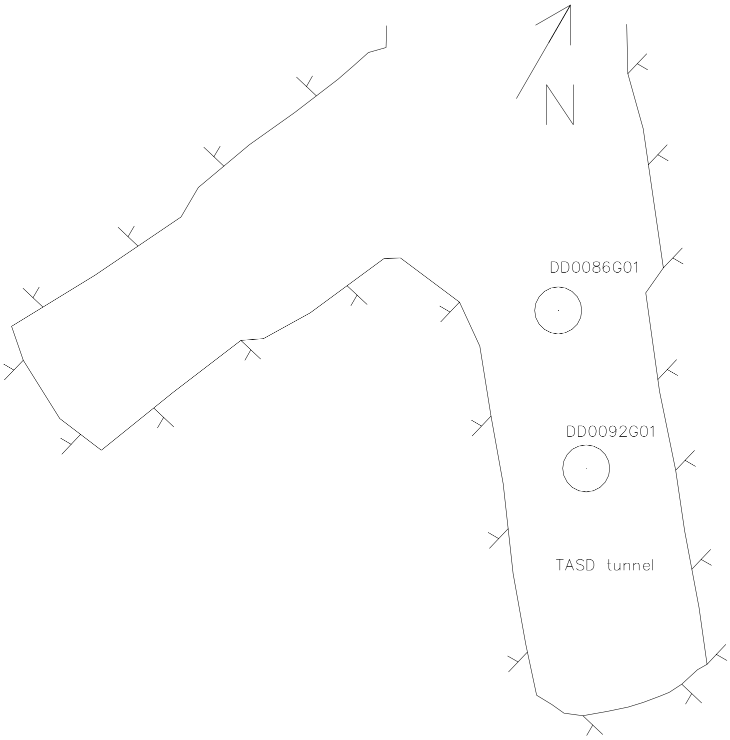


***Figure 3-1.** Plan view over the Canister Retrieval Test tunnel with its two deposition holes.*

3.2 Preparatory works

3.2.1 Deposition hole

The deposition hole was bored with a full-face tunnel boring machine rebuilt for boring vertical holes /3-1/. The deposition hole is 8.55 metres deep, including the cast floor, and has a diameter of 1.76 metres.

The upper part of the hole consists mainly of greenstone, more or less granitised. The lower part and the bottom of the deposition hole consist of so-called Äspö diorite. There are two dykes composed of fine-grained red granite, each with a width of approximately 0.5 metre. The fractures are evenly distributed in the hole. Water inflow in to the hole is approximately 5.1 litres per 24 hours. Most of the water comes from the upper part of the hole, mainly from the area between the rock surface and the concrete slab on the tunnel floor.

The deviation from start point to end point when boring is 3 mm in the X direction and –5 mm in the Y direction, where X corresponds to north and Y to south, and the maximum curvature of the hole is 5 mm.

3.2.2 Drainage

All water seeping into the deposition hole was collected in the slot between the cast bottom slab and the borehole wall. For an overview of the concrete slab and the slot see Figure 3-2.

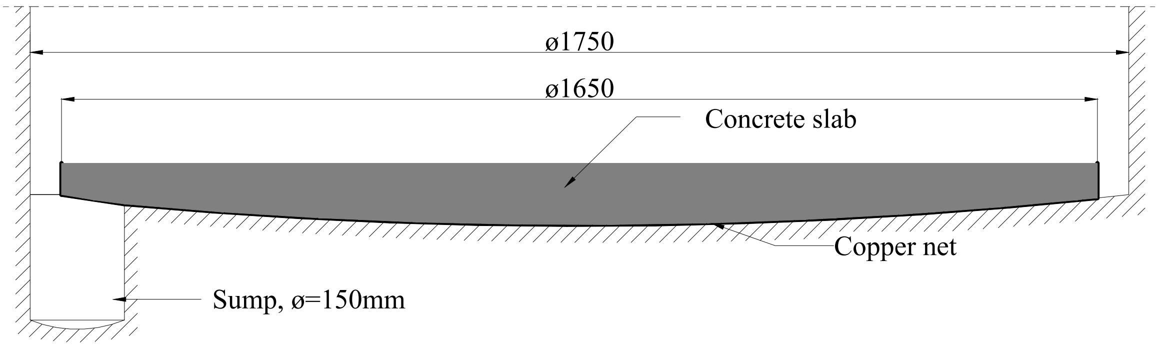


Figure 3-2*. Design of the bottom bed of the deposition hole. All water entering the deposition hole was collected in the slot between the cast bottom slab and the borehole wall.*

The drainage system consists of two suction pumps, SP15, located on the tunnel floor above the deposition holes with three drainage pipes with one end on the bottom of the slot and the other end above the deposition hole. The two pumps with drainage pipes comprise redundant systems.

The drainage pipes were of stainless steel with an inside diameter of 21 mm. The three drainage pipes were cut at angle of 45° at one end. The drainage pipes were placed standing in the slot with the 45° end in the slot and the other end attached to the tunnel floor. The pipes were flexible and could be pressed to the borehole wall by an unintentional load and still manage to keep the drainage system working.

A separate float switch was placed together with the drainage pipes in the slot to ensure that the water level never exceeded the top of the concrete slab. A hose was fitted from the drainage pipes to the pump and from the pump to the spillway.

3.2.3 Concrete foundation

To prevent seepage water from the rock from reaching the bentonite blocks and also reduce the risk of tilting the pile of bentonite rings, an elevated level foundation was built on the bottom of the deposition hole, see Figure 3-2. A fine-mesh copper screen was placed on the bottom of the hole to form an artificial fracture for water coming from under the concrete slab to the slot. The concrete slab with a thickness of approximately 150 mm formed the foundation for the placement of bentonite blocks.

The slab has the same diameter as the bottom bentonite block. To reduce the risk of a tilting of the pile of bentonite blocks after emplacement and to ensure that the centre point of each ring did not deviate from the theoretical point, the bottom slab was cast as horizontal as possible. The slab had a maximum deviation between opposite sides of 1.4 mm. One millimetre deviation gives a lateral displacement of the top ring of approximately 3 mm.

Casting of the bottom slab was divided into two steps. The two castings differ in composition to meet the requirement of the bottom slab for the bentonite blocks. The first rough casting was intended to create a gap between the deposition hole wall and the first bentonite block where water could be transported from the surrounding wall to the pipe for drainage without affecting the bentonite. The second fine casting was intended to create a level, flat surface for the pile of bentonite blocks.

The copper screen at the bottom of the hole had a mesh size of 0.15 mm.

Casting of the bottom slab included the following activities:

- Installation of formwork
- Installation of copper screen
- Casting step 1
- Mixing of concrete step 1
- Casting step 1
- Curing
- Casting step 2
- Mixing of concrete step 2
- Casting step 2
- Curing
- Dismantling of formwork
- Curing

3.2.3.1. Mixing of concrete step 1

The concrete was mixed according to the following recipe for 1.5 m^3 ready mixed concrete:

Aggregate 0-8 mm	1462 kg
Aggregate 8-16 mm	1082 kg
Cement:	575 kg
Water:	322 litres
Additive:	30 kg Rescon T-concentrate

The additive Rescon T-concentrate was used due to the possibility that a large quantity of water will flow into the deposition hole. Rescon T-concentrate is used for casting under water.

3.2.3.2. *Mixing of concrete step 2*

To create an as level a surface as possible, the second casting was performed with a water-cement ratio of 1.2. No aggregate was used in the mixture.

The concrete was mixed according to the following recipe:

Concrete:	50 kg
Water:	60 litres
Additive:	1 kg Cementa flyt 92 M

The casting was 15 mm thick.

3.2.4 Boreholes for instrumentation

Drilling of holes in the rock for installation of thermocouples was done from inside the deposition hole. The holes were drilled with a diameter of 28 mm and a length of 1.57 metres. The holes were drilled at a 10° inclination to the horizontal according to Figure 1-2 and Table 3.1. In addition to the holes in the wall there is also a borehole in the centre of the bottom of the deposition hole. This hole has a diameter of 28 mm and a length of 170 mm. The total number of holes in rock for thermocouples is 10.

Table 3.1 Level of boreholes.

Number of holes per level	Level from top of bottom slab [m]	Length of borehole [m]	Deviation from horizontal [°]	Comments
1	0	1.70	90	Situated in the centre of the bottom of the deposition hole
3	0.61	1.55	10	
3	3.01	1.55	10	
3	5.41	1.55	10	

3.2.5 Slots for cables

Cables from all instrumentation in the bentonite, deposition hole wall, canister, cables from heaters in the canister and pipes for water supply to the filter mats are placed in slots in the borehole wall and in the concrete floor for protection during the deposition process. The slots were cut with a single blade circular sawing machine bolted to the tunnel floor.

3.2.5.1 *Slots in the wall*

Four types of slots were made in the wall (Figures 3-3, 3-4 and 3-5):

Model A: Rectangular slot with a width of 200 mm, a depth of 40 mm and a length of 2200 mm. This model was used for slot numbers 2, 4, 6 and 8.

Model B: Rectangular slot with a width of 200 mm, a depth of 40 mm and a length of 2200 mm. It continues with a triangular slot with a width of 50 mm, a depth of 40 mm and a length of 900 mm. This model was used for slot number 1.

Model C: Triangular slot with a width of 150 mm, a depth of 60 mm and a length of 3100 mm. This model was used for slot number 7.

Model D: An inclined triangular slot with a width of 100 mm, a depth of 40 mm and a length of 3100 mm. This model was used for slot numbers 3 and 5.

At the bottom, where the cables enter, the slots are chamfered. The back walls of the slots were covered with a layer of concrete to protect the cables from being damaged by the rough surface left by sawing.

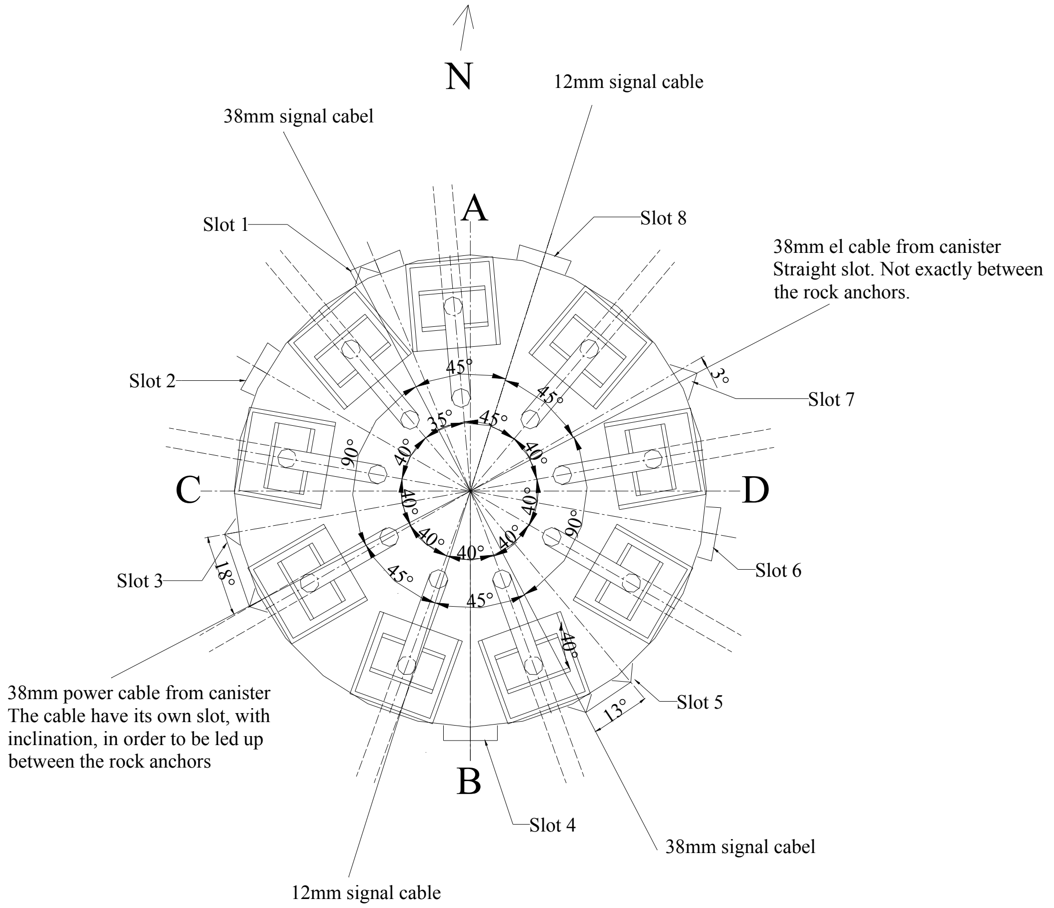


Figure 3-3*. Schematic drawing of slots (numbered 1 to 8).*

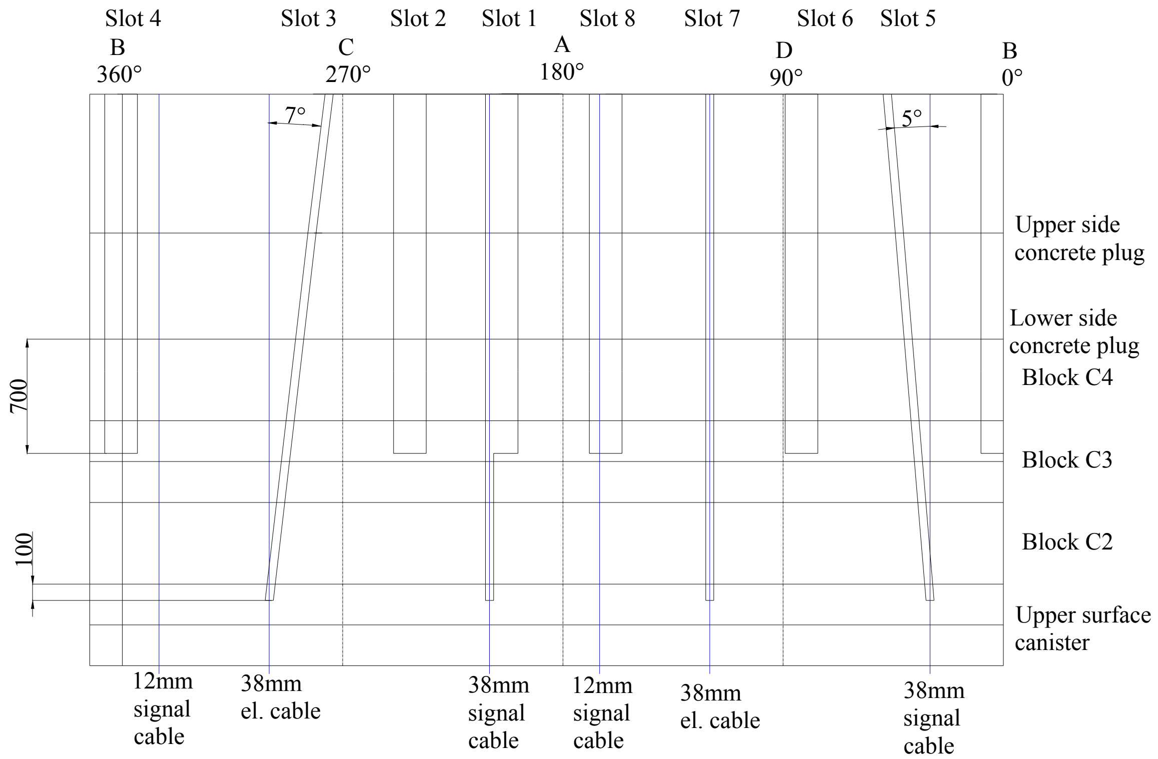


Figure 3-4. *Schematic drawing of the upper 3.5 metres of the deposition hole wall showing the positions of the slots cut in the rock wall.*

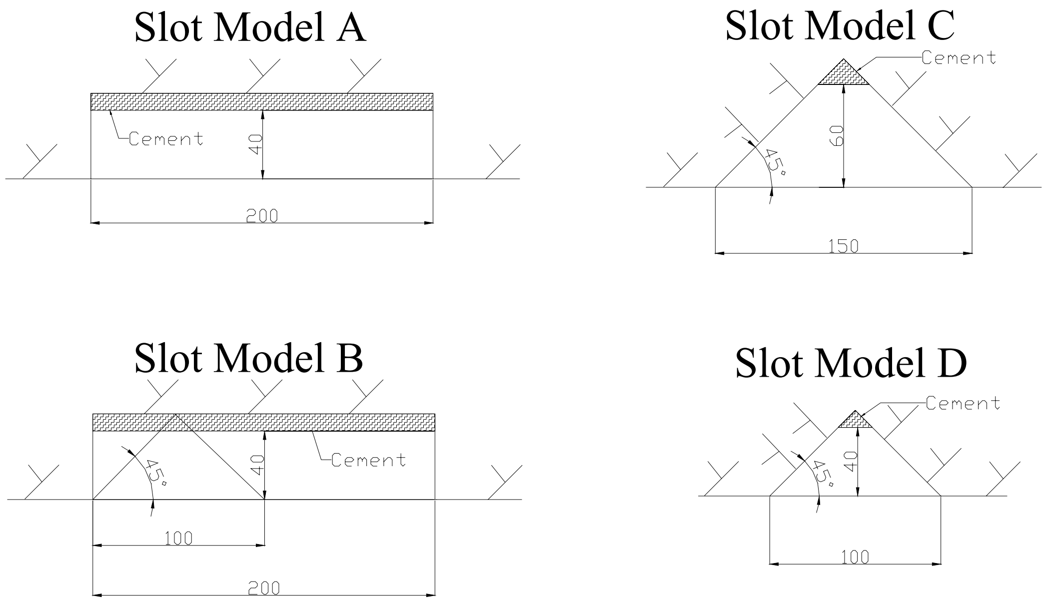


Figure 3-5*. Schematic drawings of the different slot models in the rock wall.*

3.2.5.2 Slots in the floor

The cables and tubes coming up from the deposition hole are run in a 250 by 250 mm slot in the concrete floor around the hole and then in a 250 by 250 mm channel to the eastern wall (Figure 3-6):

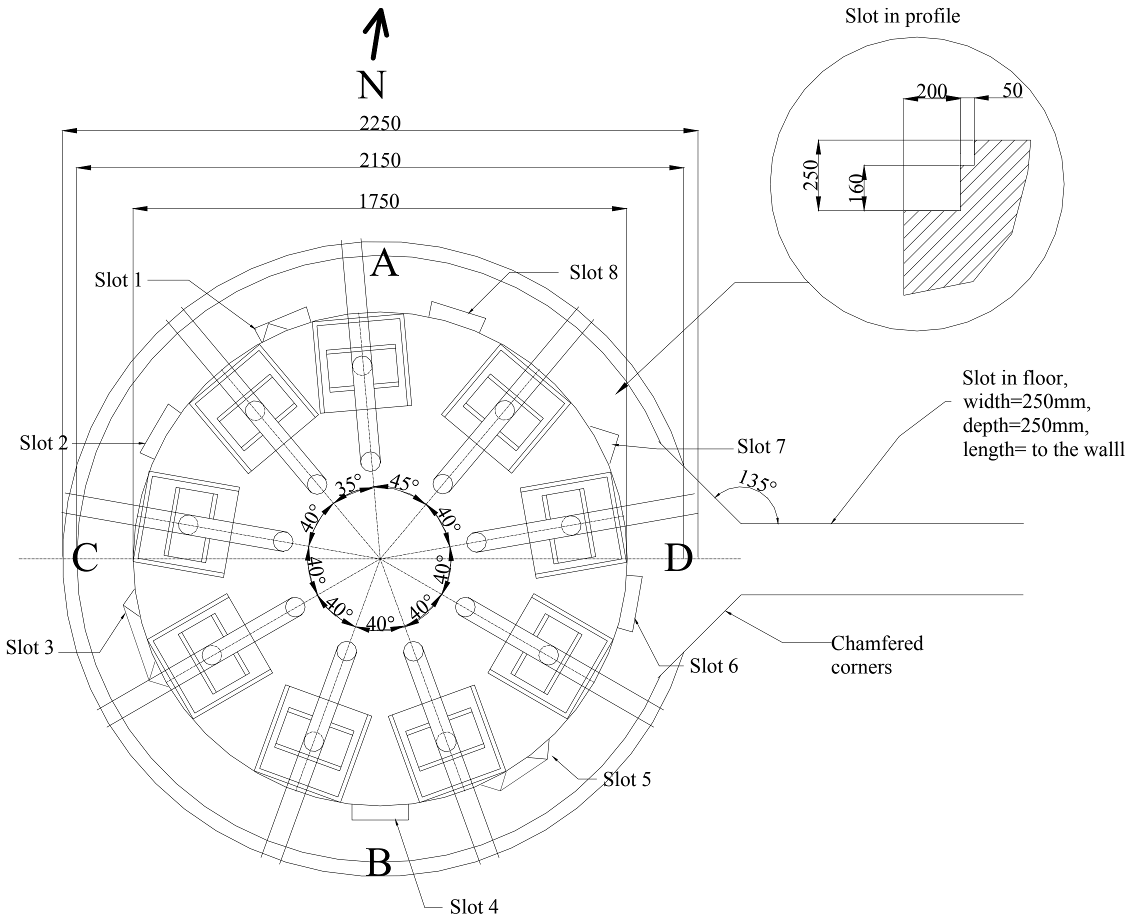


Figure 3-6. *Schematic drawing of slots in floor*

3.2.6 Smoothing of hole wall

Irregularities in the rock wall, caused by the drilling of the deposition hole DD0096G01 made it necessary to smooth the surface before attaching the filter mats. Smoothing was done in 16 vertical strips with a width of 10 cm and a spacing of 26.3 cm from the top level of the second bentonite block. The grout was cement paste.

4 Test package

4.1 General

This chapter describes the test package in detail.

4.2 Canister

The canister was positioned in the deposition holes and surrounded by bentonite buffer material. A canister obtained from the Encapsulation Project undertaken by SKB was used for the Retrieval project. The canisters are designed for Boiling Water Reactor fuel assembles (BWR) with dimensions and weight as listed below.

Table 4-1. Overview of dimensions and material of the canister

Part	Dimension	Material
Canister (BWR)	Length: 4830 mm Diameter: 1050 mm Weight: 21400 kg Incl. fuel ass.: 25012 kg	Cast iron/copper In accordance with the current plans for the deep repository
Outer corrosion protection tube	Length: 4725 mm Diameter: (out/in): 1050/950 mm Weight: 7410 kg	Copper, quality in accordance to those stated in the current plans for the deep repository
Insert	Length: 4570 mm Diameter: 949 mm Weight: 13610 kg	Cast iron, quality in accordance with the current plans for the deep repository. Number of fuel assemblies: 12
Inner canister lid	Diameter: 949 mm	Steel Attached to the insert by socket head Cap screws
Bottom lid	Diameter: 1050 mm	Copper welded to the outer tube
Top lid	Diameter 1050 mm	Copper attached to the canister by socket head cap screws. In the deep repository programme the top lid will be welded to the tube. However, in the Canister Retrieval Test this alternative is chosen to permit cable entry.

The BWR canister contains 12 channels for emplacement of fuel elements. The total diameter of the canister is 1050 mm and the diameter of the insert is 948 mm. The height of the canister is 4.83 m and the weight 21.4 tonnes empty and 25.0 tonnes including 12 BWR fuel assemblies.

Special steps were taken to achieve a waterproof (water pressure about 4.5 MPa) feed through for power and instrument cables in the canister. Water must not be permitted to enter the canister.

4.3 Heaters

The heaters used for the Canister Retrieval Test are of make Backer. The heaters were designed to generate heat for ≥ 7 years.

The heaters are designed so that the temperature on the canister surface will not, at any time, exceed 100°C (this means a design temperature of 90°C). The temperature on the canister surface − and the temperature distribution in canister, buffer, and rock − is a function of thermal properties that are constantly changing, depending on water saturation, temperature and mechanical processes.

The plan is to simulate a decay heat of about 1800 W/canister, and measure the maximum temperature of the canister surface. The simulation will be an exercise in the prediction of the maximum acceptable heating power to be installed in the canisters. The plan is to use controlled power to simulate the radioactive decay heat. However, the possibility of using controlled temperature will also be considered. The heaters will be designed with redundant heat elements in the event of failure.

Since electric heaters will simulate the spent fuel, some modifications of the top lid of the canisters had to be made. Cables for power supply to the heaters were fed through the lid. The cable feed was designed to prevent any leakage through the lid, at a water pressure ≥ 4.5 MPa. The power supply cables will be connected to the canister by a contact.

4.4 Bentonite buffer

4.4.1 Bentonite material

The bentonite used for CRT is SKB's reference material, named MX-80. It was delivered from the processing plant at Volclay Limited in Liverpool, England in big bags containing about 1 tonne of bentonite each. The material has been characterised and tested in numerous tests.

Each big bag is inspected according to a programme described in section 4.4.3.2.

4.4.2 Buffer components

4.4.2.1. General

The buffer can be divided into the following five different components:

1. the 1 cm wide empty radial gap between the cylindrical canister surface and the bentonite rings
2. the 29 cm thick bentonite rings surrounding the canister
3. the large bentonite blocks below and above the canister
4. the 5 cm wide space between the bentonite rings (and large blocks) and the rock surface, which is filled with bentonite pellets and water
5. the space between the top of the canister, the upper bentonite ring, and the lower large bentonite block, which is filled with small brick-shaped bentonite blocks (bentonite bricks)

Figure 4.4-1 shows a schematic picture of the different components of the buffer material.

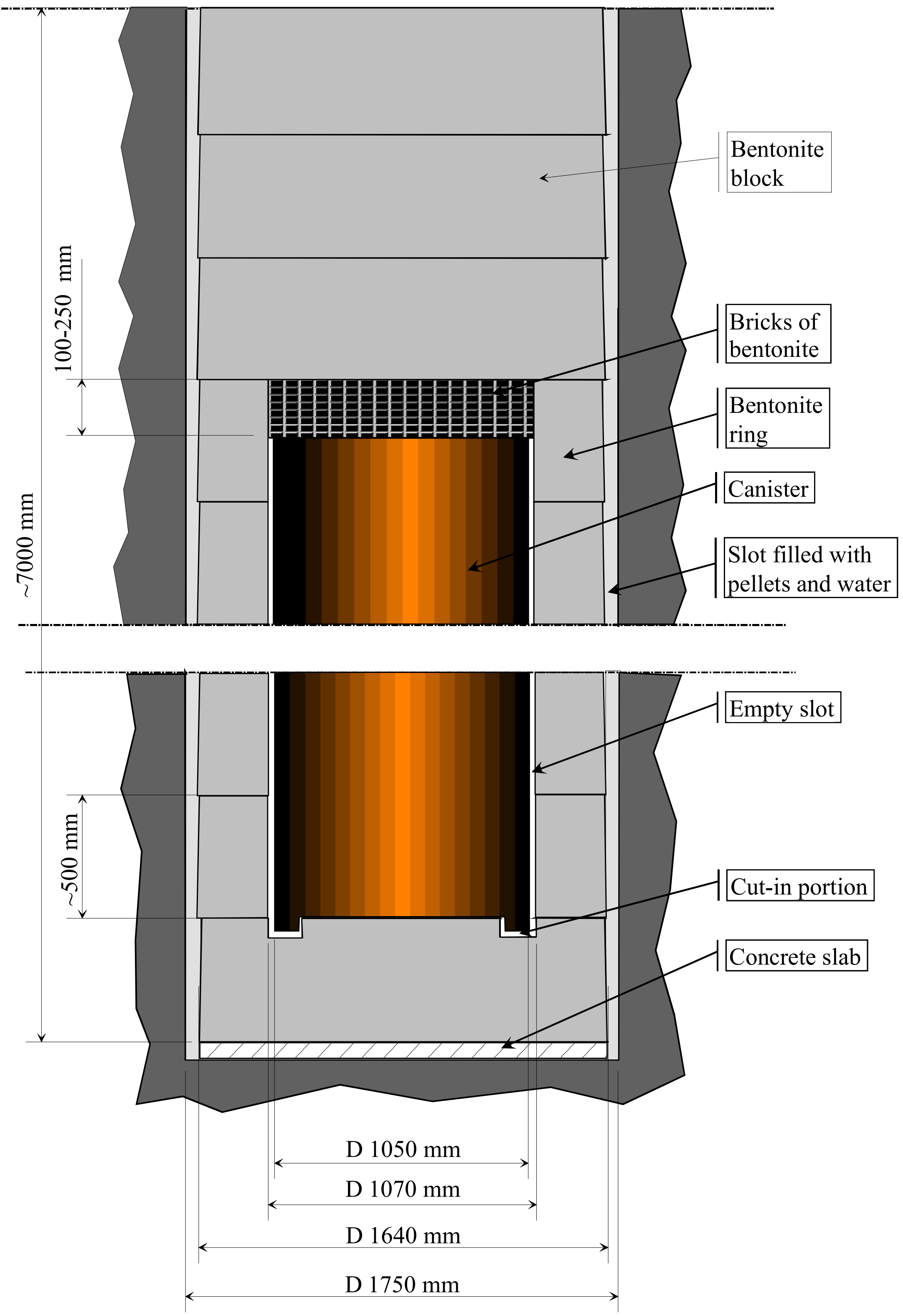


***Figure 4.4-1**. Schematic drawing of the canister hole with bentonite blocks with dimensions in mm.*

The composition of these components and the technique used for production will be described in the following sections.

4.4.2.2. Empty radial gap

The bentonite rings around the canister have an inside diameter of 1.07 m, which leaves a 1 cm gap between the canister and the bentonite, whose only purpose is to permit easy installation of the canister.

4.4.2.3. Bentonite rings

Ten bentonite rings, with an inside diameter of 1.07 m, an average outside diameter of 1.64 m, and a height of 0.50 m, are placed around the canister. The blocks have an initial water ratio (after addition of water) of 17% and an initial dry density of 1790 kg/m^3.

For compaction reasons the outer surface of the rings is slightly tapered. The diameter at the upper part of the surface is 1.630 m and the diameter at the lower part of the surface is 1.650 m.

4.4.2.4. Bentonite blocks

Four bentonite blocks with an average diameter of 1.65 m and a height of 0.5 m are used − 1 below the canister and 3 above the canister. The initial water ratio of these blocks is the same as the water ratio of the rings, i.e. 17%, but the initial dry density is only 1710 kg/m^3 in order to yield the same average density when the gaps are included.

These blocks are also tapered with an upper diameter of 1.631 m and a lower diameter of 1.651 m.

4.4.2.5. Gap with pellets

Between the bentonite rings and blocks and the rock surface is a gap with an average radial width of 5 cm, which is left for the sole purpose of permitting easy installation of the blocks. In order to increase the average density of the buffer the gap is filled with bentonite pellets and (in order to increase the wetting rate) also with water.

The average dry density of a single pellet is 1800 kg/m^3 but the average dry density including voids after filling was estimated to be 1130 kg/m^3 according to tests performed before the field installation. The natural initial water ratio of the pellets is 10%, and after the voids are filled with water the average water ratio is about 45%.

4.4.2.6. Bentonite bricks

The 10 bentonite rings have a total height of just over 5 m, which is about 25 cm higher than the canister. This remaining space is filled with bentonite bricks sized 115x234x64 mm and with a dry density of about 1800 kg/m^3. The bricks have an initial water ratio of 17%, and the average dry density including the gaps between the bricks is 1620 kg/m^3.

4.4.3 Production of bentonite components

4.4.3.1. General

Four types of bentonite products are used. They are produced by different methods, described in the following sections.

4.4.3.2 Bentonite rings and blocks

A mould for uniaxial compaction was previously designed and fabricated. Ring-shaped and cylindrical blocks can be compacted with a diameter of 1650 mm. The total weight of the bentonite needed for one deposition hole is about 22 tonnes. The mould will be used for production of bentonite blocks for 6 deposition holes, in addition to the CRT, i.e. altogether about 100 blocks. The planned initial water ratio of the bentonite blocks in both tests is 17%, but blocks with a water ratio of 10% can also be compacted with the mould. For a water ratio higher than 10% (equivalent to the water ratio of bentonite at equilibrium with an indoor climate), water must be added to the bentonite and evenly distributed, which requires a powerful mixer. A bentonite filling machine and a lifting device for the blocks were also made.

Production of the blocks can be divided into the following phases:

- Delivery inspection of bentonite
- Mixing of bentonite and water
- Compaction of blocks
- Investigation and quality control of each block

4.4.3.3 Delivery inspection of bentonite

The bentonite was inspected at delivery according to an acceptance inspection plan, described in QP TD F63-99-064. Each bag was tested with respect to the following properties:

1. Water ratio
2. Free swelling
3. Liquid limit
4. Grain size distribution in dry condition

4.4.3.4 Mixing of bentonite and water

The bentonite was mixed at Hackman-Rörstrand AB in Lidköping in a mixer used for mixing clays for porcelain ware. The mixer (see Figure 4.4-2) is an Erich mixer with a built-in weighing-machine. The maximum batch that can be handled by this mixer is about 1.5 tonnes.

The bentonite was added to a silo located above the mixer and then transported to the mixer. About 1 tonne of bentonite was mixed in each batch. A small sample was taken from the bentonite added to the mixer and the initial water content was determined by weighing a piece of the sample before and after drying in a microwave oven. This water content and the total amount of bentonite were then used to calculate the amount of water needed in order to get a final water ratio of 17%. After mixing, another sample was taken and the final water ratio determined (also in a microwave oven). A sample from each batch was saved for further investigations. The bentonite was then packaged in Big Bags. The Big Bags and the samples taken from the batches were numbered and marked with the mixing date.

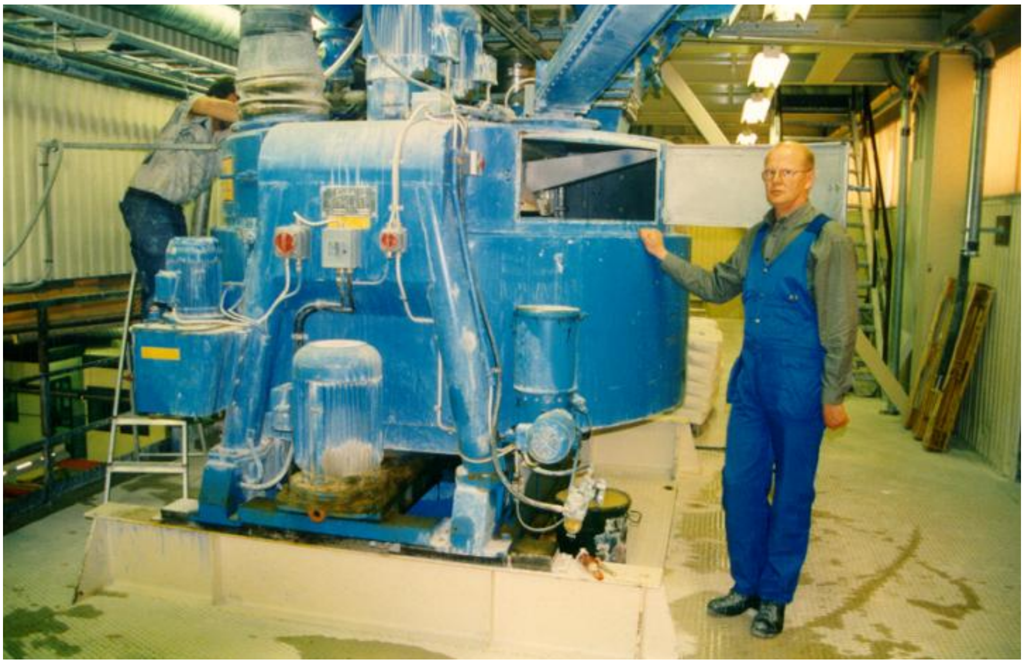


***Figure 4.4-2**. Eirich mixer used at Hackman-Rörstrand AB.*

4.4.3.5 Block compaction

The mixed bentonite was transported in Big Bags to Hydroweld AB in Ystad where the press is located. The bentonite was transferred to a silo, which is a part of the filling equipment. The required amount of bentonite was then added to the mould and the mould was placed in the press, followed by compaction of the bentonite. After removal from the form, the block was placed on a pallet by specially designed lifting equipment, and a cap was placed over the block in order to prevent the block from drying. The press is shown in Figure 4.4-3. A bentonite block after compaction is shown in Fig 4.4-4. Johannesson /4-1/ describes the compaction technique and the lifting equipment. Table 4.4-1 shows the achieved basic properties of each block compacted for CRT. In order to get a buffer with uniform density after saturation and homogenisation, the cylindrical blocks must be compacted with a lower pressure to a lower density then the ring shaped blocks.

The first block (which was placed at the bottom of the deposition hole) is named CRT1-C1 and the ring shaped blocks are named CRT1-R1—CRT1-R10 (with CRT1-R1 placed on the bottom block). The cylindrical blocks placed above the canister are named CRT1-C2−CRT1-C4.

Figure 4.4-3. *The compaction equipment at Hydroweld.*

Figure 4.4-4*. A bentonite block shown during removal of the mould.*

Table 4.4-1 Blocks compacted for the Canister Retrieval Test.

Block name	Date of compaction (yy-mm-dd)	Water ratio	Density (kg/m^3)	Weight (kg)	Average height (mm)	Degree of sat.	Void ratio
CRT NR R1	99-11-04	0.173	2091.9	1280.0	506.5	0.859	0.558
CRT NR R6	99-11-04	0.171	2102.7	1282.0	505.0	0.867	0.548
CRT NR R8	99-11-08	0.171	2099.8	1286.0	507.1	0.865	0.551
CRT NR R9	99-11-08	0.171	2098.3	1288.0	508.0	0.861	0.551
CRT NR R7	99-11-09	0.172	2099.5	1290.0	508.7	0.866	0.552
CRT NR R3	99-11-09	0.167	2102.7	1280.0	503.9	0.855	0.543
CRT NR R2	99-11-10	0.172	2095.4	1288.0	508.5	0.861	0.555
CRT NR R4	99-11-10	0.170	2116.3	1290.0	504.6	0.879	0.537
CRT NR R5	99-11-11	0.175	2086.5	1278.0	506.9	0.859	0.565
CRT NR R10	00-01-10	0.171	2069.1	1272.0	509.2	0.830	0.574
CRT NR C4	00-01-12	0.173	2016.4	2156.0	505.4	0.780	0.617
CRT NR C3	00-01-12	0.171	2004.8	2094.0	493.7	0.761	0.623
CRT NR C2	00-01-13	0.170	2003.1	2104.0	496.7	0.759	0.624
CRT NR C1	00-01-14	0.173	1987.7	2128.0	506.3	0.751	0.641

The blocks, together with the pellets filling the gap between the blocks and the wall of the deposition hole, have an average density at saturation of about 2045 kg/m^3, assuming the bulk density of the pellets including the pore space between the pellets to be 1300 kg/m^3. If the density of the pellets is instead 1000 kg/m^3 the average density of the buffer will be about 2015 kg/m^3.

Compaction of each block was performed in the following sequence:

1. Bentonite delivered in Big Bags was added to the silo, which is an integrated part of the filling equipment.
2. The mould was assembled outside the press and lubricated with MOLYKOTE BR 2 plus®, which is a lubricant for use at high pressure.
3. Using the built-in weighing machine, bentonite was dispensed into the mould with an accuracy of about ±50 kg.
4. A sample (about 5 kg) was taken from the bentonite in the mould. The sample was marked with the same number as the compacted block and the date of compaction (see Table 4.4-1). It will be further investigated with respect to chemical composition and mechanical properties.
5. The first piston was placed on top of the bentonite in the mould and the mould was placed in the press. The tubes from the filters were connected to a vacuum pump and air was evacuated from the bentonite in the mould. Evacuation was retained throughout the compaction sequence. The bentonite was then compacted by the press as much as possible, whereupon the second piston was placed on top of the first piston and compaction continued. The same procedure was repeated for the third piston. The total compaction time was about 10 minutes. The maximum load was then left on the piston for another 10 minutes (hold time 10 minutes).

6. Unloading of the block took about 10 minutes. The mould with bentonite and the pistons were then lifted with jackets. Steel plates were placed between the mould and the bottom plate and the block was pushed out of the mould with the press.
7. The mould and the block were then removed from the press and the ring and pistons lifted off the block with the lifting equipment. Finally, the block was placed on the pallet.

A protocol was filled in for each block. It contains the weight of bentonite used for the blocks, the compaction time, the maximum compaction force, the time at maximum load (hold time) and the unloading time.

4.4.3.6 Investigation and quality inspection of the blocks

After compaction, the dimensions (height and diameters) of each block were measured. The height of the blocks was measured at 12 locations around the block. The highest measured point of each block was marked. The weight of the blocks was also determined to an accuracy of ±2 kg using a weighing machine hanging from an overhead crane.

The quality of each block was also carefully investigated and the presence of any cracks was noted.

4.4.3.7 Bentonite pellets

Bentonite pellets for CRT were produced by Sahut-Conceur in France. Figure 4.4-5 shows of pellets after filling of a gap behind a Plexiglas wall. The pellets are shaped like pillows and have the dimensions 16x16x8 mm. They were compacted in double rollers under high pressure. The average dry density of a pellet was 1800 kg/m^3 and the water ratio 10%.

Several tests of filling gaps with pellets were performed. The resulting dry density, including the pore space between the pellets, varied between 1040 kg/m^3 and 1150 kg/m^3 depending on the filling technique.

When the pellet blowing machine was used in these tests the average dry density was 1120 kg/m^3. Since this technique was also used in the CRT it was concluded that this density would be achieved in the field.

Figure 4.4-5. *Bentonite pellets after filling a gap behind a Plexiglas wall.*

4.4.3.8 Bentonite bricks

Höganäs Bjufv AB in Bjufv produced bentonite bricks for CRT. The bricks have the dimensions 115x234x64 mm. They were compacted under high pressure in a machine built for compaction of fire-clay bricks. The average dry density of a brick is 1800 kg/m^3 and the water ratio 10%.

4.5 Buffer saturation system

4.5.1 General

Filter mats were installed on the rock surface of the CRT hole for the following reasons:

1. The supply of water from the rock is judged to be insufficient for saturating the buffer. The water in the rock is supplied from fractures and from the rock matrix. Only a rock with evenly distributed and frequent occurring fractures is expected to supply enough water due to the low hydraulic conductivity in the rock matrix.
2. At the end of the saturation period a high water pressure will reduce the time required to reach complete saturation.
3. For modelling purposes and for comparison with the measurements in the Prototype Repository, it is very valuable to have results with a known hydraulic boundary.

By measuring the water flow into the mats a valuable check of the water balance in the rock/buffer interface can also be obtained.

The saturation system consists of:

1. mats and tubes in the deposition hole and
2. water supply plant outside the deposition hole, which is described in the following sections.

4.5.2 Mats and tubes

Strips of matting were attached to the rock wall in a pattern shown in Figure 4.5-1. 16 strips with a width of 10 cm and a length of 6.25 m were attached with uniform spacing. In order to smooth the rock surface and prevent damage to the mats, a fine layer of cement was applied between the mats and the rock before installation. The filter strips are attached to the rock with very small bolts.

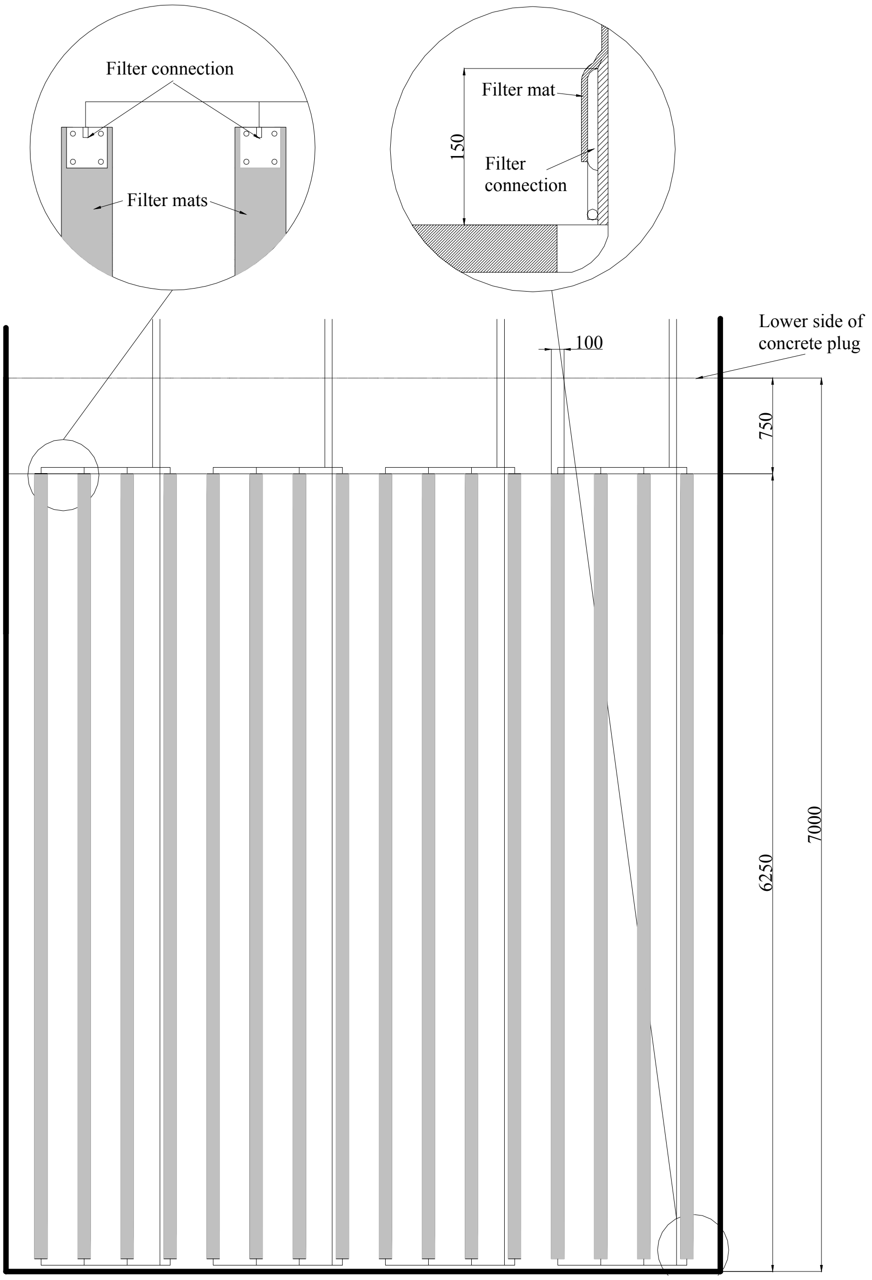


***Figure 4.5-1**. Schematic drawing of the location of the filter strips and connecting tubes in the wetting system. The surface of the deposition hole has been unfolded.*

The strips are connected to stainless steel tubes four by four. Two tubes lead from the four filters to the water supply plant, one to the bottom and one to the top as shown in the figure, for purging and flushing. The tubes are connected by plates attached to the filters.

The filter strips are made of four layers of porous plastic filters from PIAB, model PPM-F with a thickness of 1.5 mm. The average pore size of the filters is 40 μm. The filters were tested in the laboratory before installation in order to check the function and permeability. The tests were performed by enclosing filters in a rigid box under swelling pressure from water-saturated bentonite of the same density as the buffer. The tests were run for several months and the hydraulic conductivity remained at a value of about 10^{-4} m/s.

The filters were only fitted from the bottom of the hole up to the middle of the next-uppermost block, i.e. 0.75 m from the plug. The filters were not fitted all the way partly so the bentonite would seal against the plug and partly not to collide with the slots in the rock.

4.5.3 Water supply plant

The water supply equipment is shown in Fig 4.5-2. The following items describe the function of the equipment, how the equipment was installed and how to the system is operated (numbers in parentheses refer to the numbers in the figure):

1. The tubes and filters were filled with water to purge them of air. The four couplings (9) were connected to the ports leading to the bottom of the filters for this procedure. The valves on the tubes from the top of filters were left open to let the air out. Nitrogen was used as the propellant in the 50 l tank. When water came through the return tubing the valves were closed.

2. After air purging, water saturation started. To start with this was done at atmospheric pressure using nitrogen as a protective gas in the tanks (to prevent absorption of oxygen).

3. When the 50 l tank (1) needs to be refilled, the valve (7) on the 5 l tank is opened in order to equalise the nitrogen pressure in the tanks. When the crossover valve (5) is operated the saturation water is taken from the 5 l tank (2) and the 50 l tank (1) can be filled. The valve (7) on the 50 l tank (1) is closed and the water seal releases the excess nitrogen. When the 50 l tank (1) is filled, its nitrogen valve (7) is opened, and when the 5 l tank (2) is empty the valve (5) is operated to continue saturation from the 50 l tank (1).

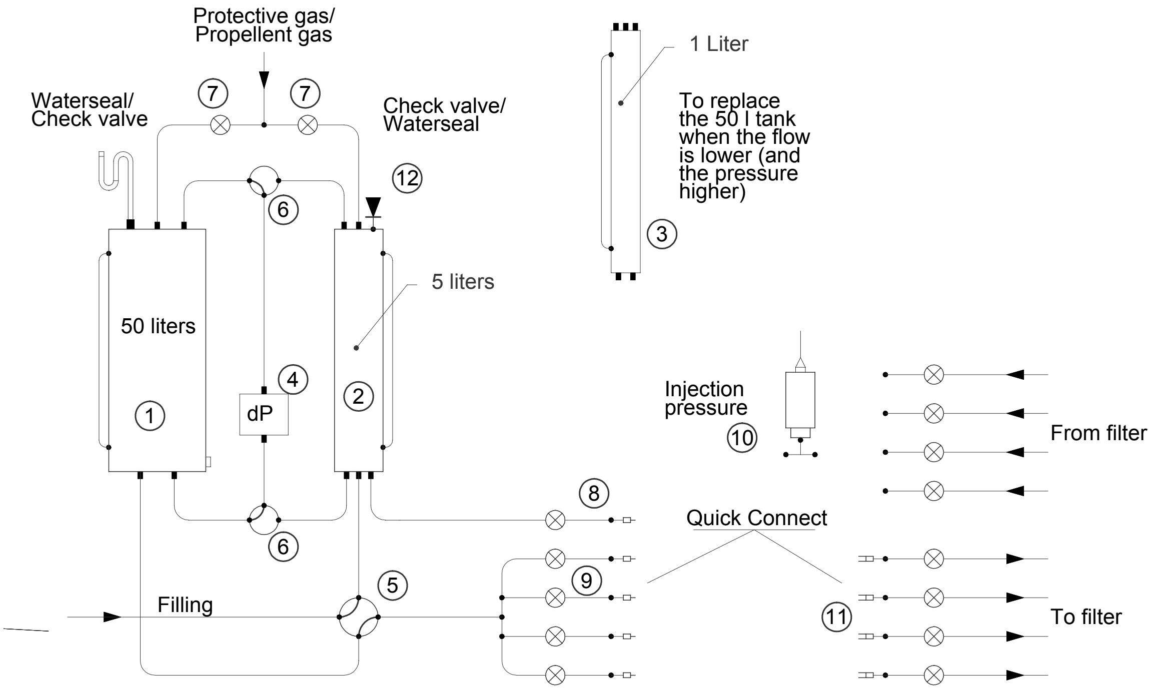
4. The flow is measured by a differential pressure transmitter that measures the difference in pressure between the nitrogen (in the top of the tanks) and the water (in the bottom of the tanks). This difference gives the water level in the tanks and the change gives the flow rate (with different constants for each tank). The switching valves (6) are used to measure the flow from the tank in operation.

5. The flow can be measured into 4 by 4 filters. When doing so both tanks should have the same gas pressure and water level. The valve (5) should be in position ”Från tank 1” (from tank 1). The quick connect (9) to the filter to be measured is disengaged and the quick coupling (8) from the 5 l tank (2) is engaged instead. The pressure transmitter is connected to the 5 l tank (2). In this position the 50 l tank (1) is supporting three filters and the 5 l tank (2) one filter. The flow from the 5 l tank (2) is measured.

6. The conditions in 4 by 4 filters can be investigated by opening the valves (from the top of the filters) one at the time and measure the outflow and the driving pressure (in the tank). The pressure in the filters can be measured by connecting the transmitter (10) to the top of the filters. This transmitter can also be used to measure the influence of the flow test in the “surrounding” filters.

7. After a while the water inflow can be reduced. Then the 50 l tank (1) can be replaced by the 1 l tank (3). The main saturation is then done from the 5 l tank (2) and the 1 l tank (3) is used for refilling (according to point 3) and testing (point 6).

8. To speed up the saturation process, the water pressure can be raised by the gas regulator and controlled by an adjustable check valve.



Legend

1. Tank, 50 litres.
2. Tank, 5 litres.
3. Tank, 1 litre.
4. Differential pressure transmitter.
5. Crossover (4-way) valve, choice of injection tank.
6. Switching (3-way) valve, choice of tank for flow measurement.
7. Ball valve, control of the protective/propellant gas.
8. Ball valve and quick coupling for connecting up an individual filter.
9. Ball valves and quick coupling for connecting up all filters.
10. Pressure transmitter, to measure the pressure in the filters.
11. Quick coupling for connecting up all filters.
12. Check valve/water seal to prevent air (oxygen) from contaminating the water.

***Figure 4.5-2**. Schematic layout of the water supply plant.*

4.6 Climate control system

The climate control system was delivered by ACE. The system consists of a dehumidifier, a fan, pipes and hoses and relative humidity sensors. The dehumidifier of make “Funktionskontroll” type DA600 has a maximum dehumidification capacity of 3.4 kg/h at +20ºC. The fan is of make Sefovent type K100M and the pipes leading air from the dehumidifier to the top of the deposition hole were galvanised. The hoses going down into the deposition hole were made of canvas. The hoses were flexible and could be installed in slots smaller then 20 mm and were also able to withstand impacts that could occur during installation of the bentonite blocks. There were six canvas tubes, each with an area of 60 mm^2.

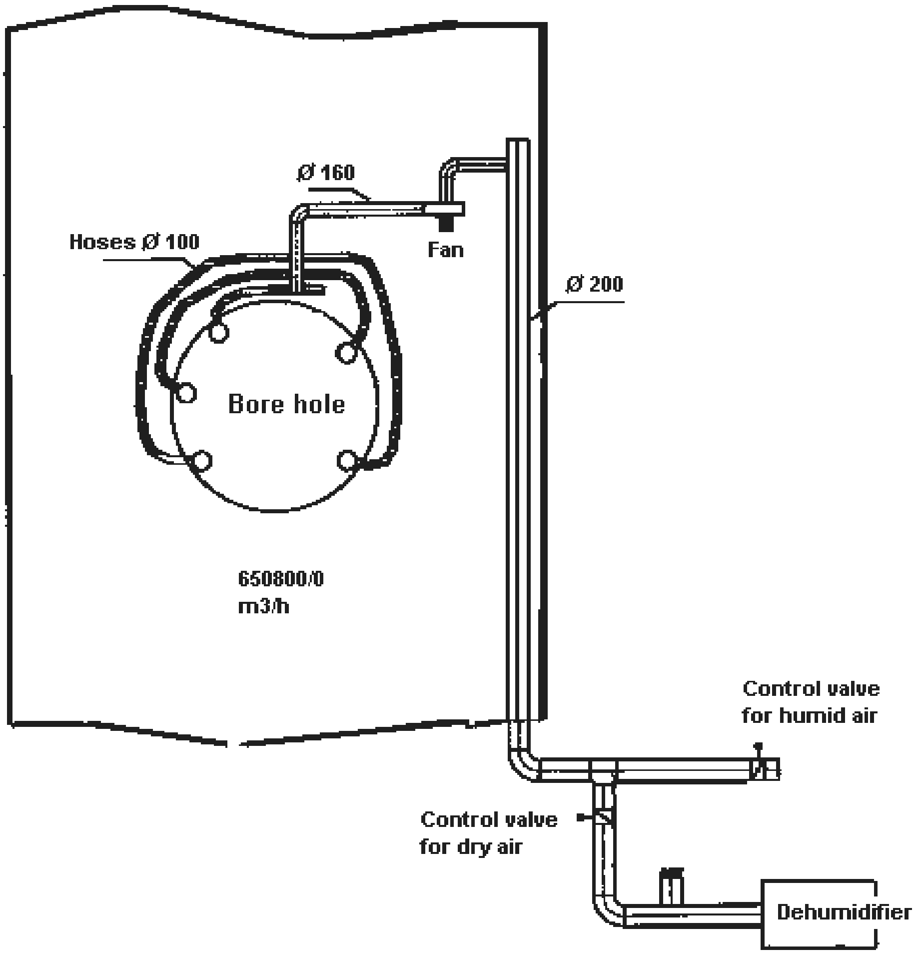


***Figure 4.6-1**. Schematic layout of the climate control system*

4.7 Retaining plug

The deposition hole in the Canister Retrieval Test was to be covered with an artificial structure as the test tunnel is left open for possible entrance. The structure consists of a concrete cone placed on the bentonite layer and a steel lid, which is pre-stressed by rock ties. Together, this structure allows all parts to be situated below the cast concrete floor in the tunnel. The aim of the structure is to prevent the blocks of bentonite from swelling uncontrollably and to simulate a real storage situation. Real storage situations, where the deposition holes are covered with backfill that allows for some upward swelling of the compacted bentonite, are such that a rigid structure is not relevant. The structure is therefore designed to allow for controlled upward displacement. To control loads and displacements a number of ties were installed with load cells. When the design was performed two holes were considered. However, only one hole has been used for test installations.

The plug was designed to withstand a uniform pressure of 9 MPa. The design of the plug is shown in Figures 4.7-1 to 4.7-3. Figure 4.7-1 shows the plan of the two deposition holes. They are spaced 6 m apart. The covers consist of a concrete cone placed on the bentonite layers and a steel lid, pre-stressed by rock ties. A section of the structure is seen in Figure 4.7-2.

When bentonite absorbs water it swells. If free swelling is prevented a pressure is built up against, in this case, the concrete cone. This load is transferred through a 500 mm concrete cone, concrete grade K40, to the steel lid. The concrete cone, with a bottom diameter of 1714 mm and a top diameter of 1734 mm, is reinforced with ϕ12 bars, horizontally and vertically spaced at 250 mm, in the bottom and in the top. The concrete cover is 50 mm thick. During the measurement stage, the whole structure must allow vertical translations.

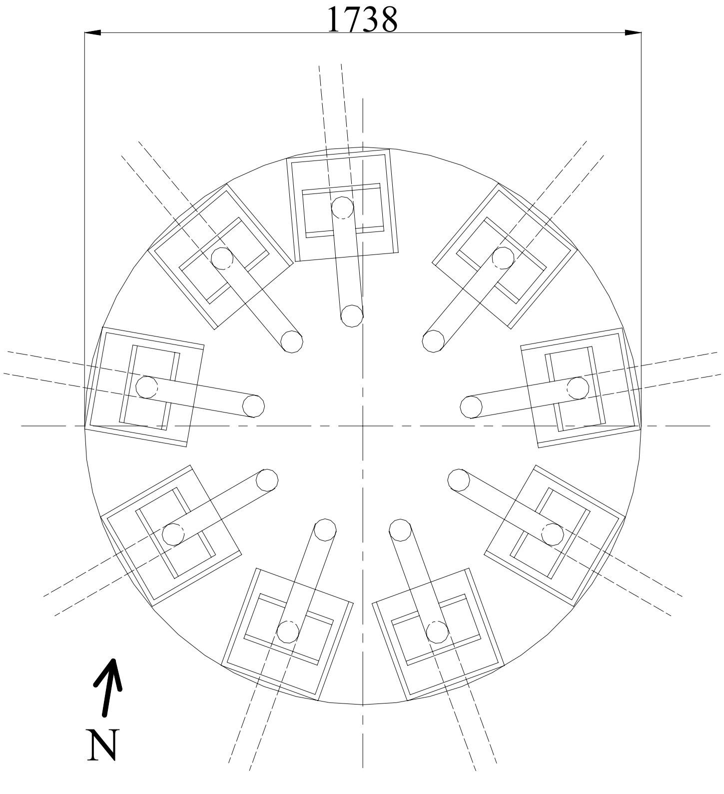


Figure 4.7-1 *Plan of the retaining plug with rock anchors*

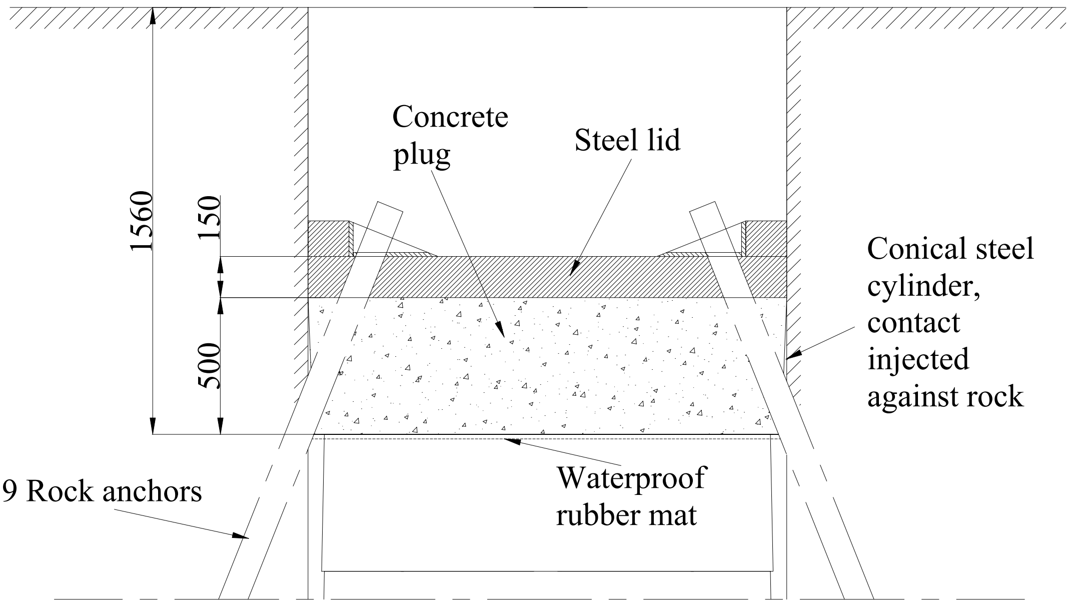


Figure 4.7-2. *Section of retaining plug with rock anchors*

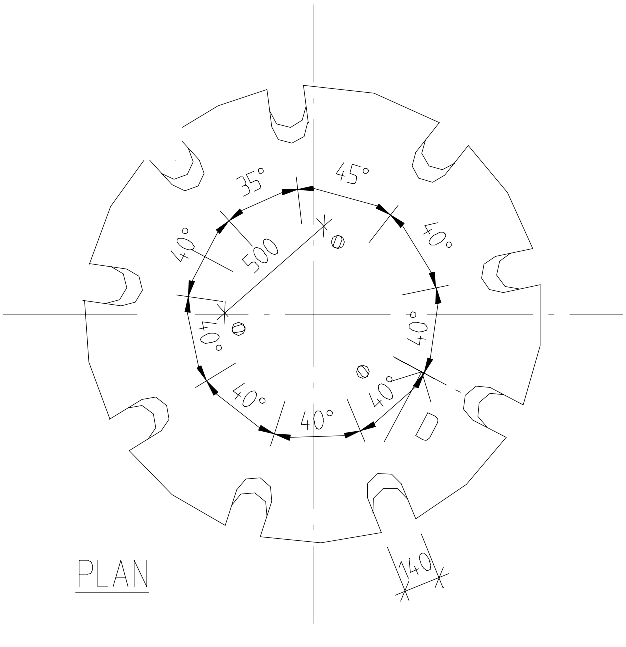


Figure 4.7-3. Plan of steel lid component of the plug (including recesses for rock anchors)

4.8 Instruments

4.8.1 Instrumentation of canister

The following measurements are performed in the canister: Temperature is measured in the steel insert in 18 points. Figure 4.8-1 shows the locations. Strain is measured in two perpendicular directions in six evenly distributed points on the inner surface of the canister, 100 mm below the top. The same configuration is used on the outer surface with the addition of a third direction of 45°.

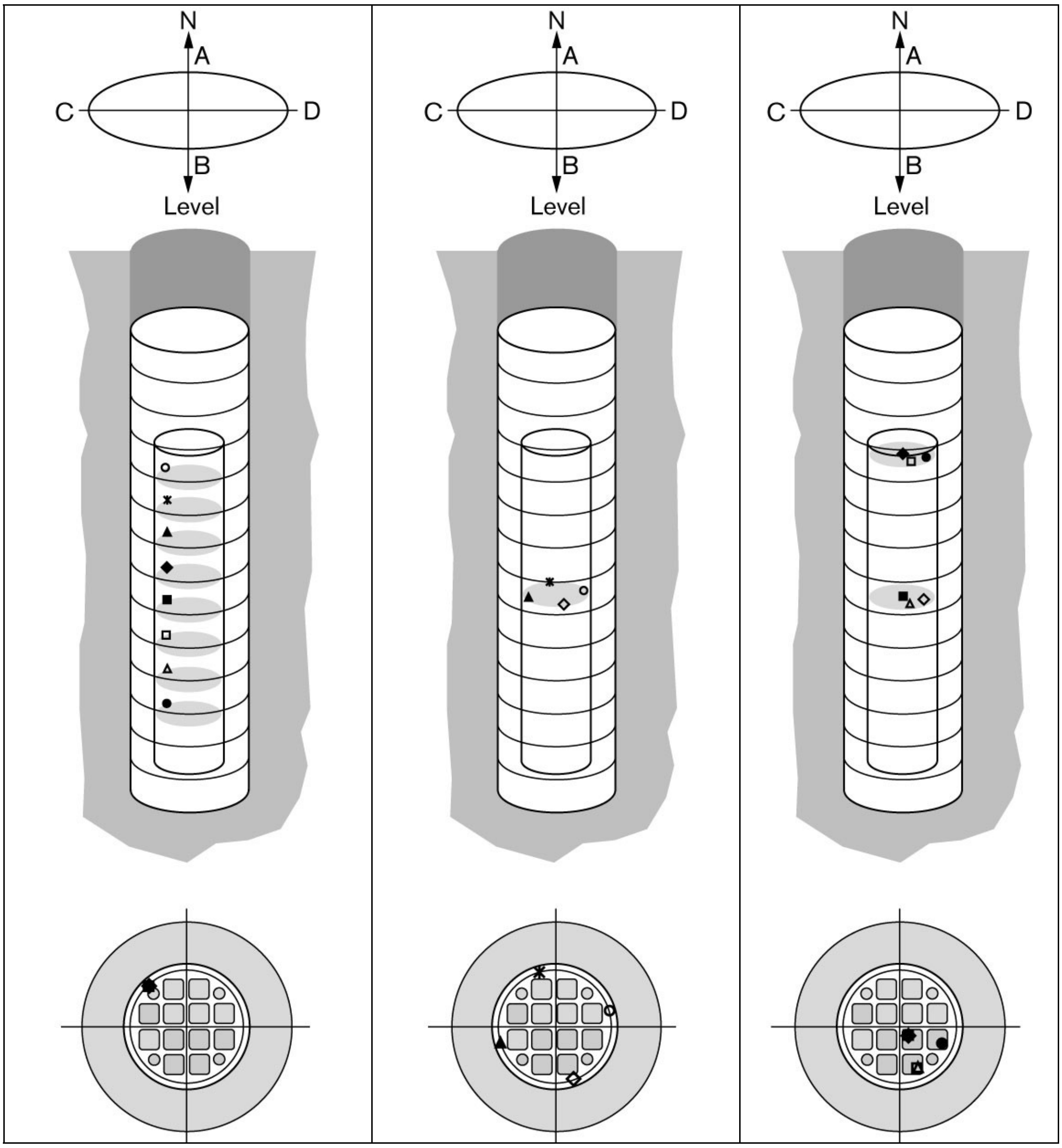


Figure 4.8-1. *Location of thermocouples inside canister*

4.8.2 Instrumentation of retaining plug

Measurements are also made on the plug: Force is measured in 3 of the 9 anchors with transducers of GLÖTZL type. Vertical displacement is measured in three points with transducers of type LVDT with a range of 0 – 50 mm.

The location of the force transducers can be described in reference to Figure 4.8-2, which shows a schematic view of the plug with the slots, rods and cables.

The rods are numbered 1-9 anti-clockwise and number 1 is assumed to be the northern rod in direction A. The force transducers are placed on rods 3, 6, and 9. The displacement transducers are placed between the rods 5 cm from the rock surface of the hole and according to Table 4.8-1. They are fixed on the rock surface and thus measure the displacement relative to the rock.

Table 4.8-1. Location of displacement transducers

Transducer No.	Located between rods No.
1	4 and 5
2	7 and 8
3	1 and 2

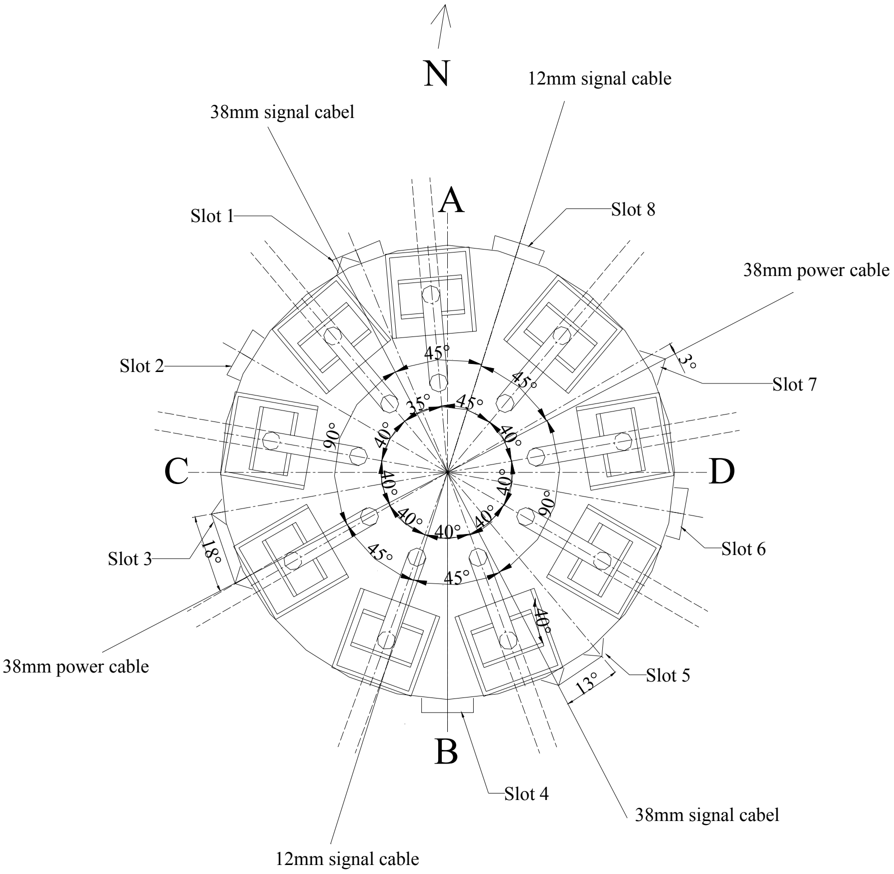


Figure 4.8-2. *Schematic view of the deposition hole, showing the position of the slots, the rods and the cables from the canister.*

4.8.3 Instrumentation of rock mass

The aim of the instrumentation in rock is to monitor mechanical and thermal processes during the complete test cycle, i.e. excavation – saturation – retrieval. The monitoring programme in rock includes stress change, vertical strain and temperature measurements. Instruments for stress measurements and vertical strain were installed prior to excavation of the canister holes in order to monitor stress redistribution and displacements over a number of defined joints formed by the excavation of the canister holes. These instruments are long-term reliable and are installed to monitor the stress change and possible displacements during the complete test cycle, i.e. from the excavation phase to the retrieval phase. The stress change monitoring system is capable of monitoring stresses induced by mechanical loading as well as thermal loading.

Temperature gauges around the canister hole are installed to monitor temperature distribution in the rock formation during the heating and saturation phase. Based on data on temperature distribution, calculated expected temperatures will be verified. Temperature data will also be relevant when evaluating stress changes and thermal properties of the rock.

During the excavation phase the mechanical instrumentation was a part of an investigation aimed at clarifying the disturbed zone and the rock mechanical response in the host rock around the mechanically excavated large boreholes. Besides the monitoring of stress and strain changes the monitoring programme also included acoustic emission and ultra sonic velocity. In the excavation stage two canister holes where included and instrumented for the canister retrieval test. However, in the heating and saturation phase only one canister hole is in operation.

Embedded biaxial stressmeter

The biaxial stressmeter, Figure 4.8-3, model 4350, is designed to measure compressive stress changes in rock, salt, concrete or ice. The instrument consists of a rigid high-strength steel cylinder 318 mm in length with an outside diameter of 57 mm. The deformation in a plane perpendicular to the borehole is measured by means of three pairs of vibrating wire sensors spaced a 60° intervals at the centre of the cylinder. Two similar sensors measure longitudinal deformation along the cylinder and two sensors absolute temperature. Changes of deformation and temperature produce corresponding changes in the resonant frequency of the sensors. These changes can be related to stress changes using factory supplied calibrations.

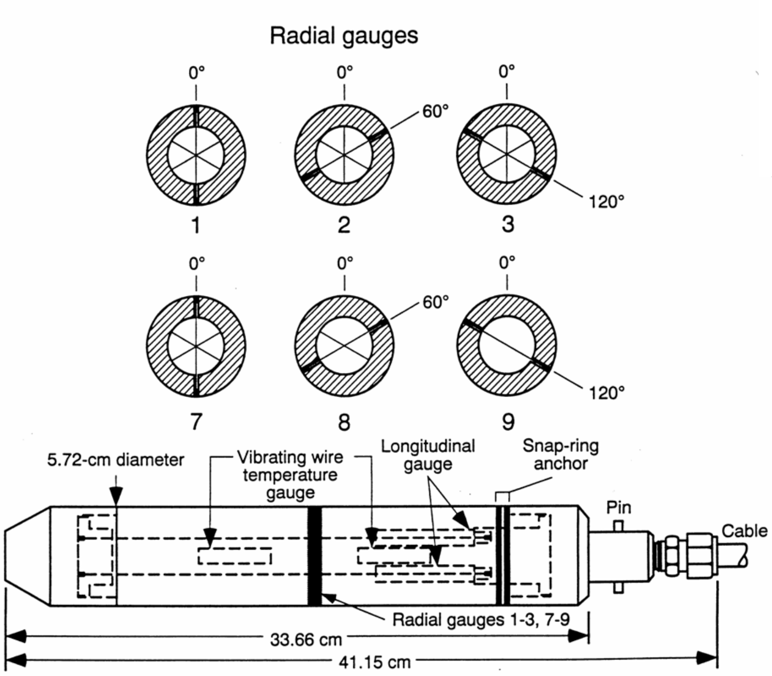


Figure 4.8-3 *Diagram of the biaxial stressmeter (after Geokon)*

Vibrating wire strain gauges

The vibrating wire strain gauge, model GEOKON 4200, is designed for direct embedment in cement paste. A steel wire is tensioned between two end blocks and the strain of the wire is measured using the vibrating wire principle. Deformation in the rock mass induces movements of the hard cement causing the two blocks to move relative to one another across the joint, thus altering the tension in the steel wire. The distance between the two end blocks is 15 cm. The tension is measured by plucking the wire and measuring the resonant frequency of the vibration by using an electromagnetic coil.

Nine strain gauges were installed across joints in the same boreholes as the biaxial stressmeters at depths shown in Table 5.6-1.

Temperature measurement

Temperatures around the deposition hole are measured with thermocouples type K. The temperature gauges are installed to measure the radial temperature flow in the rock formation around the canister hole. Temperatures are also measured from the bottom of the deposition hole. Locations and numbering of thermocouples are given in section 5.6.

4.8.4 Instrumentation of buffer

4.8.4.1. General

An important part of the work is to measure the thermal, hydraulic and mechanical processes in the bentonite during saturation. 128 instruments were installed in the bentonite.

This chapter deals with the instruments in the bentonite. The bentonite is instrumented with pressure cells (total and water pressure), thermocouples and moisture gauges. The positions and the technique for placing them in the bentonite blocks will be described. The transducers and the measuring system are not described.

4.8.4.2. Brief description of instruments

The different instruments that will be used in the experiment are briefly described in this section.

4.8.4.3. Measurements of temperature

Thermocouples from BICC have been installed for measuring temperature. Measurements are done in 32 points in the test hole. In addition, temperature gauges are incorporated in the capacitive relative humidity sensors (29 sensors) as well as in the pressure gauges of vibrating wire type (13 gauges). Temperature is also measured in the psychrometers.

In addition, temperature is measured on the surface of the canister with optical fiber cables. The system and the location of the cables are described in chapter 4.8.4.10.

4.8.4.4. Measurement of total pressure

Total pressure is the sum of the swelling pressure and the pore water pressure. It is measured with the following instrument types:

- Geocon total pressure cells with vibrating wire transducer. Fifteen cells of this type have been installed.

- Kulite total pressure cells with piezo-resistive transducer. Six cells of this type have been installed.

4.8.4.5. Measurement of pore water pressure

Pore water pressure is measured with the following instrument types:

- Geocon pore pressure cells with vibrating wire transducer. Thirteen cells of this type have been installed.

- Kulite pore pressure cells with piezo-resistive transducer. One cell of this type has been installed.

4.8.4.6. Measurement of water saturation process

The water saturation process is recorded by measuring the relative humidity in the pore system, which can be converted into water ratio or total suction (negative water pressure). The following techniques and devices are used:

- Vaisala relative humidity sensor of capacitive type. Twenty-nine cells of this type have been installed. The measuring range is 0-100 % RH.

- Wescor psychrometers model PST-55. The devices measure the relative humidity in the pore system. The measuring range is 95.5-99.6% RH corresponding to a pore water pressure of -0.5 to –6 MPa or a water ratio of 25-65% in the bentonite. Twenty-six cells of this type have been installed.

4.8.4.7. Preparation of instruments

All instruments were prepared by enclosing the transducers in protective casings of titanium (or other material) and running all cables in titanium tubes with watertight connections. The transducers were checked and calibrated.

- Protective tubes for the relative humidity instruments and the soil psychrometers were furnished with housing (including filter) for the sensor by welding.

- The delivered instruments were inspected and compared with the order specification.

- Signal cables for the relative humidity instruments were disconnected from the electronic unit and placed in titanium protection tubes. The signal cables were then re-connected to the electronic unit. After that, the relative humidity instruments were calibrated at three different humidity levels.

- Signal cables for the soil psychrometers were placed in the titanium protection tubes.

- The titanium tubes were connected to the pressure sensors by welding. This concerns the pressure sensors of type Fabry-Perot or piezo-resistive. A certified welder carried out the work. The vibrating wire pressure sensors were delivered with protection tubes already assembled.

- A selection of the soil psychrometers were calibrated at two different humidity levels or tested at one level.

- Zero reading of pressure sensors was done.

4.8.4.8. Strategy for describing the position of each device

The deposition hole is termed DD0086G02 where “86” denotes the distance to the middle line in the A-tunnel. Instruments have been installed in four vertical sections A, B, C and D according to Figures 4.8-4 and 4.8-5. Directions A and B are positioned in the tunnel’s axial direction with A aimed almost north.

The bentonite blocks are called cylinders and rings. The cylinders are numbered C1-C4 and the rings R1-R10 (Figure 4.8-4).

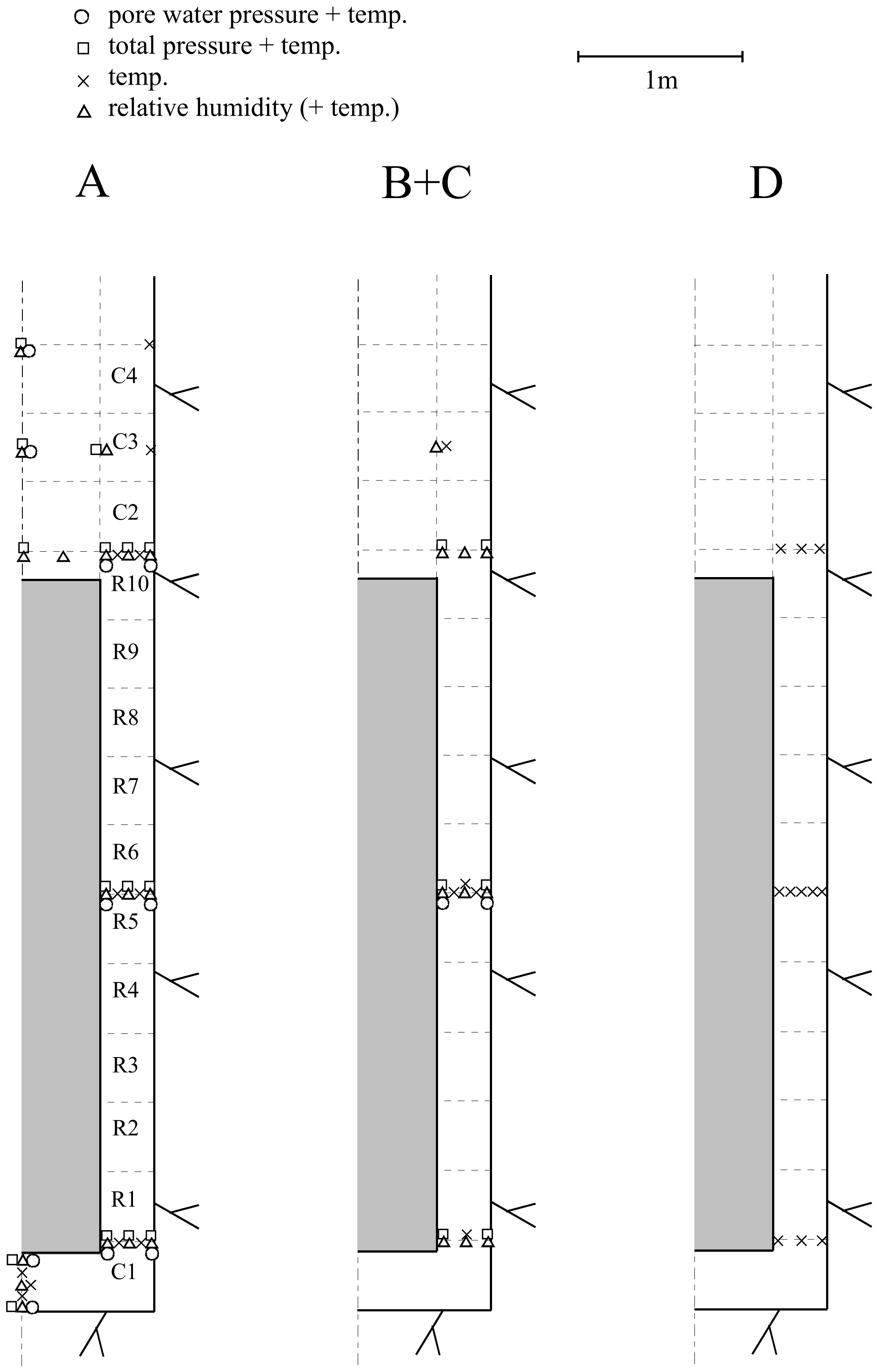


Figure 4.8-4. *Schematic view of the instruments in four vertical sections and the block designation.*

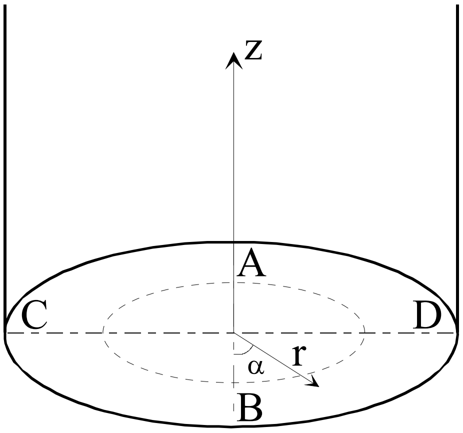


***Figure 4.8-5**. Figure describing the coordinate system used to determine the instrument positions.*

Each instrument has been named with a short unique name consisting of 1-2 letters describing the type of measurement and 3 digits numbering the device. Each instrument position is described by three coordinates according to Figure 4.8-5. The *r*-coordinate is the horizontal distance from the center of the hole and the *z*-coordinate is the height from the bottom of the hole (the block height is assumed to be 500 mm). The *α*–coordinate is the angle from the vertical direction B.

4.8.4.9. Position of each instrument in the bentonite

The instruments are located at three main levels in the blocks, 50 mm, 160 mm and 250 mm from the upper surface. Most thermocouples are placed at the 50 mm level, Geocon pore water and total pressure transducers are placed at the 250 mm level and the other gauges at the 160 mm level.

The positions of the instruments are described in Tables 4.8-2 to 4.8-5. In the field all instruments are marked with the type and number according to these tables except for the first digit, which is 2 instead of 1 (2XX instead of 1XX).

Table 4.8-2. Numbering and position of instruments for measuring temperature (T)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
T101	Cyl. 1	Center	90	50	50	242	BICC	
T102	Cyl. 1	Center	90	50	250	238	BICC	
T103	Cyl. 1	Center	90	50	450	230	BICC	
T104	Cyl. 1	A	180	635	450	206	BICC	
T105	Cyl. 1	A	180	735	450	202	BICC	
T106	Cyl. 1	B	365	685	450	38	BICC	
T107	Cyl. 1	C	275	685	450	274	BICC	
T108	Cyl. 1	D	90	585	450	96	BICC	
T109	Cyl. 1	D	90	685	450	94	BICC	
T110	Cyl. 1	D	90	785	450	92	BICC	
T111	Ring 5	A	180	635	2950	224	BICC	
T112	Ring 5	A	180	735	2950	218	BICC	
T113	Ring 5	B	360	610	2950	318	BICC	
T114	Ring 5	B	360	685	2950	322	BICC	
T115	Ring 5	B	360	735	2950	324	BICC	
T116	Ring 5	C	270	610	2950	258	BICC	
T117	Ring 5	C	270	685	2950	260	BICC	
T118	Ring 5	C	270	735	2950	262	BICC	
T119	Ring 5	D	90	585	2950	44	BICC	
T120	Ring 5	D	90	635	2950	46	BICC	
T121	Ring 5	D	90	685	2950	48	BICC	
T122	Ring 5	D	90	735	2950	50	BICC	
T123	Ring 5	D	90	785	2950	52	BICC	
T124	Ring 10	A	180	635	5450	200	BICC	
T125	Ring 10	A	180	735	5450	194	BICC	
T126	Ring 10	D	90	585	5450	54	BICC	
T127	Ring 10	D	90	685	5450	56	BICC	
T128	Ring 10	D	90	785	5450	58	BICC	
T129	Cyl. 3	A	180	785	6250	166	BICC	
T130	Cyl. 3	B	365	585	6250	358	BICC	
T131	Cyl. 3	C	275	585	6250	280	BICC	
T132	Cyl. 4	A	180	785	6950	66	BICC	

Table 4.8-3. Numbering and position of instruments for measuring total pressure (P)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
P101	Cyl. 1	Center	180	50	50	244	Geocon	
P102	Cyl. 1	Center	180	50	250	232	Geocon	
P103	Cyl. 1	A	185	585	250	208	Geocon	
P104	Cyl. 1	A	185	685	250	204	Geocon	
P105	Cyl. 1	A	185	785	250	186	Geocon	
P106	Cyl. 1	B	365	585	250	40	Geocon	
P107	Cyl. 1	B	365	785	250	2	Geocon	
P108	Cyl. 1	C	275	585	250	278	Geocon	
P109	Cyl. 1	C	275	785	250	270	Geocon	
P110	Ring 5	A	185	585	2750	228	Geocon	
P111	Ring 5	A	185	685	2750	222	Geocon	
P112	Ring 5	A	185	785	2750	188	Geocon	
P113	Ring 5	B	365	535	2750	36	Geocon	
P114	Ring 5	B	365	825	2750	16	Geocon	
P115	Ring 5	C	275	585	2750	296	Geocon	
P116	Ring 5	C	275	785	2750	290	Geocon	
P117	Ring 10	Center	180	50	5250	24	Kulite	
P118	Ring 10	A	180	585	5250	216	Geocon	
P119	Ring 10	A	180	685	5250	198	Geocon	
P120	Ring 10	A	180	785	5250	192	Geocon	
P121	Ring 10	B	365	585	5250	20	Kulite	
P122	Ring 10	B	365	785	5250	18	Kulite	
P123	Ring 10	C	275	585	5250	286	Kulite	
P124	Ring 10	C	275	785	5250	284	Kulite	
P125	Cyl. 3	Center	180	50	6250	158	Geocon	
P126	Cyl. 3	A	180	585	6250	162	Geocon	
P127	Cyl. 4	Center	180	50	6750	64	Kulite	

Table 4.8-4. Numbering and position of instruments for measuring pore water pressure (U)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
U101	Cyl. 1	Center	270	50	50	246	Geocon	
U102	Cyl. 1	Center	270	50	250	236	Geocon	Horizontal
U103	Cyl. 1	A	175	585	250	126	Geocon	
U104	Cyl. 1	A	175	785	250	178	Geocon	
U105	Ring 5	A	175	585	2750	138	Geocon	
U106	Ring 5	A	175	785	2750	180	Geocon	
U107	Ring 5	B	355	535	2750	314	Geocon	
U108	Ring 5	B	355	825	2750	348	Geocon	
U109	Ring 5	C	265	585	2750	256	Geocon	In the slot
U110	Ring 5	C	265	825	2750	264	Geocon	In the slot
U111	Ring 10	A	175	585	5250	146	Geocon	
U112	Ring 10	A	175	785	5250	152	Geocon	
U113	Cyl. 3	Center	270	50	6250	156	Geocon	
U114	Cyl. 4	Center	270	50	6950	62	Kulite	

Table 4.8-5. Numbering and position of instruments for measuring water content (W)

		Instrument position in block				Cable pos.		
Type and number	Block	Direction	α	r	Z	α	Fabricate	Remark
W101	Cyl. 1	Center	360	50	50	248	Vaisala	
W102	Cyl. 1	Center	360	400	160	240	Vaisala	
W103	Cyl. 1	Center	360	50	450	234	Vaisala	Horizontal
W104	Cyl. 1	A	180	585	340	128	Vaisala	
W105	Cyl. 1	A	180	685	340	132	Vaisala	
W106	Cyl. 1	A	180	785	340	184	Vaisala	
W107	Cyl. 1	A	170	585	340	124	Wescor	
W108	Cyl. 1	A	170	685	340	130	Wescor	
W109	Cyl. 1	A	170	785	340	134	Wescor	
W110	Cyl. 1	B	360	585	340	304	Vaisala	
W111	Cyl. 1	B	360	685	340	308	Vaisala	
W112	Cyl. 1	B	360	785	340	360	Vaisala	
W113	Cyl. 1	B	355	585	340	302	Wescor	
W114	Cyl. 1	B	355	685	340	306	Wescor	
W115	Cyl. 1	B	355	785	340	310	Wescor	
W116	Cyl. 1	C	270	585	340	250	Wescor	
W117	Cyl. 1	C	270	685	340	252	Wescor	
W118	Cyl. 1	C	270	785	340	254	Vaisala	
W119	Ring 5	A	180	585	2840	226	Vaisala	
W120	Ring 5	A	180	685	2840	220	Vaisala	
W121	Ring 5	A	180	785	2840	182	Vaisala	
W122	Ring 5	A	170	585	2840	136	Wescor	
W123	Ring 5	A	170	685	2840	140	Wescor	
W124	Ring 5	A	170	785	2840	142	Wescor	
W125	Ring 5	B	360	535	2840	316	Vaisala	In the slot
W126	Ring 5	B	360	685	2840	34	Vaisala	
W127	Ring 5	B	360	785	2840	350	Vaisala	
W128	Ring 5	B	350	535	2840	312	Wescor	In the slot
W129	Ring 5	B	350	685	2840	320	Wescor	
W130	Ring 5	B	350	785	2840	346	Wescor	
W131	Ring 5	C	270	585	2840	294	Wescor	In the slot
W132	Ring 5	C	275	685	2840	292	Wescor	
W133	Ring 5	C	270	785	2840	288	Wescor	
W134	Ring 10	Center	360	50	5340	22	Vaisala	
W135	Ring 10	A	180	262	5340	26	Vaisala	
W136	Ring 10	A	180	585	5340	214	Vaisala	
W137	Ring 10	A	180	685	5340	196	Vaisala	
W138	Ring 10	A	180	785	5340	190	Vaisala	
W139	Ring 10	A	170	585	5340	144	Wescor	
W140	Ring 10	A	170	685	5340	148	Wescor	
W141	Ring 10	A	170	785	5340	150	Wescor	
W142	Ring 10	B	360	585	5340	328	Vaisala	
W143	Ring 10	B	360	685	5340	332	Vaisala	
W144	Ring 10	B	360	785	5340	336	Vaisala	
W145	Ring 10	B	355	585	5340	326	Wescor	
W146	Ring 10	B	355	685	5340	330	Wescor	
W147	Ring 10	B	355	785	5340	334	Wescor	
W148	Ring 10	C	270	585	5340	266	Wescor	
W149	Ring 10	C	270	685	5340	268	Wescor	
W150	Ring 10	C	270	785	5340	272	Vaisala	
W151	Cyl. 3	Center	360	50	6250	154	Vaisala	
W152	Cyl. 3	A	180	585	6250	160	Vaisala	
W153	Cyl. 3	B	360	585	6250	356	Vaisala	
W154	Cyl. 3	C	270	585	6250	276	Wescor	
W155	Cyl. 4	Center	360	50	6840	60	Vaisala	

4.8.4.10. Fibre optic system

An optical measurement system called FTR (Fibre Temperature Laser Radar) for measuring the canister surface temperature is used. The supplier of the system is BICC.

The measuring principle is shown in Figure 4.8-6. A laser light source sends a light pulse into one of the ends of an optical fibre. Most of the light is transported all the way through the fibre and exits the fibre at the other end. A smaller fraction of the light is scattered and reflected through the entire fibre backward to the light source. The back-scatter light is called Rayleigh scattering light and is a result of density variation in the fibre material. The back-scattering light is analysed with respect to the Raman scattering spectrum, which consists of a shorter wavelength (Stokes light) and a longer wavelength (Anti-Stokes light) than the original laser light wavelength. The intensity ratio between the Stokes light and the Anti-Stokes light is a measure of the temperature. The time it takes for the back-scattering light to return to the light source is a measure of the position along the fibre. As a result a temperature profile is achieved along all the cable length.

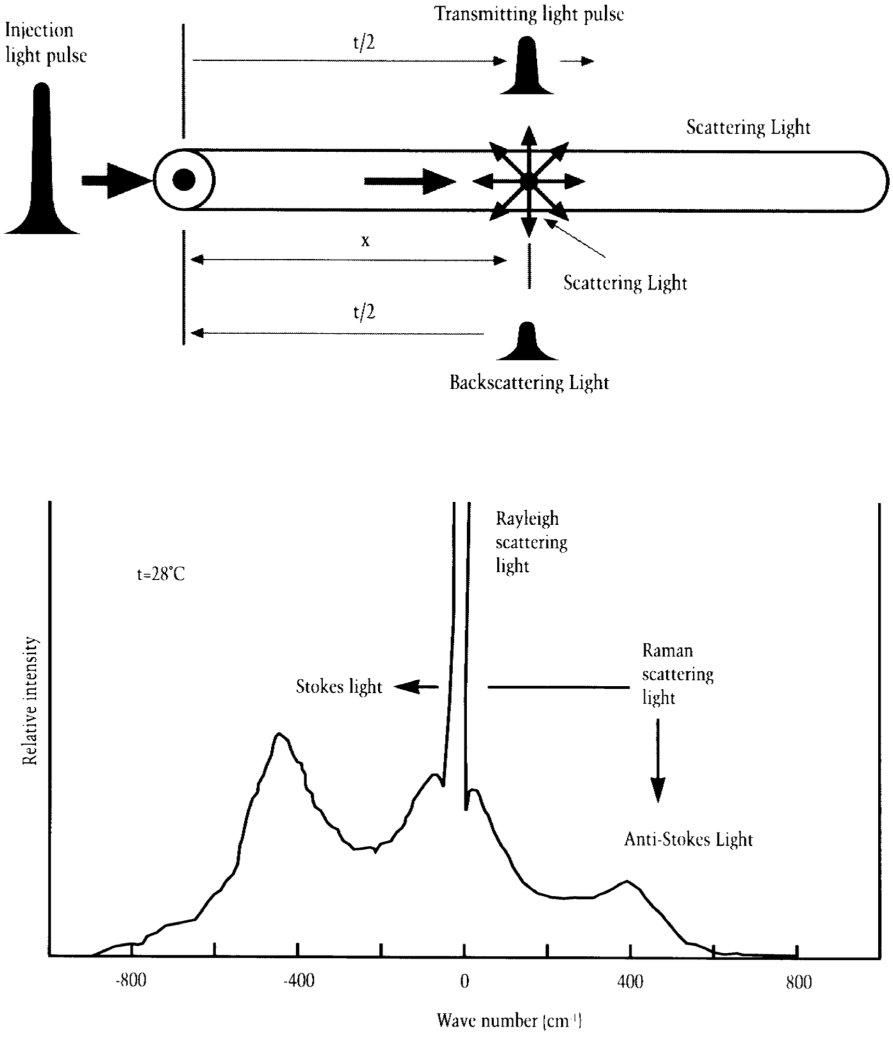


Figure 4.8-6. *Back-scattering light generation in an optical fibre (upper figure) and the Raman scattering spectrum in an optical fibre (lower figure).*

Since a time integration of the measurement signal, which can be regarded as a stochastic variable, has to be done, the measurement result is equal to an average temperature along a distance of the cable.

The spatial resolution is defined as the distance along which the measuring signal changes from 10% to 90% of the actual temperature difference at a stepwise temperature change as can be seen in Figure 4.8-7. The average temperatures achieved are shown in Table 4.8-6.

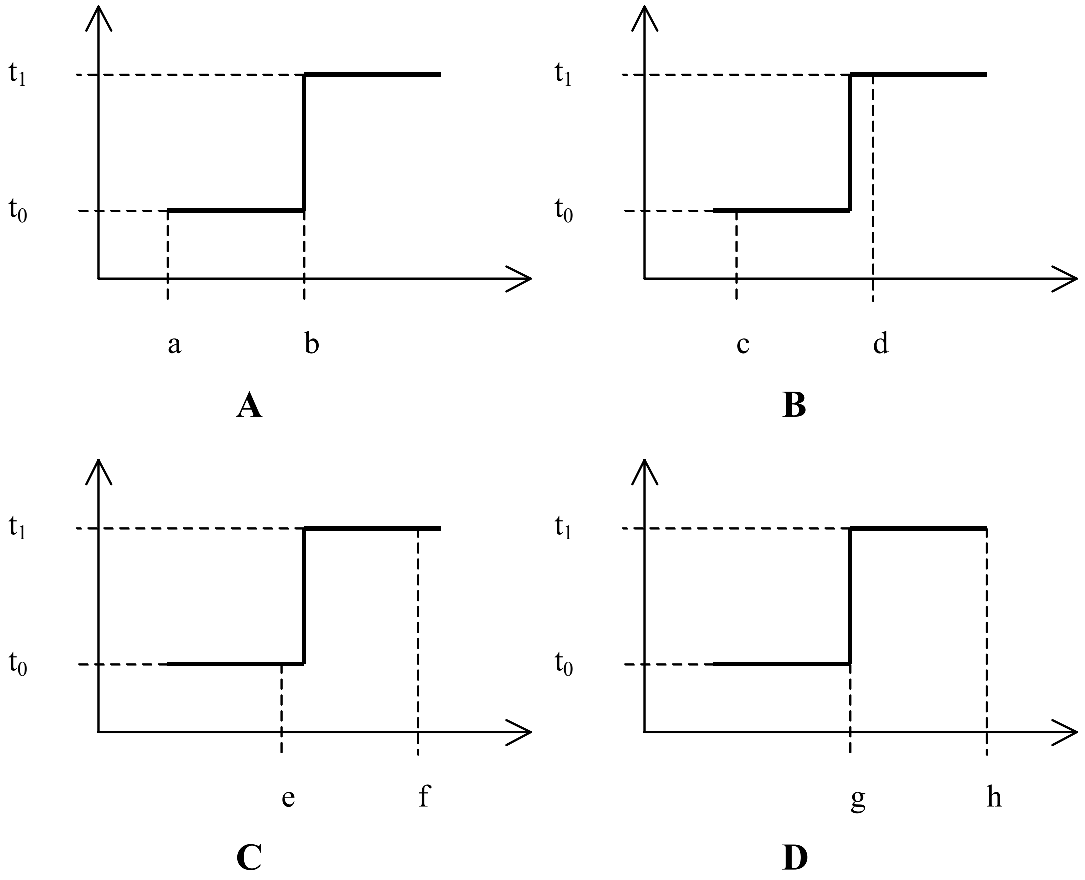


Figure 4.8-7*. Definition of the spatial resolution, which in these graphs is equal to the distance between position c and e.*

Table 4.8-6. Average temperature along the optical fibre

Distance a-b in graph A	t_0
Distance c-d in graph B	t_0+plus 10% of the difference between t_1 and t_0
Distance e-f in graph C	t_0+plus 90% of the difference between t_1 and t_0
Distance g-h in graph D	t_1

Figure 4.8-6 shows how the two optical fibre cables are placed on the canister surface. Both ends of a cable are used for measurements. This means that the two cables are used as four measuring channels as described in Table 4.8-7.

With this laying the cable will enter and exit the surface at almost the same position. Curvatures are shaped as a quarter circle with a radius of 20 cm. The cable is placed in a milled-out channel on the surface. The channel has a width and a depth of just over 2 mm.

Table 4.8-7. Combination of cables and channels

Channel 1	Outlet of cable 1
Channel 2	Inlet of cable 1
Channel 3	Outlet of cable 2
Channel 4	Inlet of cable 2

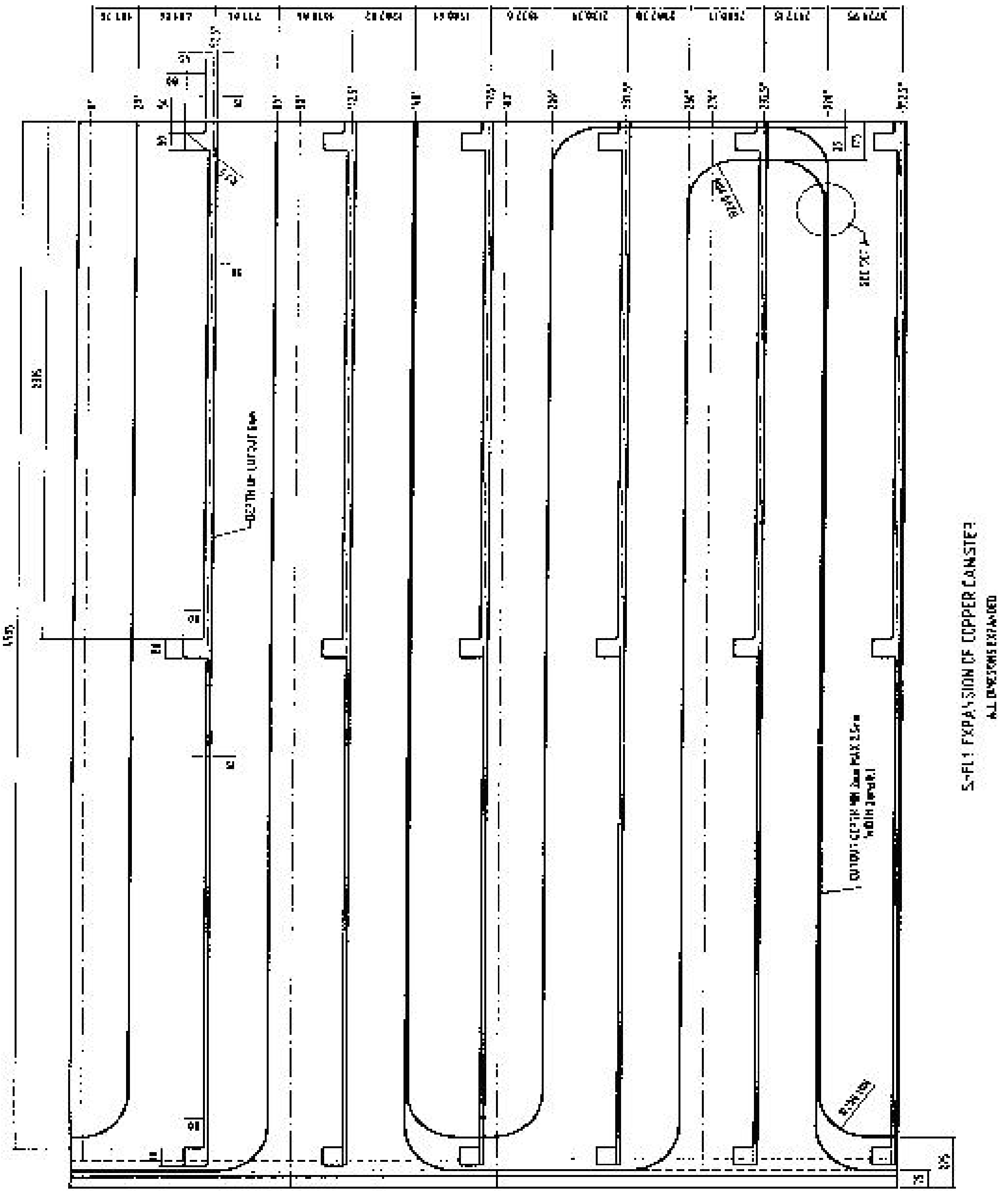


Figure 4.8-8. *Laying of two fibre optic cables with protective tube of Inconel 625 (outer diameter 2 mm) for measurement of the canister surface temperature (surface unfolded).*

The measurement result can be presented as a temperature profile, which is shown in the example in Figure 4.8-9, and as a maximum temperature, which is shown in Figure 4.8-10.

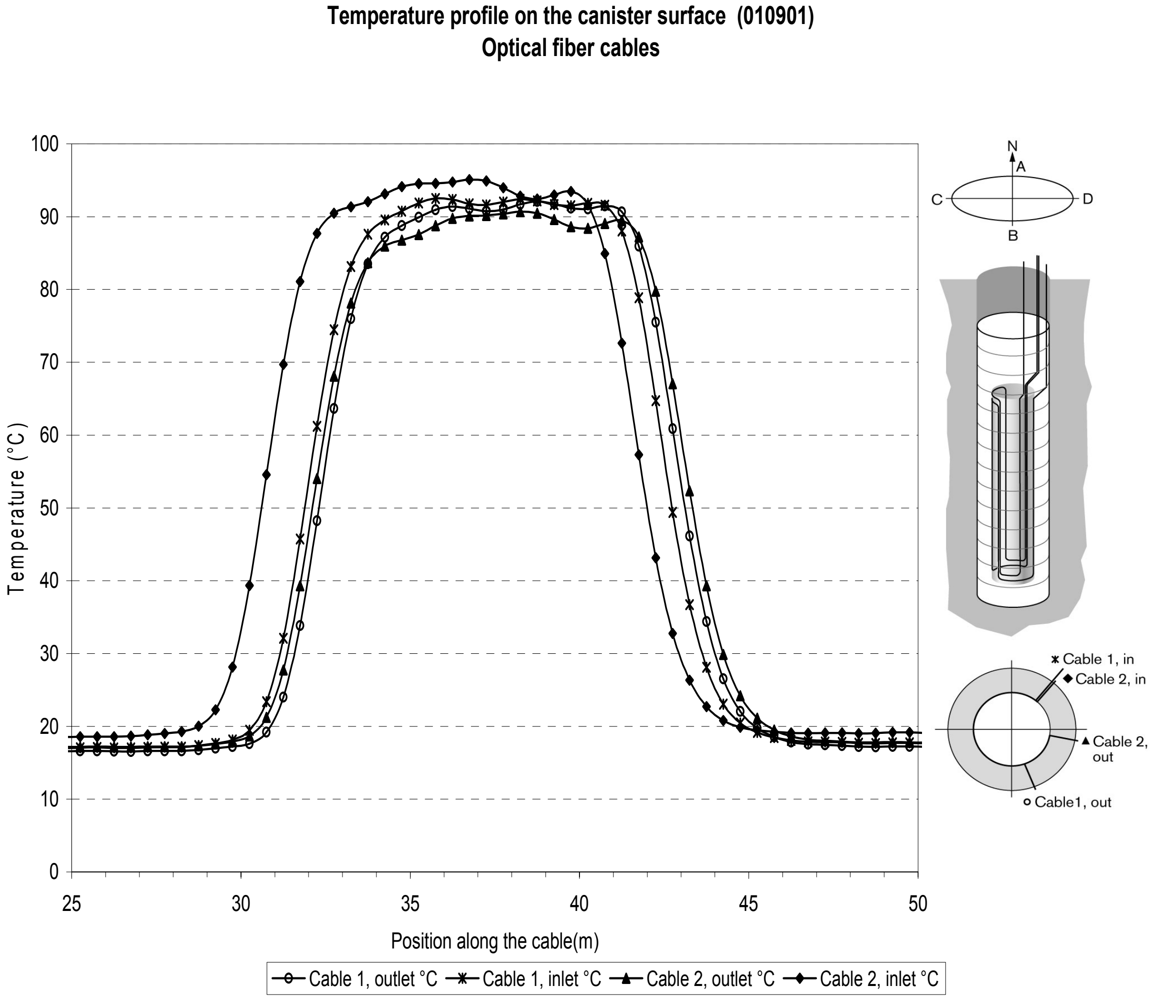


__Figure 4.8-9.__ Example of temperature profile (temperature in ℃ on the Y-axis and position in meters along the cable on the X-axis) on the canister surface as measured on 7 February 2001. Approximately 20 m of cable is located on the surface, between positions 66 m and 86 m.

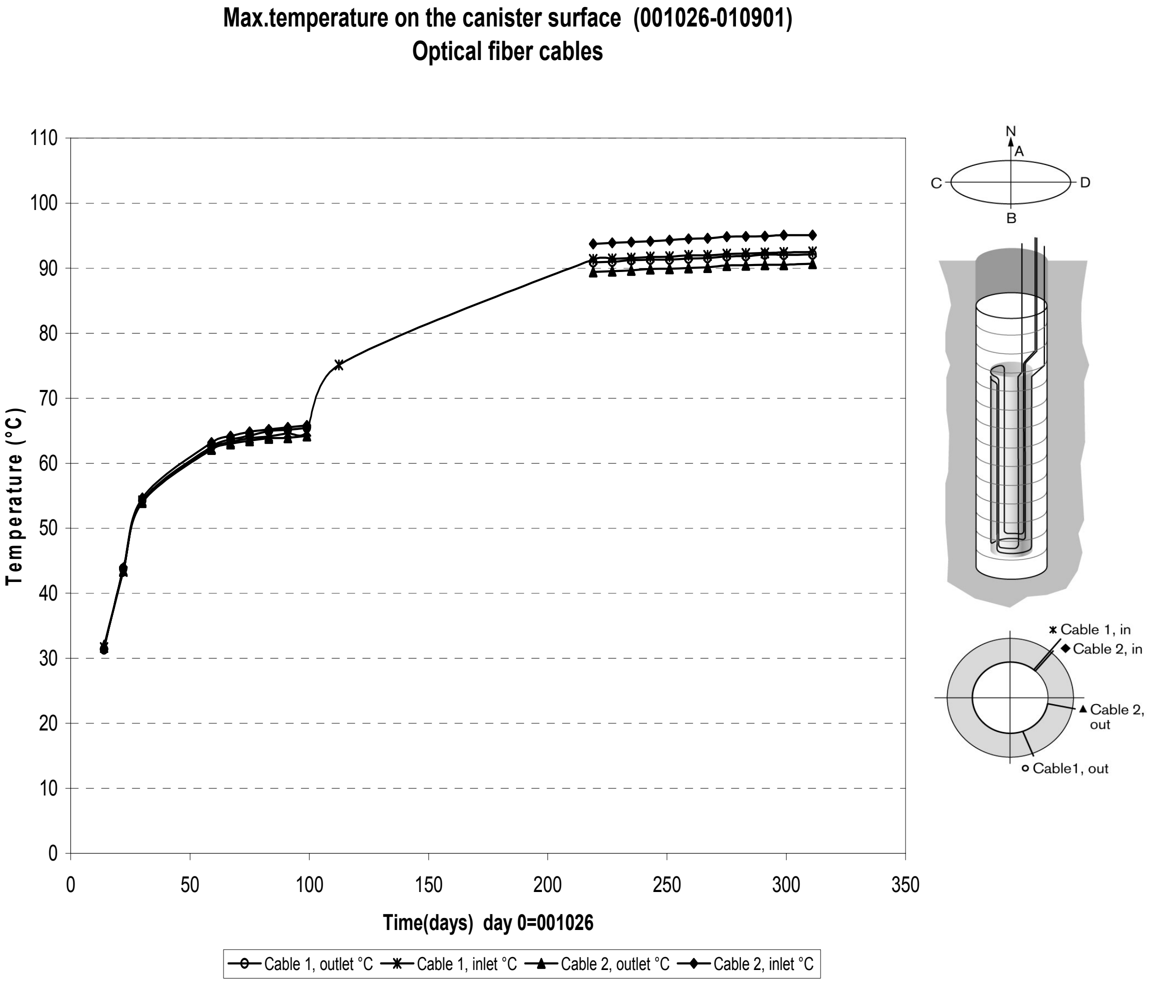


Figure 4.8-10. *Maximum temperature on the canister surface during the first eleven months.*

4.8.5 Instrumentation for climate control

To observe and regulate the relative humidity, five sensors of type Regin HRT250 were installed in the deposition hole and removed before addition of the pellets (Figure 4.8-11). Four of the sensors were installed at different levels in the gap between the rings and the borehole wall. Two of them were installed at the same level as the bottom block and the other two at the same level as ring number five. The last sensor was installed outside the Canister Retrieval Test site (outside the constructed wall) to measure the variation in relative humidity in the tunnel system before the air for the test was dehumidified. Three of the sensors also measure temperature. Data were stored in a portable computer and visualised with the program WinLog.

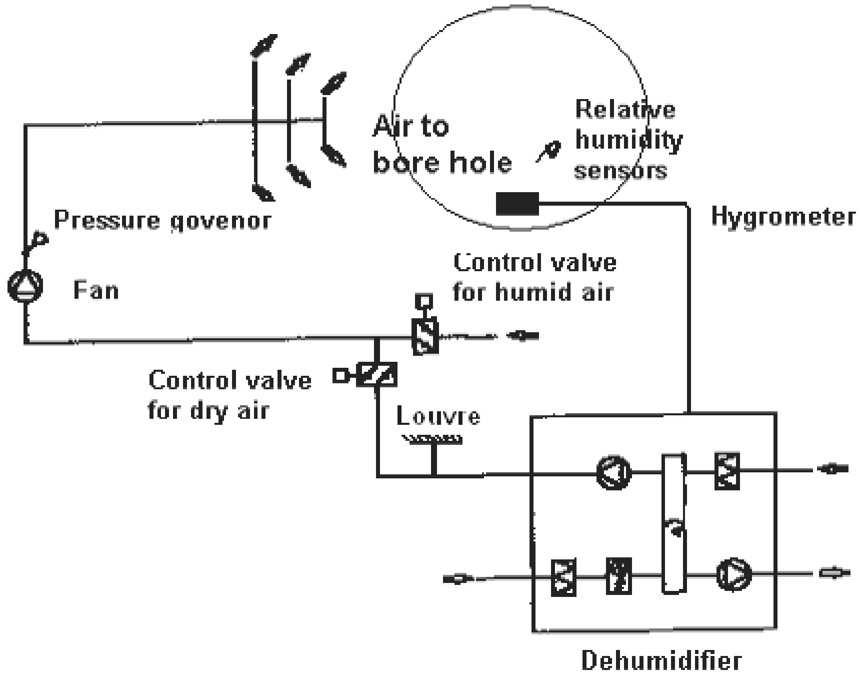


Figure 4.8-11. *Schematic layout of the climate control system*

4.9 Data acquisition system

4.9.1 Overview

The system consists of a measurement computer and several different kinds of dataloggers. The computer is placed in the backfill container and the dataloggers are located next to the experiment. The dataloggers handle the signals from sensors and transmitters. The measured values are transferred via a serial link from the dataloggers to the measurement computer. The Orchestrator software, which is Äspö's measuring programme, is installed. All data is saved on the hard drive. Backups are made by a Unix server system once a week. The computer is connected to Äspö data network.

4.9.2 Dataloggers

All moisture transmitters, thermocouples, pressure sensor and strain gauges are connected to the datascan loggers.

All vibrating wire pressure sensors are connected to the Campbell logger CR10x.

All psychrometers are connected to the Campbell logger CR7.

4.9.3 Fibre optic system

The fibre optic cable installed on the canister surface measures the canister surface temperature. The fibre optic logger was at first placed inside the backfill container but was after one year moved to the Prototype container. The logger consists of an electrical cabinet with an integrated computer, which is connected to the Äspö data network.

5 Installation of test package

5.1 Climate control system

The dehumidifier, fan and control devices, except the hygrometer, were placed outside the wall separating the test site from the untreated tunnel air, see Figure 4.8-11. Treated air from the main duct was distributed to six ventilation hoses. Five of the hoses were installed in the gap between the bentonite rings and the borehole wall and the last one was an extra hose to be installed in the centre of the tube of rings if deemed necessary. They were removed before the gap was filled with pellets. To observe and regulate the relative humidity, five sensors of type Regin HRT250 were installed in the deposition hole. Four of the sensors were installed at different levels in the gap between the rings and the borehole wall. Two at of them were installed at the same level as the bottom block and the other two at the same level as ring number five. The last sensor were installed outside the Canister Retrieval Test site (outside the separating wall) to measure the relative humidity variation in the tunnel system before the air for the test was dehumidified. Three of the sensors also measure temperature. Data were stored in a portable computer and visualised with the program WinLog.

5.2 Buffer saturation system

The system is described in chapter 4.5. Figure 5.2-1 shows a picture of the mats and the water supply plant after installation.

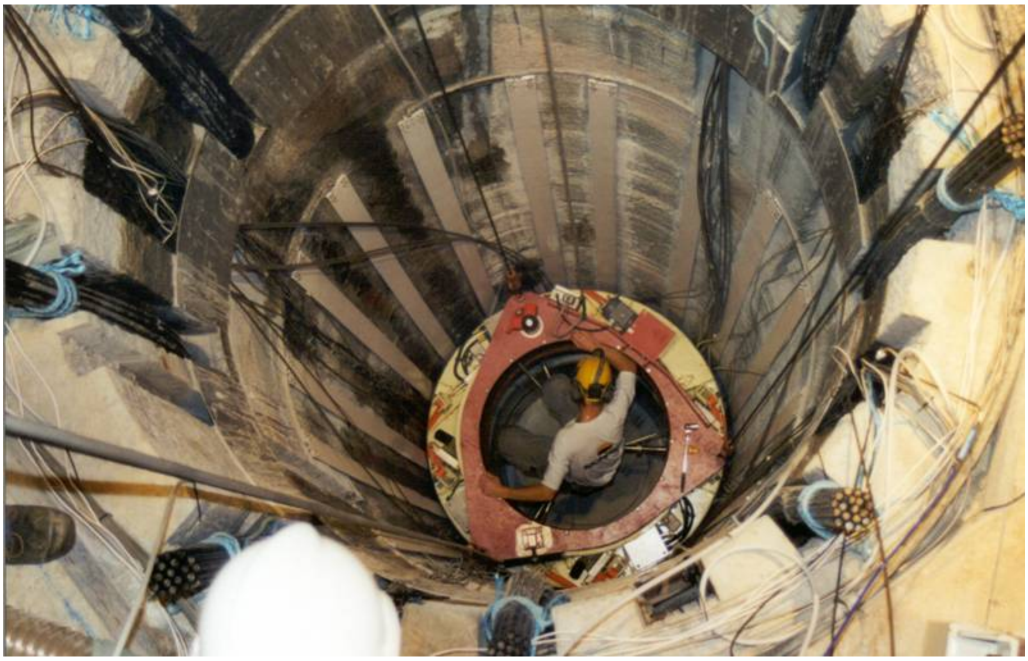


Figure 5.2-1. *The deposition hole after installation of mats (upper) and the water supply plant (lower).*

5.3 Bentonite buffer

5.3.1 General

The installation of the bentonite buffer and instruments can be divided into the following phases:

1. Preparation of blocks for instruments and cables
2. Placement of blocks in the deposition holes
3. Installation of instruments and cables in the blocks
4. Placement of bentonite bricks
5. Addition of pellets and water to the gap

Phase 1, 2, 4, and 5 will be described in this chapter, while phase 3 will be described in chapter 5.7.

5.3.2 Installation description

After compaction the bentonite blocks were enclosed in airtight boxes and brought to the canister laboratory in Oskarshamn. The dimensions of the blocks were measured very carefully for the purpose of planning the position of each block in the hole. Both the block sequence and the angular direction were prescribed. The angular direction was important in order to get a completely vertical pile of blocks since the height of the blocks varied a few mm within a block

The blocks needed to be prepared for installation of both instruments and cables by drilling holes and cutting slots in the blocks. Preparation was done before transportation to the Äspö HRL. The instruments were, however, not installed until after emplacement of each block in the deposition hole. The cables were run in slots on the upper surface of the blocks and spread in a pre-planned manner to the periphery of the blocks. The aim was to run the cables to different parts of the periphery so that no cable was in direct contact with another cable.

Before installation the blocks were transported in their boxes to an interim storage facility at the test site. Some of the instruments in the bottom block needed to be installed in the block before the block was placed in the hole. After installation of the bottom block the rest of the instruments in that block were installed and the tubes run up along the rock wall and temporarily fixed to the wall in the prescribed manner. Then the ring-shaped blocks were placed one by one and the instruments gradually installed in the blocks.

The upper ring-shaped block was expected to reach 20-25 cm above the lid of the canister. The thick cables from the canister were run in slots in the upper block to the slots in the rock wall all the way up to the floor. The 1.07 m diameter empty space on top of the canister was filled with bentonite bricks. The three final upper blocks were then installed.

Before installation of the final block all cables and tubes from the instruments were collected, inserted into the slots in the rock and run up to the floor.

After completed emplacement of all blocks the gap between the blocks and the rock was filled with bentonite pellets and then immediately filled with water from the tubes that ended in the bottom of the hole.

A rubber mat was placed on top of the upper block and the plug cast directly after water filling. A great effort was made to minimise the time between water filling and casting of the plug in order to minimise the swelling of the bentonite.

During preparation and installation the blocks were given new designations (see Figure 1-2). The first block was named CRT1-C1 and the ring-shaped blocks were named CRT1-R1 to CRT1-R10 (with CRT1-R1 placed on the bottom block and so on). The cylindrical blocks placed above the canister were named CRT1-C2 to CRT1-C4, where CRT1-C2 was placed on the last cylindrical block.

5.3.3 Preparation of blocks

5.3.3.1. Handling of blocks

The bentonite blocks are very sensitive to changes in the surrounding relative humidity (RH). The blocks were kept in tight boxes during storage (see Figure 5.3-1). General goals during preparation and handling, when a box was open or when the blocks were installed, were to ensure that:

1. the relative humidity was kept between 75 and 80%
2. if the blocks were exposed to either lower or higher relative humidity the duration of exposure was limited to about half an hour.

***Figure 5.3-1**. Boxes for storage and transportation of the blocks.*

5.3.3.2. Excavation of slot for the canister

The bottom of the canister is not flat. At the periphery of the bottom there is a collar (a skirt) with a thickness of 100 mm and a height of 75 mm. A slot or recess had to be made on the bottom block for the collar in order to ensure the density of the buffer close to the bottom of the canister. The recess had a width of about 120 mm and a depth of about 80 mm (see Figure 5.3-2).

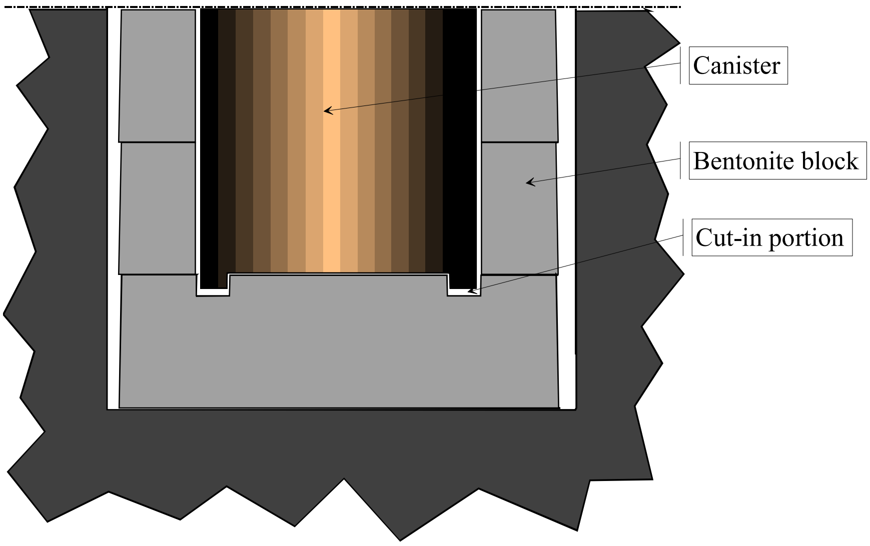


Figure 5.3-2. *Schematic drawing of recess in bottom block.*

The slot was made in the following sequence:

1. The block was transported to the preparation area by a forklift truck, and the cap over the block was removed from the pallet.
2. The shape of the recess was marked on the upper surface of the block.
3. A drilling machine with a drill bit with a diameter of 117 mm was placed on the top of the block
4. Overlapping drilling (see Fig 5.3-3) was done to cut the recess down to a depth of 80 mm.

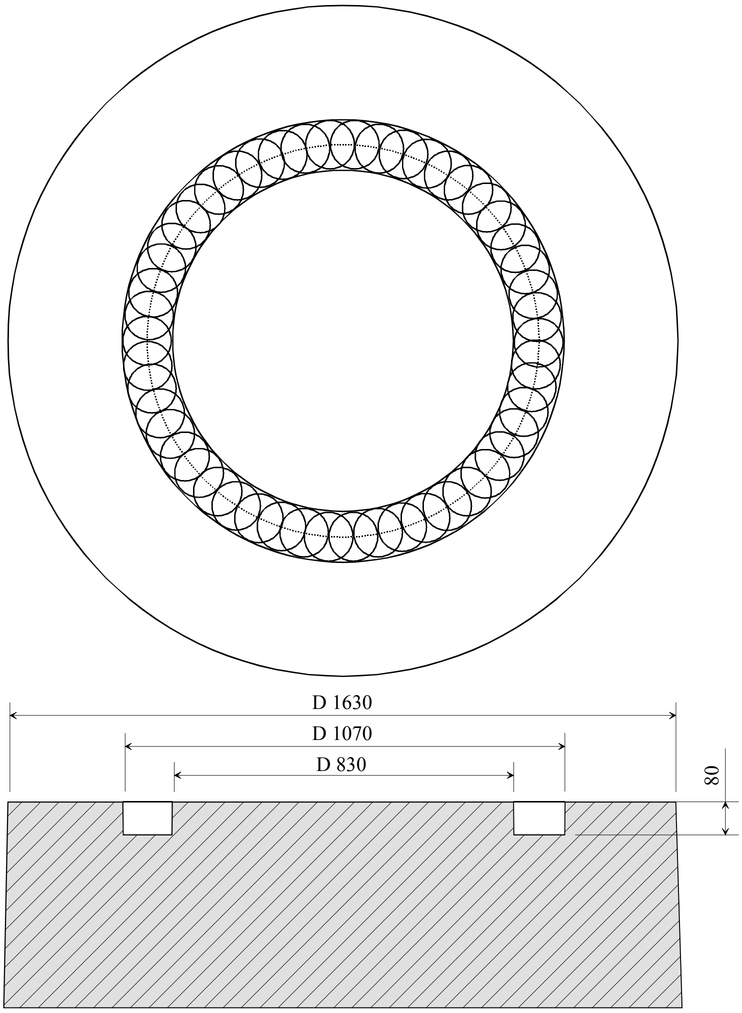


Figure 5.3-3. Recess in bottom block.

5.3.3.3. Holes and slots for instruments and cables

A detailed description of the instrument positions was given in section 3.8.4. This section describes how the titanium tubes with cables were placed, i.e. in what direction they were run out to the periphery of the blocks and to which slot they went in order to pass the plug, as well as the work with drilling of holes and cutting of slots.

5.3.3.4. Strategy for describing the position of each device

See section 4.8.4.8.

5.3.3.5. Working procedure

- The container with the block to be prepared was placed in the room with RH set to 75-80%. The cap was removed and the block exposed.

- The centre of the block was defined with a special tool. All directions, A, B, C and D were marked. The radius was marked with a pair of compasses (r-coordinate).

- The positions aside from the four main directions were marked where necessary with a protector and a ruler.

- Holes for the thermocouples were drilled with the handheld drill. The holes for the rest of the instruments were drilled with the Hilti machine and a core drill. The stand for this machine was fastened to the block surface with a vacuum plate.

- During drilling of the instrument holes, the positions of the cable tubes were marked on the periphery of the bentonite block.

- Using the handheld cutter, tracks were cut from the instrument hole out to the periphery. The dimensions of the tracks depended on the instrument types. The thermocouples have a diameter of 4.5 mm, which means that the tracks were made with a 5 mm cutter. The other instrument cables are run in titanium tubes with a diameter of 6 or 8 mm.

When the work was finished and approved, the block, the holes, the tracks and the container were vacuumed. The cap was put in place and fastened.

5.3.3.6. Cables and tubes on the block periphery

All cables and tubes from the instruments in the bentonite blocks, from the thermocouples in the rock and from the filter mats, the two 12 mm signal cables from the canister and the four fibre optic cables from the canister were run up in the gap between the rock and the blocks, along the peripheral surface of the bentonite block. In order to pass the concrete plug, slots were cut in the rock (Figure 5.3-4). The other cables from the canister (2 x 38 mm power cable and 2 x 38 mm signal cable) were run directly into slots on a level with the upper surface of the canister. The other cables and tubes entered the slots about 700 mm below the cement plug.

Since many cables and tubes were run in the gap between rock and bentonite in the deposition hole (about 180 units) it was important to distribute them on the block periphery in the prescribed order. Each cable or tube has an α−coordinate (See chapter 4.8.4.8), which is the angle from direction B (see Fig 4.8-5). The cable or tube was run in this position on the bentonite block periphery. The tubes and cables were held in place by expandable straps.

The bentonite block periphery was divided into sections, where the cables and tubes within each sector were predestinated for a special slot (Table 5.3-1).

Cables and tubes from instruments in the bentonite

All instrument cables were run in titanium tubes (Ø 8 mm or Ø 6 mm) except for the thermocouples (Ø 4.5 mm), which were made of cupro-nickel. Tracks were made on the block surface from the instrument position in the bentonite block to the determined position on the bentonite block periphery. They were bent and run axially along the bentonite block.

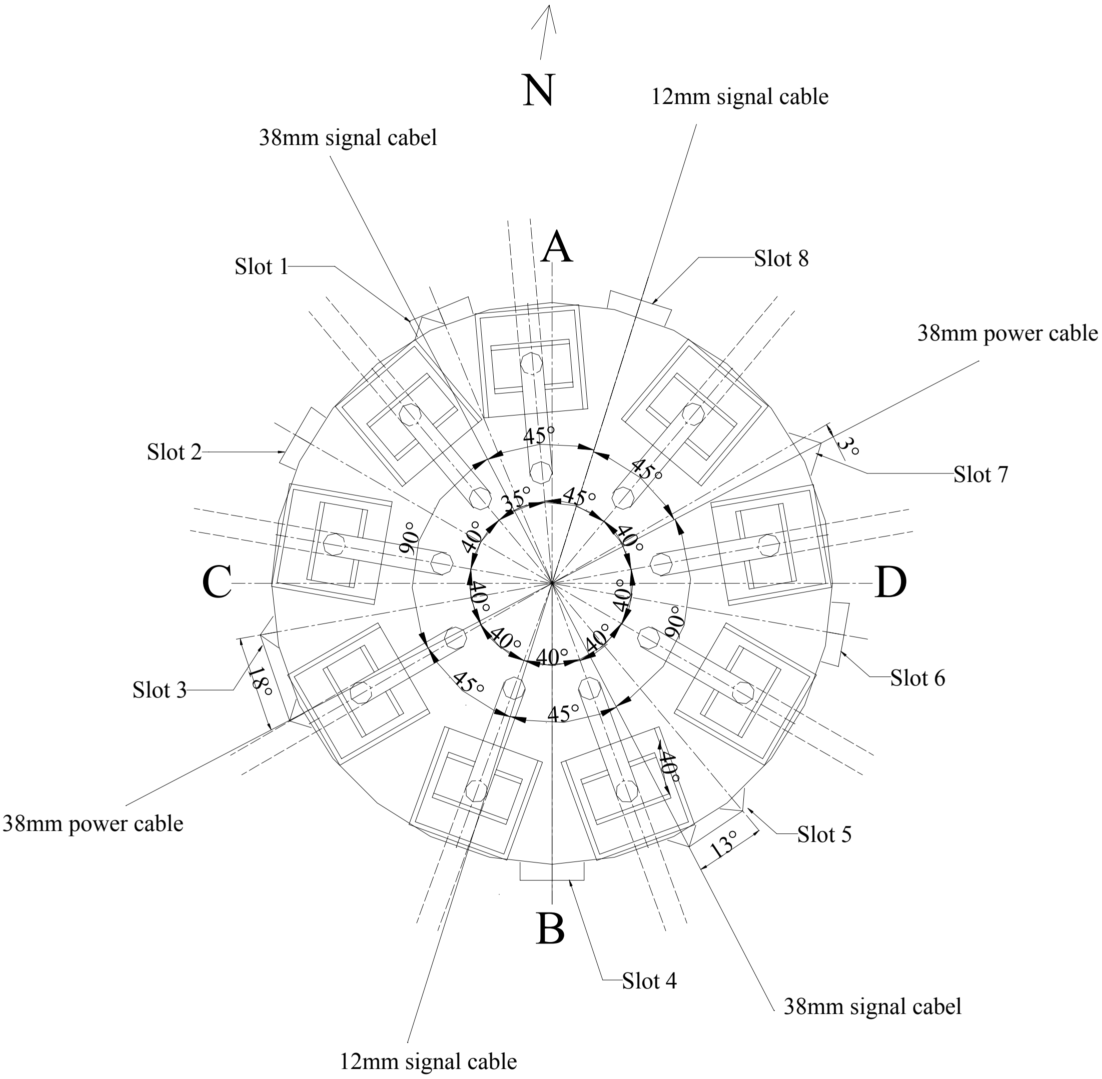


Figure 5.3-4. *Schematic view of deposition hole, showing the position of the slots relative to the rods and the cables from the canister.*

Table 5.3-1. Table showing how the cables and tubes are distributed in the slots in deposition hole DD0092G01.

Slot 1

Instrument No.	Cable position α
W121	182
W06	184
P105	186
P112	188
W138	190
P120	192
T125	194
W137	196
P119	198
T124	200
T105	202
P104	204
T104	206
Optic Fiber	207
P103	208
38mm Signal	210
	212
W136	214
P118	216
T112	218
W120	220
P111	222
T111	224
W119	226
P110	228

Slot 2

Instrument No.	Cable position α
T103	230
P102	232
W103	234
U102	236
T102	238
W102	240
T101	242
P101	244
U101	246
W101	248
W116	250
W117	252
W118	254
U109	256
T116	258
T117	260
T118	262
U110	264
W148	266
W149	268
P109	270
W150	272
T107	274
W154	276
P108	278
OpticFiber	280
T131	280
38mm El.Out	282
P124	284
P123	286
W133	288
P116	290
W132	292
W131	294
P115	296

Slot 3

Instrument No.	Cable position α
38mm El.In	300

Slot 4

Instrument No.	Cable position α
W113	302
W110	304
W114	306
W111	308
W115	310
W128	312
U107	314
W125	316
T113	318
2 x Optic Fiber	320
W129	322
T114	324
T115	326
W145	328
W142	330
W146	332
W143	334
W147	336
W144	338
	340
	342
12mm Signal	344
W130	346
U108	348
W127	350
	352
	354
W153	356
T130	358
W112	360
P107	2
	4
TR105-TR108	6
	8
TR117-TR120	10
	12
TR129-TR132	14
P114	16
P122	18
P121	20
W134	22
P117	24
W135	26
	28
38mm Sig.In	30
	32
W126	34
P113	36
T106	38
P106	40

Slot 5

Instrument No.	Cable position α
38mm Sig.Out	42

Slot 6

Instrument No.	Cable position α
T119	44
T120	46
T121	48
T122	50
T123	52
T126	54
T127	56
T128	58
W155	60
U114	62
P127	64
T132	66
	68
	70
	72
TR101-TR104	74
	76
TR109-TR112	78
	80
TR121-TR124	82
	84
TR133-TR136	86
	88
	90
T110	92
T109	94
T108	96
	98
	100
	102
	104
	106
	108
	110
	112
	114
	116

Slot 7

Instrument No.	Cable position α
	118
38mm El.	120
	122

Slot 8

Instrument No.	Cable position α
W107	124
U103	126
W104	128
W108	130
W105	132
W109	134
W122	136
U105	138
W123	140
W124	142
W139	144
U111	146
W140	148
W141	150
U112	152
W151	154
U113	156
P125	158
W152	160
P126	162
12mm Signal	164
T129	166
TR113-TR116	168
	170
TR125-TR128	172
	174
TR137-TR140	176
U104	178
U106	180

Cables from the canister

The following cables are run from the canister:

- 2 x 38 mm power cables for the electrical heaters
- 2 x 38 mm signal cables from strain gauges inside the canister
- 2 x 12mm signal cables from strain gauges on the canister surface
- 4 x 2 mm fibre optic cables (two loops) from the temperature sensors on the canister surface

Figure 5.3-5 shows how the cables were run from the canister through the bentonite to the rock.

The cables were run in slots that had been sawn in advance in block No. R10 (see Figure 5.3-5). The four 38 mm cables were then run directly into slots in the rock, but the two 12 mm signal cables and the four fibre optic cables were run up along the peripheral surface of the bentonite block and entered the slots in the rock about 700 mm below the cement plug.

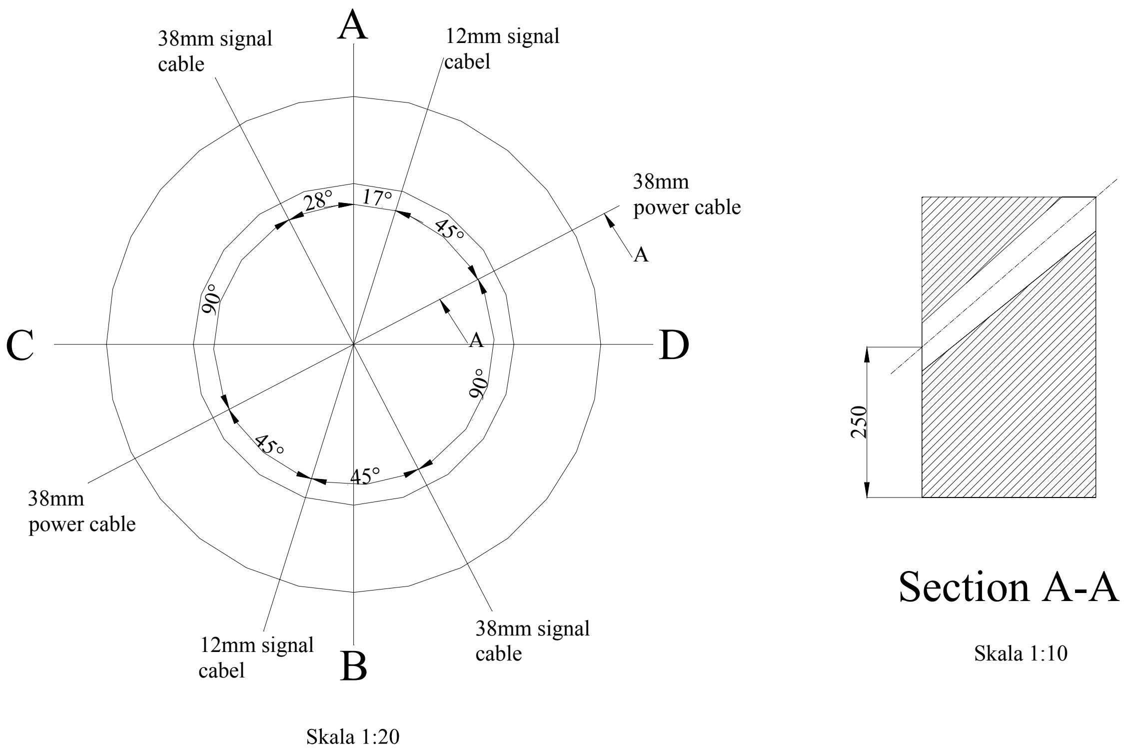


***Figure 5.3-5**. Figure showing the directions of cables from the canister in relation to the instrument directions A, B, C and D. In this block (R10) slots were made in order to let the cables pass through the bentonite and out to the slots in the rock. The fibre optic cables ran in the same direction as the 38 mm power cables.*

Preparation for instruments

Each instrumented block was prepared in advance, i.e. most of the bentonite work was done on the ground in a laboratory. The preparation was somewhat different depending on the type of instrument.

Thermocouples

The thermocouples have an outside diameter of 4.5 mm. A handheld drilling machine with a 5.0 mm drill was used for installation.

Total pressure

- Geokon. This device has an outside diameter of 25 mm and a length of 117 mm. The holes for these gauges were drilled with a drilling machine (Hilti) attached to a vacuum plate.

- Kulite. This device is shaped like an ice hockey puck with a diameter of 55 mm and a thickness of 23 mm. The instruments were countersunk in the bentonite block surface by means of a handheld cutter.

Pore pressure

- Geokon**.** This device has an outside diameter of 25 mm and a length of 127 mm. The holes for these gauges were drilled with the same equipment as the holes for Geokon total pressure cells.

- Kulite**.** This device has an outside diameter of 19 mm and a length of 55 mm.. The holes for these gauges were drilled with the same equipment as the holes for Geokon total pressure cells.

Water content

- Vaisala**.** This device has an outside diameter of 22 mm and a length of 63 mm. The holes for these gauges were drilled with the same equipment as the holes for Geokon total pressure cells.

- Wescor. This device has an outside diameter of 22 mm and a length of 35 mm. The holes for these gauges were drilled with the same equipment as the holes for Geokon total pressure cells.

Figure 5.3-6 shows a picture taken during preparation of bentonite ring R10.

***Figure 5.3-6**. Preparation of bentonite ring R10.*

5.3.4 Placement of blocks in the deposition hole

The hoisting equipment with the bentonite block was positioned in the centre of the deposition hole with the positioning device. To assure that the hoist would return to the same position for deposition of each block, the stopper on the crane was fixed in the right position.

Deposition of the bottom and the rings block included the following activities:

1. Positioning of the centre of the hoisting equipment over the centre of the hole.
2. Rotation of the gripping device to assure that the block was correctly orientated in the hole.
3. Check that the gripping device was horizontal.
4. Lowering of the block to a level approximate 20 centimetres above the concrete slab or bentonite block.
5. Visual check of the position of the block as it was slowly lowered the last 20 centimetres.

6. Check of the position of the block by optical planets /4-2/.
7. Release of the bentonite block from the gripping device.
8. Check of the exact position of the block.

Figure 5.3-7 shows placement of a bentonite ring and Figure 5-3-8 shows the deposition hole after placement of block C2.

Figure 5.3-7. *Placement of a bentonite ring.*

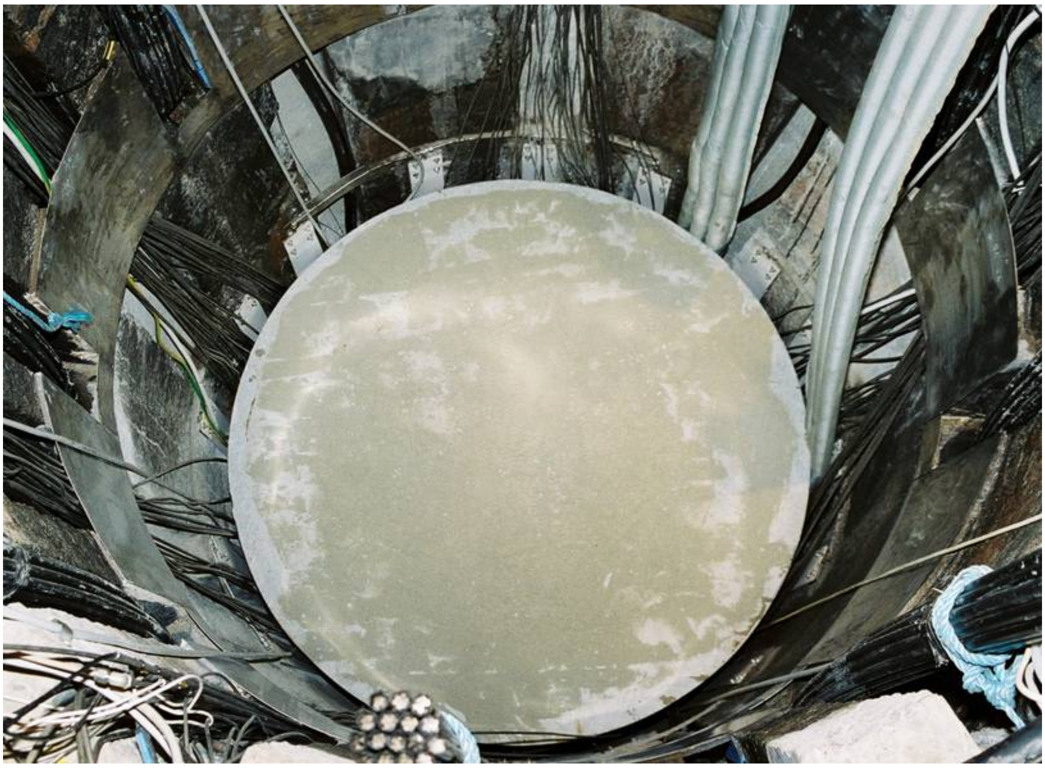


Figure 5.3-8. *The deposition hole after placement of block C2.*

The average dry density of the buffer material that was achieved between the canister and the rock (including the ring and the gap with pellets) is 1586 kg/m^3 assuming a hole diameter of 1.762 m. This corresponds to a density after saturation of 2015 kg/m^3.

The average dry density of the buffer material that was achieved above and below the canister (including the with pellets) is 1618 kg/m^3 assuming a hole diameter of 1.762 m. This corresponds to a density after saturation of 2036 kg/m^3.

5.3.5 Emplacement of bentonite bricks on canister lid

The space left between the top of the canister and the top of the last ring-shaped block was filled with small bentonite bricks as shown in Figures 5.3-9 and 5.3-10. The average height of 10 ring-shaped blocks exceeds the height of the canister by 217 mm. In order to get the same density at saturation at the top of the canister as in the rest of the buffer, the bulk density of the volume filled with bricks should be about 1930 kg/m^3 at a water ratio of 17%. The measured bulk density of the bricks after production was higher and the difference was taken care of by leaving some gaps between the bricks. Table 5.3-2 shows the basic data for the filled space.

Table 5.3-2. Basic data for the space filled with bricks, pellets and bentonite powder.

Total volume	0.195 m^3
Weight bricks+powder+pellets	367 kg
Average water ratio	16%
Average dry density	1616 kg/m^3

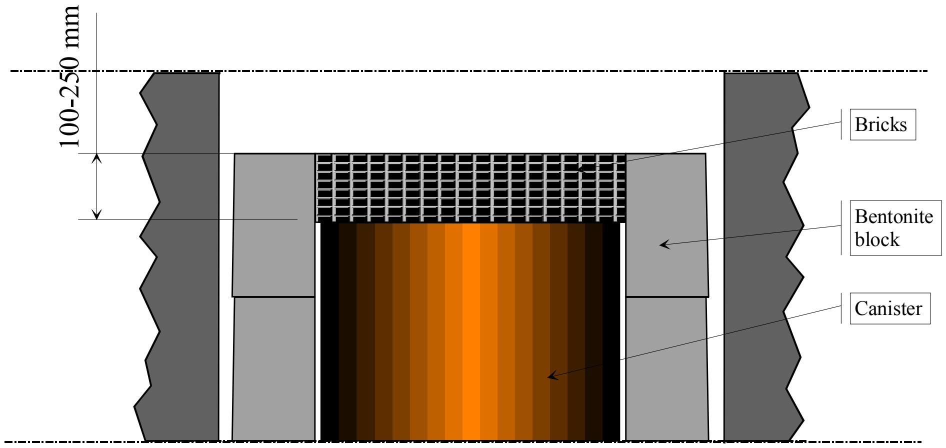


Figure 5.3-9*. Schematic illustration of bricks placed on top of the canister.*

Emplacement of the small bentonite bricks took place as follows:

1. Bricks were transported down to the top of the canister in a basket.
2. The bricks were emplaced by hand. The weight of each brick is about 4 kg.
3. In order to fill the space above the canister lid some of the bricks had to be cut into smaller pieces. This was done with a band saw.
4. Some bricks were prepared in advance for instruments and cables. To get the right position of the instruments in the bricks, some of the bricks had to be cut into smaller pieces
5. All bricks that were emplaced were weighed to permit calculation of the final bulk density. Some gaps between the bricks were filled with bentonite powder.

The average bulk density of the space above the canister after filling was 1882 kg/m^3, which corresponds to a dry density of 1616 kg/m^3.

The average dry density of the buffer material that was achieved in this part of the hole (including the ring and the gap with pellets) is 1618 kg/m^3 assuming a hole diameter of 1.762 m. This corresponds to a density after saturation of 2036 kg/m^3.

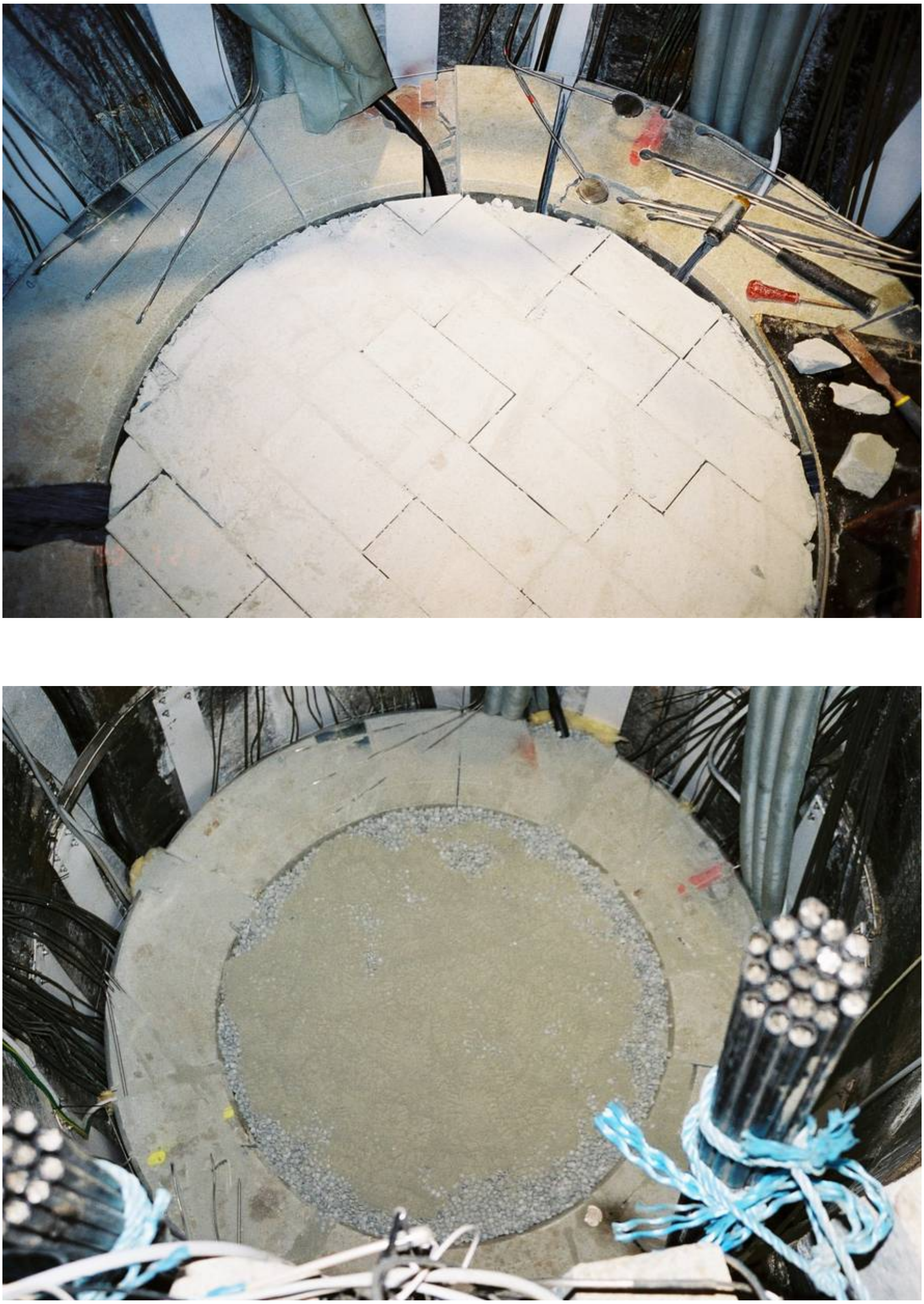


***Figure 5.3-10**. Pictures taken after emplacement of the bentonite bricks on top of the canister (upper) and after supplementary filling with pellets and powder (lower).*

5.3.6 Filling the gap with pellets and water

5.3.6.1. Pellets

In order to get a buffer with a sufficiently high density, the gap between the bentonite blocks and the rock surface was filled with bentonite pellets. The bentonite pellets had a width and length of about 16.3 mm and a maximum thickness of about 8.3 mm. The bulk density of an individual pellet varied between 1970 and 2110 kg/m^3 and the water ratio of the pellets was $w \approx 10\%$. The expected bulk density of the pellet filling was between 1100 and 1300 kg/m^3.

The pellets were placed in the gap after all the bentonite blocks had been emplaced and the gap was drained before and during the filling procedure.

The filling sequence was:

1. The pellets were delivered in big bags. Three big bags were transported to the test site. The pellets left over after filling were also weighed.
2. Four tubes with a diameter of 12 mm and a length of 8.0 m were placed in the gap (for subsequent filling with water)
3. The pellet blowing machine was filled with pellets and the pellets were blown into the gap through a specially designed nozzle. This was done from the upper bentonite block (C4).
4. Filling worked very well, but dust was a major problem.

The total weight of pellets in the filled gap was 2576 kg. Assuming a gap width of 0.055 m, an average hole diameter of 1.762 m (which was measured) and a height of 7.07 m, the average estimated dry density in the gap after filling is 1020 kg/m^3, which is lower than expected (1130 kg/m^3), probably due to the fact that all cables are located in the gap.

5.3.6.2. Water

The voids between the pellets in the gap were filled with water. To assure that all the voids between the pellets would be filled, the water was fed into the gap from the bottom of the deposition hole. Four tubes with an outside diameter of 10 mm and a length of 8 m (placed in the gap before it was filled with pellets) were used to fill the gap with water. The tubes were gradually withdrawn as water was added in order to prevent the swelling bentonite from sealing the water transport pathways. The total volume of water needed was estimated to be about 800 litres. Site water was used for this purpose. It was taken from hole HD0025 in the D-tunnel.

Filling of the voids with water was done as follows:

1. The four tubes were connected to a pump with tecalan tubes and connectors.
2. Water was added to the gap by pumping water from a reservoir at a flow rate of about 25 litres per minute.
3. When about 115 l had been filled with water (corresponding to 1.0 m in the pellet-filled gap), pumping was stopped and the tubes were pulled up 1.0 m). The procedure was then repeated and continued until the water table was visible at the top of the pellet filling. The degree of filling was also checked by measuring the water volume.

About 950 l of water was added to the gap.

5.4 Canister (including heaters)

Installation of the canister into the deposition hole was carried out in a number of sequences as described below. Since the bentonite rings were already installed, correct positioning and alignment of the deposition machine and canister was of the utmost importance.

Deposition of the canister included the following activities:

1. Mounting of stools for placement of the deposition machine over the hole
2. Positioning of the deposition machine on the stools
3. Removal of transport vehicle for the deposition machine
4. Mounting of canister lid and lifting yoke
5. Raising of canister to a vertical position, see Figure 5.4-1
6. Fine adjustment of canister position
7. Lowering of canister into deposition hole
8. Detachment of lifting yoke

Figure 5.4-1. *Raising of canister to an upright position*

5.5 Retaining plug

The retaining system is designed to allow small vertical displacements initially. Thus, the concrete cone was test lifted before the steel lid and the rock ties were installed. The concrete cone was cast using a mould made of stainless steel with a thickness of 2 mm. The mould was coated with mould release oil to ensure that the lifting of the concrete cone would be possible. This procedure was carried out to ensure that no constraint was induced by the concrete cone.

The lid is made of steel of grade S 355JR. The diameter of the steel lid is 1738 mm. The thickness of each steel lid is 150 mm. The lid is shown in Figure 4.7-2. The recesses permit the rock ties to anchor the structure. Nine rock ties, evenly spaced on the perimeter of the lid, are used to pre-stress each lid. Each rock tie consists of 13 $\phi 19$ with an ultimate load capacity of 3530 kN. The rock ties have each an anchorage length of 5 m and a free length of 5 m. As measurements are to be carried out, the plugs had to be flexible enough to allow a pre-defined behaviour. The work description describes the pre-stressing procedures in detail. These procedures include two phases, one for lower load levels and one for higher load levels. In the first phase only three rock ties were pre-stressed. In the second phase all rock ties were pre-stressed.

A special arrangement of triangular blocks, welded onto the steel lid, was designed to permit the rock ties to be installed in the correct position with the correct slope. The hydraulic jacks were placed on top of these blocks but before the lock bolt.

To permit the rock ties to be installed in the rock, holes with a diameter of 120 mm were drilled. The slope of these holes was 2.5:1. The covers were removed after the end of the measurement and evaluation period was finished. Slits were cut out of the rock to permit the removal of the ties and the covers after the end of the test period. Two of these slots can be seen in Figure 4.7-2.

5.6 Instruments

5.6.1 Installation of instruments and cables

5.6.1.1. Instruments in bentonite

The instruments were installed in the different blocks after placement of each block. Installation was carried out in the following manner:

- Block C1 was lowered and positioned in the deposition hole.
- Instruments for the block were collected and marked according to the instrument plan.
- The instruments were then placed in the bentonite. The instruments were installed in their holes and the tubes were bent in order to fit the tracks in the blocks out to the periphery of the bentonite block. A new bend was then made outside the block to enable the tubes to go up along the rock surface. The thermocouples were very easy to bend by hand, but tools were required for the tubes from the other instruments (titanium tubes ø6 and ø8 mm)

- The tubes from C1 were then fastened to the rock surface of the deposition hole in at least two points on their way up. This was done with expandable rings that pressed the tubes against the rock. This was an important procedure in order to facilitate the installation of the next block.
- Block R1 was then lowered and positioned. The tubes from the instruments in C1 were fastened around the periphery of R1 with straps.
- Block R2-R5 were then lowered and positioned. The tubes were fastened around each block in a prescribed pattern.
- New instruments were installed in block R5. They were handled in the same way as the instruments in C1.
- Blocks R6-R10 were lowered and installed. The tubes were fastened around each block.
- The canister was installed after block R10.
- Block R10 was instrumented. Since the upper surface of block R10 ended about 20 cm above the copper canister the central hole was filled with bentonite bricks and instrumented. Fig 5.6-1 shows the instruments in the bricks. These bricks were prepared in advance in order to facilitate instrument installation. After emplacement of the cables from the canister (see below) blocks C2 and C3 were placed.
- The instruments in block C3 were positioned in the same way as the instruments in block C1. Figure 5.6-2 shows the instruments in block C3.
- Finally, block C4 was lowered, positioned and instrumented.

5.6.1.2. Cables from the copper canister

Since the cables from the canister came through the middle (vertically) of ring R10, slots had to be made in this block as shown in Figure 5.6-3. The following technique was used:

Slots were sawn from the upper surface of the block, sloping from the periphery of the block down to the middle. The advantage of this technique is that the installation of the cables was easy. The disadvantage was that it greatly reduces the strength of the block, which could result in a broken block during handling. Fig 5.6-3 shows a picture after installation of some of the instruments in ring R10.

***Figure 5.6-1**. Picture taken after placement of the bentonite bricks on top of the canister and installation of three instruments.*

***Figure 5.6-2**. Picture taken after placement of bentonite block C3 and installation of the instruments.*

Figure 5.6-3. *Picture of the upper ring (R10) taken after placement of the canister and installation of the instruments. The big radial slots are for the fibre optic cables on the canister surface (left) and the cables from the thermocouples and strain gauges in the canister. The two pucks are total pressure gauges and the six holes contain relative humidity sensors.*

5.6.2 Instrumentation of the rock

Configuration and installation of stress and vertical strain gauges

The stress monitoring programme includes measurements of stress changes around the deposition hole in four cored boreholes parallel to the deposition hole. The installation holes (diameter 60 mm) were drilled 0.3 m from the periphery of the deposition hole at four perpendicular locations, Figure 5.6-4. The initially planned installation depths were 4 and 7 m. (The installation depths in the deposition hole not included in the saturation phase were 1 and 4 m). The final locations differ from the planned to avoid fractures or other discontinuities that may affect stress monitoring on a smaller scale. Final locations are presented in Table 5.6-1 and Figure 5.6-4.

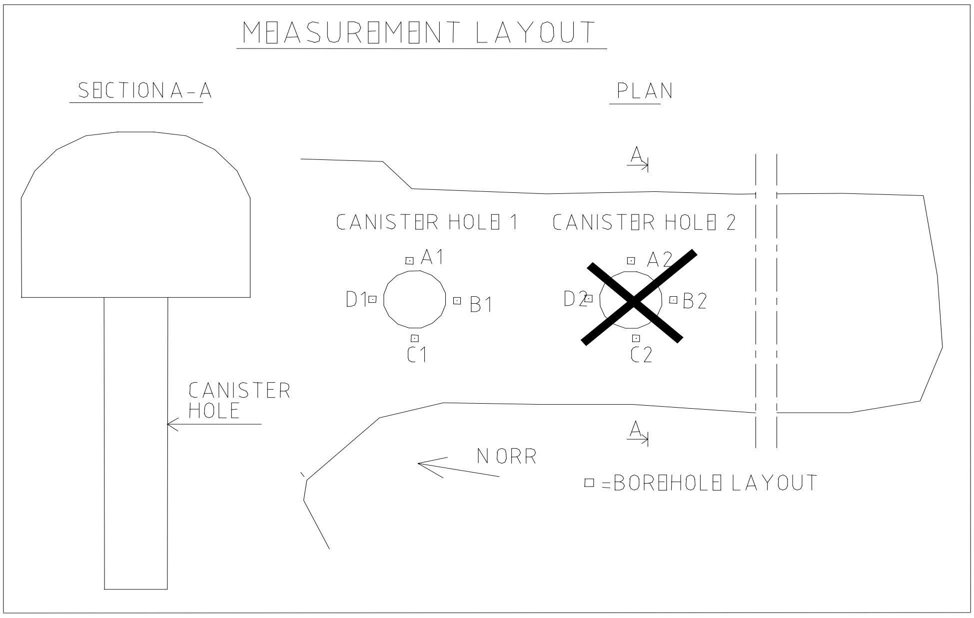


***Figure 5.6-4.** Layout and identification of boreholes around the canister hole*

A total of 6 strain gauges were installed over observed fractures. Table 5.6-1 shows installation depth and horizontal or steeply-dipping fracture.

Table 5.6-1. Installation position and depth of stress and vertical strain gauges

Stress gauges	**Installation hole**	**Installation depth**	**Rock structure**
	A1	3.90	Intact rock
	B1	6.90	Intact rock
	C1	6.95	Intact rock
	D1	4.05	Intact rock
Strain gauges			
	A1:1	1.46	Fracture horizontal
	B1:1	1.55	Fracture horizontal
	C1:1	3.03	Fracture horizontal
	C1:2	1.55	Fracture horizontal
	D1:1	2.37	Fracture steep
	D1:2	1.95	Fracture steep

Installation of the gauges where accomplished by inserting the gauge into the grout-filled 60 mm diameter borehole.

Special cement, Densitop T2, was used to insure that the grout had properties close to those of the intact rock. Typical values from laboratory tests of the grout have revealed a uniaxial compressive strength of 192+/- 13 MPa and a Young´s modulus of 52 +/- 1 MPa.

The stressmeters were positioned in non-fractured parts of the rock mass. The installation sequence was carefully planned in order to get the instrument positioned at the pre-selected depth. The gauge was pushed into the grout and orientated so that the first vibrating wire (V_r1) was positioned tangentially to the canister hole. The borehole was completely filled with grout after positioning.

The strainmeters were fixed to a glass fibre rod and located at the selected depth in the borehole before the grout passed the location.

Temperature gauges

The temperature monitoring programme includes measurements of temperatures radially from the canister hole and from bottom. Radial measurements are monitored in three directions at three levels. Three directions are chosen in order to identify potential anisotropic heat flow.

Holes for installations were drilled radially from inside the deposition hole in three directions and at three levels, see Table 5.6-2 and Figure 5.6-5. One vertical hole was also drilled centrically in the bottom. The monitoring profiles are located to match the location of monitoring profiles in the buffer. The holes drilled in the periphery of the deposition hole were inclined 10° in order to ensure that the thermocouples were perfectly embedded in the grout material.

Table 5.6-2. Data on holes for installation of thermocouples.

Number of holes per level	Level from levelled bottom [m]	Hole length [m]	Inclination from horizontal [°
1	0	1.70	
3	0.61	1.55	
3	3.01	1.55	
3	5.41	1.55	

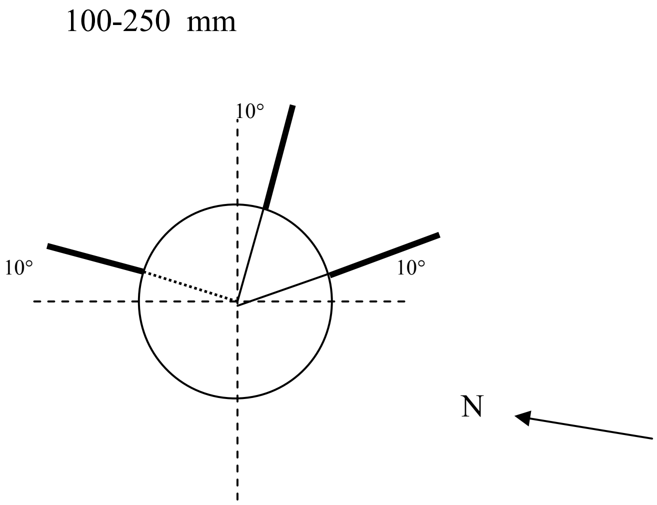


Figure 5.6-5. *Plan view of the orientation of the radial holes for temperature gauge installation.*

Three thermocouples type K were installed in each hole at three different distances from the surface of the deposition hole wall: 0.375-m, 0.75 m and 1.50 m.

In all, 30 thermocouples were installed.

After the thermocouples had been positioned at the exact location in the holes, the holes were filled from the bottom up with cement grout.

5.7 Data acquisition system

In general the sensors were connected to the data acquisition system as soon as they were in place and cables had been routed. The system consists of a measurement computer and a few different kinds of dataloggers. The computer and the Campbell datalogger CR-7 are located in the container for the Backfill and Plug test and the other dataloggers are placed next to the experiment. The measured values are transferred via a serial link from the dataloggers to the measurement computer. The Orchestrator software, which is Äspö's measuring programme, was installed. The computer is connected to Äspö data network.

6 Launching of test

6.1 Introduction

It was very important that all installations and equipment were complete before the start of the test. Filling with pellets marked the point of no return, after which there could be no interruptions if any preparations had been overlooked or had failed. It was thus very important to ensure the following, related to the start procedures, before the start of pellet filling:

1. That all instruments were connected to the data collection system and their function verified.
2. That the heaters were connected to the power generation system.
3. That the system for supplying water to the bentonite (by filling the mats with water, pressurising the water and measuring the water inflow) was complete with all tubes, pressure tanks and flowmeters installed and checked.
4. That preparations for building the plug were completed so that there would be no delay.

6.2 Test start

Since pellet filling marks the start of the test, the best description of the launching of the test is a step-by-step description of the procedures from that point in time.

1. Before the pellets were blown into the gap, all preparations described in Chapter 5 (instruments, heaters and wetting system installed) were finished and the tubes for the drainage (pumping) system were removed along with the tubes and transducers for the ventilation system
2. Data collection was started immediately before pellet filling
3. The gap was filled with pellets on October 26, which thus can be considered the starting date
4. Water was pumped into the gap and the filter mats, and the water supply tubes were withdrawn immediately after pellet filling.
5. Measurement of water inflow into the filters started immediately after water filling
6. The rubber mat was placed on top of the upper block
7. The cable slots behind the conical ring were sealed with cement
8. The plug was cast when all preparations had been finished. Not more than 12 hours were allowed to pass between water filling and casting

9. Heating was started with an initially applied constant power of 700 W on October 27, i.e. one day after test start
10. Three prescribed rods were locked on October 31 and the force and displacement transducers installed
11. Between test start and locking of the rods (5 days) the plug rose 13 mm due to swelling of the bentonite.
12. The displacements and forces on the plug were carefully monitored
13. When the total force exceeded 1500 kN, the remaining rods were fixed in a prescribed manner. This procedure took place 12-14 December, i.e. 46-48 days after test start
14. The canister heating power was raised twice: to 1700 W on November 13 and to 2600 W on February 13.

7 References

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