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Äspö Hard Rock Laboratory

Canister Retrieval Test

Test Plan

Part 1 – Geotechnical characterisation, test installation and monitoring during saturation

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November 1999

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ABSTRACT

One of the full-scale tests in the Äspö HRL target area "Demonstrate technology for and function of important parts of the deep disposal system" is the Canister Retrieval Test, which comprises two parts:

Part 1: Installation of buffer and canister in two deposition holes followed by monitoring of the saturation process

Part 2: Freeing of the canisters from the buffer after that the bentonite has swollen followed by retrieval of the free canisters

This Test Plan presents the work of Part 1.

Today the tunnel has been excavated by drill and blast and the two holes bored with a down-the-hole machine with a nominal diameter of 1.75 m. Both holes are about 8.5 m deep measured from the concrete floor in the tunnel.

Bentonite blocks and canisters with heaters will be installed and the holes sealed with a concrete plug in the top part. The holes are very dry and artificial saturation is deemed necessary. Permeable filter mats are installed as stripes along the wall of the holes, and formation water is fed via them to the bentonite. Bentonite pellets and water are added to the hole as part of the deposition process in accordance with the measures that are found appropriate after testing the deposition process in "Test of Deposition Process". The latter is a supporting task, which is carried out prior to installation. It has the aim of testing the equipment to be used as well as the exact deposition sequences to be applied.

Instrumentation will be based on the rock mechanics instrumentation, that was used during boring of the two deposition holes, and that consequently already is in place, and on instrumentation of the bentonite blocks for measurement of temperature, pore water pressure, total pressure and relative humidity. Some thermocouples will also be installed in the rock around the deposition holes.

The concrete plug on top of each hole will be anchored to the floor by cable bolting. Sensors on the cables as well as sensors below the plugs will be installed in order to monitor the development of the upward pressure created by the swelling bentonite. All cables from heaters and instruments in the holes will have to be lead-through respective plug.

The installation will be designed for an operating period of 5 years. The heaters will according to the plan be turned on in June year 2000.

SAMMANFATTNING

En av fullskaletesterna i ett av Äspölaboratoriets mål: "Demonstration av teknik för och funktion hos betydelsefulla komponenter i djupförvarssystemet" är Återtagsförsöket, som omfattar två delar:

Del 1: Installation av buffert och kapsel i två deponeringshål samt övervakning av vattenmättnadsprocessen.

Del 2: Friläggning av kapslarna från bufferten efter det att bentoniten har svällt samt återtag av de frilagda kapslarna.

Föreliggande Testplan presenterar arbetet i Del 1.

Per idag har tunneln tillretts med borrning-sprängning samt de två deponeringshålen borrats med en "down-the-hole"-maskin med en nominell diameter på 1.75 m. Båda hålen är ungefär 8.5 m djupa räknat från betonggolvet i tunneln.

Bentonitblock och kapslar med värmare kommer att installeras i hålen, och hålen kommer att förslutas med en betongplugg i toppen. Hålen är mycket torra och artificiell bevätning bedöms vara nödvändig. Permeabla filtermattor installeras i remsor längs bergväggen och formationsvatten matas via dem fram till bentoniten. Bentonitpellets och vatten tillförs hålet som en del av deponeringsprocessen i överensstämmelse med de åtgärder som bedöms lämpliga efter testningen av deponeringsprocessen i "Test av deponeringsprocess". Det senare testet är ett stödjande test som genomförs före installationen. Dess uppgift är att testa utrustningen som skall användas liksom att fastställa exakt den deponeringssekvens som skall tillämpas.

Instrumenteringen består dels av den bergmekaniska instrumenteringen, som användes vid borrningen av de två deponeringshålen och som redan finns på plats, dels av ny instrumenteringen i bentonitblocken för mätning av temperatur, porvattentryck, totalt tryck och relativ fukthalt samt termoelement i berget runt deponeringshålen.

Betongpluggen över hålen förankras i berget med hjälp av kabelbultar. Givare installeras på kablarna liksom givare under pluggarna i syfte att mäta utvecklingen av det uppåtriktande tryck som kommer från bentoniten. Alla kablar från värmare och instrument i hålen måste ledas genom pluggarna och upp i tunneln

Installationen utformas för en driftperiod om 5 år. Värmarna slås enligt planen på i juni år 2000.

CONTENTS

1 BACKROUND

The Äspö Hard Rock Laboratory, Äspö HRL, is an important part of SKB´s work on design of the deep repository and is constructed with the aim of providing possibilities for research, development and demonstration in a realistic and undisturbed under ground environment at the depth which is considered for the deep repository. The main objectives are to:

- Increase the scientific understanding of the safety margins of the deep repository.
- Develop and test technology, which decreases costs and simplifies the final disposal concept with maintained high quality and safety level.
- Demonstrate the technology, which will be used for deposition of spent nuclear fuel and other long-lived waste.

The work in the Äspö HRL is divided into three phases: pre-investigation, excavation and operation. During the pre-investigation phase (1986-1990) the site of the laboratory was selected. The natural properties of the rock were described and predictions were made with respect to geohydrology and other conditions, which were observed during the excavation phase. During the excavation phase (1990-1995) a ramp was driven down to 460 meters depth below the ground surface and additional shafts for ventilation and personnel transports as well as surface facilities were completed. Extended bedrock investigations and tests were carried out in parallel. During 1995 the operating phase started. For this phase the work in the ÄHRL has been grouped into four target areas:

- Verify pre-investigation methods.
- Document detailed investigation methods.
- Test models for description of the barrier functions of the rock.
- Demonstrate technology for and function of important parts of the deep disposal system.

The fourth target area "Demonstrate technology for and function of important parts of the deep disposal system" aims to test and study different aspects required for a deep repository such as:

- Function
- Handling techniques
- Development and testing of equipment

The different aspects will be tested, studied and developed in a number of tests and comprises the following projects:

- Prototype Repository
- Demonstration of Repository Technology
- Canister Retrieval Test
- Backfill and Plug Test
- Long Term Test of Buffer Material and Tests of Adverse Conditions

The **Prototype Repository** will be a full-scale copy of a repository with four to six deposition holes. It aims at a demonstration of the integrated function of the repository components and a comparison of the results with models and assumptions. It includes testing of characterisation methods in the deposition tunnel, boring of deposition holes, emplacement of buffer, canister and backfill, construction of plug and instrument installations. The modelling is carried out as integral parts of the Test.

The **Demonstration of Reposition Technology** will constitute a full size copy of a deposition tunnel with four deposition holes. It aims at developing and testing technology and equipment as well as demonstration of deposition of canisters in a deep geologic repository. The Test comprises construction of a deposition machine in full scale which is equipped with a radiation shield that fully surrounds the canister. The machine has been delivered to Äspö HRL and it will be used in repeated deposition tests in the same deposition hole. The bentonite blocks will in the test be simulated by more strong blocks, made of concrete. Two of the other holes will be used for exhibition of the deposition sequence (Project Bedrock 500).

The **Canister Retrieval Test** (Part 1 is presented in this Test Plan) will be a full size copy of a repository with two deposition holes, but without backfilling of the tunnel. The Test aims at testing methods for canister retrieval from a saturated buffer. Part 1 comprises the installation in the two holes and monitoring during saturation, and Part 2 the development of the equipment to be used as well as the actual freeing of the canisters followed by retrieval of the canisters up to the tunnel floor.

The **Backfill and Plug Test** is a full size copy of a backfilled deposition tunnel and an ending temporary plug. It aims at testing different backfill materials and techniques for backfilling and plugging, and studying of the integrated function of rock, backfill and plug.

The **Long Term Test of Buffer Material** and **Tests of Adverse Conditions** will be carried out in a scaled down geometry, in single bore holes. They aim at either simulating conditions that are unlikely to occur but still possible, or exaggerate conditions in order to study certain phenomena. The Long Term Tests will also include some long time reference tests.

2 OBJECTIVES

The overall aim 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, especially after the initial operation of the Deep Repository that addresses disposal of about 400 canisters. In order to provide the test conditions necessary for actual retrieval tests the test set-up (Part 1 of the Test) has to achieve the following objectives

- Two vertically bored test holes in full repository scale, which fulfil the quality requirements deemed necessary for the Deep Repository. This objective has already been achieved with success.
- Knowledge of the geotechnical properties of these holes including the boring disturbed zone.
- Complete geotechnical characterisation of the rock volume around the test holes.
- Emplaced bentonite blocks, bentonite pellets, canisters with heaters, instruments in the buffer and filter mats for artificial saturation.
- Construction of plugs in the upper part of the holes.
- Monitored saturation and swelling of the buffer.

3 RATIONALE

3.1 Relevance of test

The KBS-3 concept for final disposal of spent nuclear fuel has been developed to fulfil SKB´s, the public's and the Authorities´ criteria for safe disposal without long-term monitoring and supervision. But the concept is also made flexible in the sense that the spent fuel is retrievable for future generations in case a new technique is developed that is judged to provide safer means of handling the waste. One further requirement on the disposal process is that it itself shall be possible to reverse and restart in case any malfunction occurs that makes it impossible to continue the disposal of that particular canister. This gives three different modes of retrieval:

1. Retrieval during disposal.
2. Retrieval of canister after disposal but before the bentonite buffer has saturated and swollen.
3. Retrieval after the bentonite buffer has saturated and swollen. (The tunnel in the deep repository is backfilled before the bentonite swells which prevents the bentonite from swelling up into the tunnel: a plug is cast on top instead in the Canister Retrieval Test)

The first mode occurs before the disposal device has loosened its grip of the canister and is a question of design of the disposal machine. The second mode requires a gripping device that captures the canister; a device that is planned to be the same device as the one holding the canister during disposal. The third mode requires that the canister has been made free from the bentonite before it can be pulled up and out of the deposition hole. Excavation of the backfill in the tunnel is not considered to be any major technical problem and is not going to be tested.

Of these three modes the two first mentioned ones will be tested as part of the Demonstration of Deposition Technology using the prototype deposition machine. Mode one is tested separately in different stages of the deposition up to the point when the canister is released from the gripping device. Mode two comes naturally when the canister is recovered after the completion of one deposition sequence – when the canister has been covered by blocks and the deposition machine moved away from the hole.

The third mode of retrieval requires another test site because it takes at least a couple of years to fully saturate the bentonite, and the tunnel is blocked during this time. Then the site becomes occupied by the freeing of the canister before the deposition machine can be moved in for recovery of the canister.

The issue of retrieval is also a question of concern for SKI, who in its evaluation of SKB´s RD&D programme 95 wrote: "SKI presumes that SKB plans and constructs machines for possible retrieval of deposited canisters, as SKB´s reliability otherwise might be questioned regarding both intention and ability to retrieve canisters, if deemed necessary." /1/.

3.2 Current state of knowledge

The wide scoop of investigated technical methods /2/ has resulted in preference for the so-called Batch Disintegration Method /3/.

The key issues of this method is the process of disintegration of the bentonite surface and the efficiency by which the disintegrated layer is washed away, so that again a fresh bentonite surface is exposed to the disintegrating solution. The work has initially been concentrated on the chemistry of the water, i e salt type and concentration. The mechanical part that concerns the nozzles and their design for an effective washing away of the disintegrated layer will be studied later. A tentative indication of how the machine set-up can look like is shown in Figure 3-1.

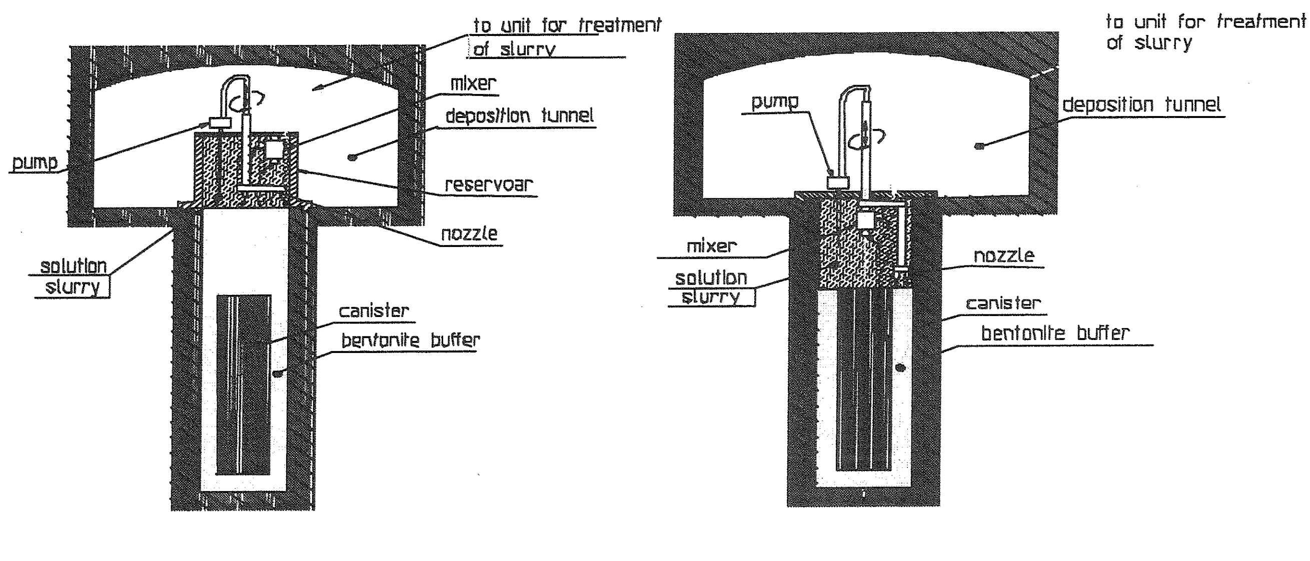

Figure 3-1 Disintegration of the bentonite buffer and flash removal of the disintegrated bentonite layer

Disintegration of the bentonite takes place also in pure tap water, but very slowly probably because a gel is formed on the surface, which prevents water from penetrating further into the bentonite. With time, however, the bentonite does disperse in pure water forming a diluted slurry. The time for disintegration is much shorter if additives are used which either promote dispersion of agglomerates or coagulation of dispersed solutions, the effect being a more effective penetration of water into the bentonite surface.

Several different additives have been tested in order to determine the efficiency and thus indirectly the most important chemical processes for an effective disintegration. Such additives are, besides NaCl and $CaCl_2$, NaOH, sodium silicate ($Na_2Si_xO_{2x+1}$), Na_2CO_3, commercial machine-wash detergents, and commercial substances used for dispersion of clays in the ceramics industry. In all cases the time for disintegration of a bentonite test sample was much shorter than when only pure tap water was used. The viscosity of the slurry that was produced varied, however, and this is important because the viscosity of the slurry determines the efficiency by which the disintegrated layer can be washed away. The conclusion so far is that NaCl or $CaCl_2$ are preferable due to the disintegration process. Optimum salt contents is approximately 4-6% TDS.

3.3 Justification of the experimental work

With the intention to test retrieval of canisters, which have been deposited for some time, it is necessary to take appropriate measures for providing as repository-like conditions as possible. Today one very promising method for freeing the canister from the grip of the swollen bentonite exists, but technically interesting alternative methods are also investigated. Only one method can be tested in one deposition hole, and the ambition to test two methods calls for a test set-up with two deposition holes.

In the deep repository the spent fuel emits decay heat and provides a source for radioactive components to pollute the bentonite in case of a defect in the canister. The heat is inducing processes in the bentonite which affect the saturation process and which lead to sustaining differences in the buffer material between a bentonite which has been saturated at ambient temperature and one which has been saturated at elevated temperature. These processes are know to their phenomena, but are difficult to quantify accurately. The most repository-like condition is therefore judged to be achieved if heaters are installed in the canisters, despite the negative consequences the cables to the heaters may have to the test. The alternative is to try to predict the differences, which meets difficulties in verifying the results.

The radioactive pollution may be addressed by confined handling of the removed bentonite or by not removing it from the hole. There is, however, no possibility to use radioactive substances in the test for this purpose, so any test has to be generic in this respect.

For the Canister Retrieval Test only limited number of sensors are required and then for observing the saturation process and the heat distribution. Cables are in the way when the bentonite is removed and the canister retrieved. But there is information to be gained from the test that can be useful in evaluating the future results from the Prototype Repository regarding the evolution of THM processes in the buffer. As artificial wetting of the bentonite will be used the holes will serve perfectly as a test on bentonite saturation with well defined boundary conditions at the interface between the rock and the bentonite. Therefore, a compromise has to be made between the ambition of acquiring useful information on processes taking place in the buffer and the problem the instruments introduce in the tests of retrieval later.

No conflicts exist regarding any installation in the rock, and several temperature sensors are installed in holes drilled from the floor of the tunnel at different distances from the deposition holes.

The mechanical response in the bedrock to boring of the deposition holes was studied in both the Canister Retrieval Test and the Prototype Repository with similar type of methods and sensors – acoustic emission, ultrasonic waves, biaxial cells and displacement sensors. Only the biaxial cells and the displacement sensors are maintained during the heating and saturation phase in the Canister Retrieval Tunnel, while all the instruments are maintained in the Prototype Repository. The reason for the prolonged monitoring in the Canister Retrieval Test is to provide a second set of observations that can match the prime ones in the Prototype Repository.

4 EXPERIMENTAL CONCEPT

4.1 General

The SKB-proposed design of the repository is based on deep disposal in a tunnel system between 400 and 700 m depth in crystalline bedrock, see Figure 4-1. The spent nuclear fuel is encapsulated in canisters consisting of an outer corrosion resistant copper cylinder, and an insert of cast-iron with slots for the fuel types used in Sweden. Each canister has room for 12 BWR elements or 4 PWR elements.

The canisters are deposited in vertically bored holes in the tunnel floor. The space between the canister and the bore hole walls is filled with blocks of highly compacted bentonite. The centre distance between deposition holes is about 6 m. After deposition of the steel/copper canister, the deposition tunnel will be backfilled with crushed excavation material or a mixture of bentonite and crushed rock, and sealed-off with a plug at the mouth of the tunnel.

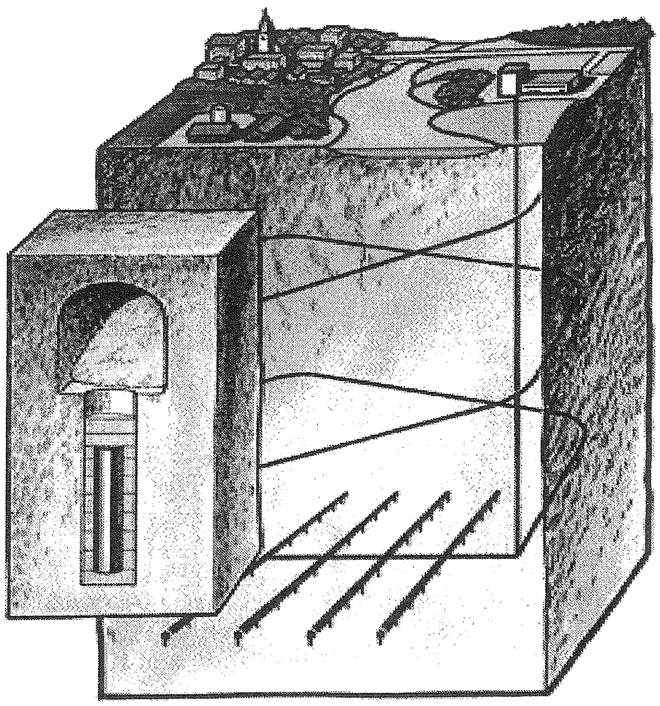

Figure 4-1 The deep repository according to the KBS-3 concept

4.2 Experimental configuration

4.2.1 Experimental tunnel

The deposition tunnel for the experiment is located on the 420-meter level in the extension of the D-tunnel, and has been excavated by conventional drill and blast. The tunnel is 6 meters wide and 6 meters high, and is orientated in the NNW-SSE direction, i.e. almost parallel to the general direction (NW-SE) of the major principal stress in the laboratory. The centre distance between the two bored deposition holes is 6 meters, which is in agreement with the distance considered for the deep repository. In the Canister Retrieval Test, however, the temperature influence from surrounding canisters is less than the case will be in the deep repository , which may have the effect that a higher thermal output is needed from the canisters in order to obtain a temperature of 90°C on the surface of the canisters.

4.2.2 Deposition holes

The deposition holes have been bored with a nominal diameter of 1.75 m and a depth of about 8 m below the tunnel´s rock floor. The tunnel floor was cast with concrete in order to provide a flat surface for the boring machine and for the rails to the machine for lifting up the canisters. In total the hole depth is 8.5 m from the concrete surface.

4.2.3 Canisters

The canisters for Boiling Water Reactor fuel assembles (BWR) with dimensions and weight according to the current plan for the deep repository will be positioned in the deposition holes and surrounded by bentonite.

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 meters and the weight 21.4 tonnes excluding fuel and about 25.0 tonnes with a simulated load of 12 BWR fuel assemblies.

4.2.4 Heaters

The design of the Test aims at reaching a temperature of 90°C on each canister´s surface. The temperature on the surfaces, temperature distributions inside canisters, in buffer, and in rock are a function of thermal properties that are continuously changing, depending on water saturation, temperature and mechanical processes.

Cables for power supply to the heaters will be fed through the lid.

4.2.5 Buffer

The bentonite buffer will be emplaced as blocks of highly compacted Na-bentonite. Since a final homogeneous density of the buffer is desirable, the properties of the initial blocks will have to vary depending on location in the deposition hole. The blocks located above and under the canister will have an initial dry density (density of dry bentonite minerals) of 1.66 t/m^3 and a void ratio (ratio between pore volume and bentonite volume) of 0.67 whereas the blocks surrounding the canister will have a density of 1.78 t/m^3 and a void ratio of 0.56. The initial water ratio (ratio between weight of water and weight of dry bentonite) in the blocks is 17% and the degree of water saturation is about 70-80% depending on location in the hole. The blocks will fill up the space between the rock and the canister but leave in average a slot of 50 mm between the rock blocks and 10 mm between the blocks and the canister. The outer slot will be filled with bentonite pellets (w=10%, dry density=1.9 t/m^3), which in the slot provides an average dry density of about 0.9 t/m^3.

The final average bulk density in the deposition hole after water saturation will be about 2 t/m^3 (combined weight of bentonite minerals and water in one m^3). At that density the void ratio is about 0.77 (pore volume divided with volume of bentonite minerals). The confined swelling pressure of this bentonite buffer is approximately 5 MPa.

4.2.6 Arrangement for filling with fresh water

The most favourable situation is obtained if all open volumes, both the slot around the canister inside the bentonite blocks and the void in the backfill of bentonite pellets outside the blocks are filled with fresh water before the deposition hole is sealed-off. Different techniques for these fillings are under discussion and the project "Test of Deposition Process" is aiming at shedding some light on the feasibility and technically sound approaches.

Basically the inner slot can be filled from a pipe extending down to the bottom of the slot or by adding water before the canister is installed.

The outer slot should be filled from the bottom. The pipes used for draining the slot may be used for infiltration as well. The slots, with bentonite pellets, may, however, clog before the whole height is water filled due to swelling of the bentonite and sealing of the voids between the pellets. With salt water this swelling/clogging is fast but with fresh water very moderate. The test will show the possibilities available to the Canister Retrieval Test.

4.2.7 Plugs

As no backfilling of the tunnel is going to be made, the swelling force of the bentonite in the deposition hole has to be taken up by a plug that covers the hole. The preferred design aims at a plug of concrete that is anchored to the floor by cable bolts. The plug extends about one meter down into the deposition hole (i e down to the bentonite block on top of the canister), and has probably a wider body in its upper part, for spreading the force from the anchors.

In order to be able to use the large deposition machine for the retrieval operation it is necessary to recess at least one of the plugs so that the top comes at the same elevation as the rest of the cast floor, because the deposition machine covers also the other hole when it is in operation. (The hole with a recessed plug is used after the other one.)

Another evaluated alternative is to use steel pit props and to take support from the ceiling, in the same way as in the Buffer Container Experiment in URL, Canada.

4.2.8 Arrangement for artificial saturation

The hydraulic tests carried out in the pilot holes and the geological mapping of the tunnel and the floor in particular as well as visual observations in the bored deposition holes indicated that the water inflow to the deposition holes is low, and consequently that the time for full saturation of the buffer may be very long, maybe tens of years.

In order to be able to saturate the bentonite as quick as possible a system for artificial saturation is deemed necessary. One alternative is to use infiltration holes that are drilled around the deposition holes at a certain distance from the periphery of the holes and with certain spacing. But the performance of this method depends

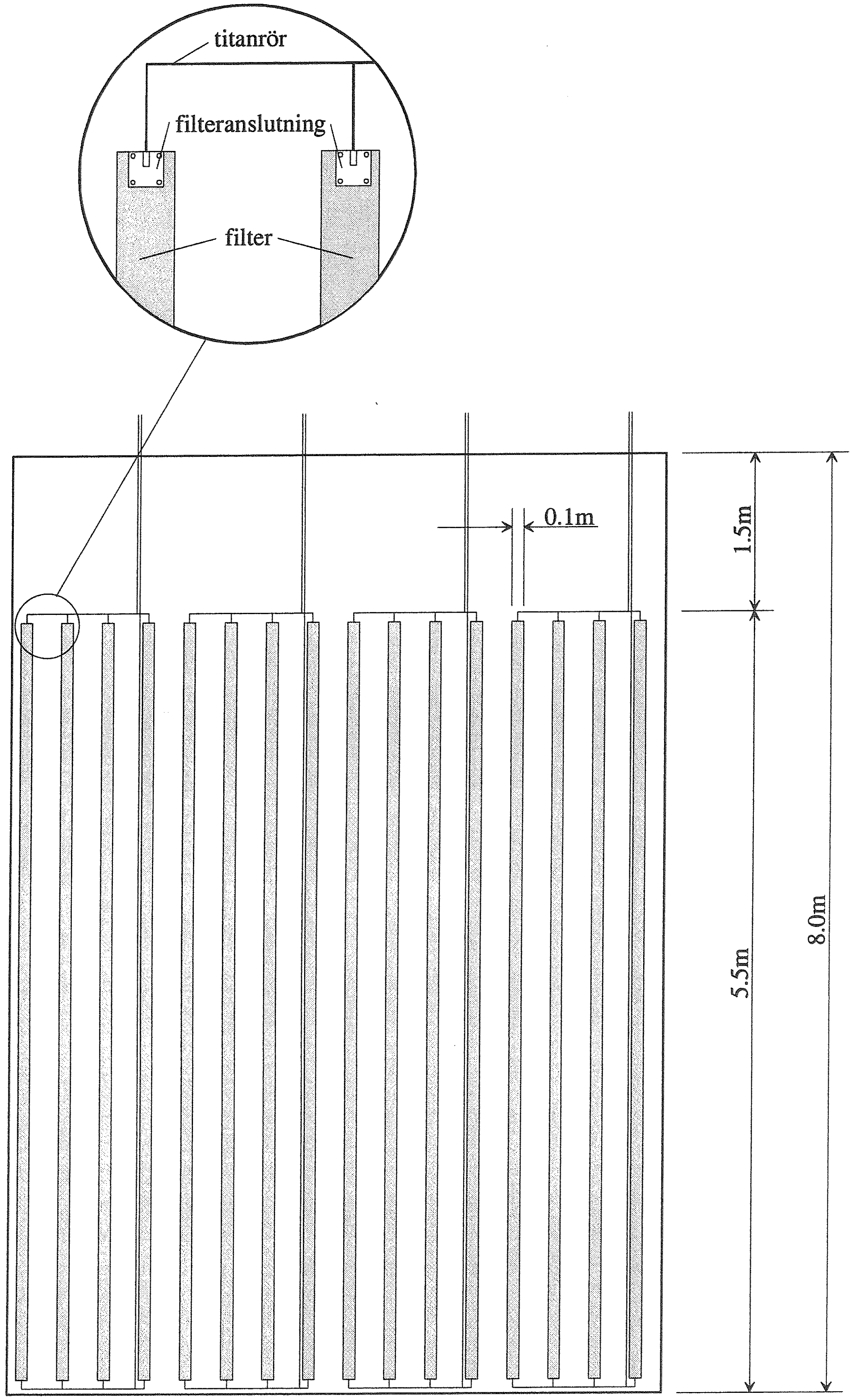

Figure 4-2 Proposed arrangement of filter mats and piping on the rock wall. Bottom and top respectively in the figure represents the deposition hole bottom and tunnel floor respectively

on the fracture pattern and its hydraulic properties, and is judged to have a low probability to succeed. Another method is to attach permeable mats with a suitable spacing on the bore hole wall. This method is preferred. A schematic drawing of the possible arrangement is shown in Figure 4-2.

4.2.9 Emplacement sequence

A detailed plan will be made for the emplacement sequence in the two deposition holes. The installation equipment for handling the canisters with heaters, bentonite blocks, bentonite pellets and water as well as techniques for installation will be tested in-situ to achieve practical experience, before installations in the two deposition holes starts. This testing is made as a part of also the Prototype Repository, and many details are of more importance to this project than to the Canister Retrieval Test, so the Prototype Repository will consequently take the lead in the testing of emplacement techniques.

4.3 Measurements

The rock and buffer will be instrumented in order to measure the thermo-hydro-mechanical processes during the test period.

4.3.1 THM in buffer

The function of the buffer is controlled by a number of measurable properties /5/. Most of these properties are given as material specification at installation. However, during saturation these properties as well as properties in the host rock will undergo a number of mechanical, hydraulic, thermal and chemical changes, that are varying with time. In order to follow those changes measurements will be made in-situ of:

- Temperatures
- Pore water pressure
- Total pressure
- Humidity

Instrumentation is also planned in such a way that information is gained, besides the general information on the state of saturation of the whole buffer, on the following processes:

- Water saturation in the buffer close to the rock surface.
- Temperature development in gaps between bentonite blocks
- Temperature development in the bentonite close to each canister´s surface

4.3.2 Temperature in buffer and rock

Temperature is easy to measure and is important for the understanding of the water up-take in the buffer and the consequent development of the swelling pressure. Several temperature sensors are installed in the buffer but concentrated to a few levels. In order to provide for redundancy two different systems are considered, e g thermocouples and fibre optics.

Also the canisters will be equipped with temperature sensors.

In the rock the temperature is also obtained as a spin-off, because the registration is needed for the correction of the stress/strain data readings against the actual temperature. This is in supplement to the additional installation of new temperature sensors.

4.3.3 Degree of water saturation in buffer

One process of concern is the water up-take by the buffer, which basically can be monitored by measurements of the suction. Psychrometers are therefore used in combination with capacitive sensors for observing the increasing saturation of different parts of the buffer.

4.3.4 Water pressure in buffer and rock

The water pressure in buffer will gradually increase and at a certain stage, the natural water pressure will be established. At this stage the repository system will be completely water saturated. The time until the natural water pressure is obtained is decided by the rate of the addition of water via the infiltration system that can be made. If the system works well mainly the water diffusion process in the bentonite will decide the time for saturation. Two independent systems are considered due to the redundancy issue: vibrating string and fibre optics (Fabry-Perot).

The water pressure in the rock is observed with the piezometres already installed.

4.3.5 Total pressure in buffer

The total pressure gauges will measure the sum of the pore water pressure and the swelling pressure. Also for these measurements two independent systems are considered: vibrating string and fibre optics (Fabry-Perot).

4.3.6 Rock mechanical response

The measurements of rock mechanical response will provide information on temperature, water pressure, deformation and fracturing around the deposition holes. The following measurements are made

- Water pressure
- Temperature
- Strain/displacement

4.3.7 Measurement in plugs

The only instrumentation of the plugs, that is planned, is installation of total pressure sensors for monitoring the load applied by the swollen buffer. Also the anchoring bolts, which consist of cables, are equipped with sensors measuring the force acting on the plug. These measurements can also serve the purpose of analysing the kinetics of saturation and swelling prior to emplacing the backfill in the deep repository.

4.4 Expected outcome

Part 1 of the project aims at installation of the two deposition holes in such a way that tests of canister retrieval can be made. Saturation is calculated to take about two years in the buffer along the canister with saturation through permeable mats (i e if water diffusion in the buffer determines the saturation process). In order to be certain when the bentonite has saturated and swollen the instruments shall provide continuous and accurate information on the status of the conditions in the buffer.

In addition practical experience is expected to be gained, and used in the installation of the inner 4 holes (Section I) of the Prototype Repository.

4.5 Problem areas and alternative solutions

The problem areas may be separately considered for issues related to practicalities during installation and uncertainties during saturation.

4.5.1 Installation issues

A number of practical questions regarding the installation activities have been raised and answers can be given only when the pre-test "Test of Deposition Process" have been made. They are all questions, which can be solved by the engineer, and the risk is small that major problems will stay unsolved. But the complexity of the installation procedures makes it important to test all uncertain details before the installation of the Canister Retrieval Test starts (as well as the Prototype Repository). The time plan is tight and consequently a time delay in the pre-test will delay the start of the installations in the Canister Retrieval Test.

4.5.2 Uncertainties during saturation

The problem areas after sealing are corrosion and instrument malfunction.

The problem of corrosion is addressed by choosing titanium, and such measures should be satisfactory for the relatively short period of time the test will be in operation.

But there are earth currents and other corrosion phenomena, which have not, but will be studied for the Prototype Repository. If any risk is considered engineering measures will be taken.

A more difficult problem is the failure of instruments. But even if all instruments would fail the bentonite will saturate and the conditions for the retrieval test will be fulfilled anyhow. The problem is to supervise the development of the saturation/swelling processes in the buffer. The experiences from other tests (Stripa, FEBEX, URL and Äspö) are, however, good and provide a basis for selection of instrument types with a good availability record.

The most serious problem is failure of the heaters, because heating is one of the necessary conditions for providing accurate conditions in the Canister Retrieval Test. The experience of heaters are, however, good from 3.5 years in Stripa and 9 years in the Asse mine. But the Buffer Container Experiment in URL suffered the loss of one circuit (out of three) after about 3 years. The technical difference in Äspö is that the canisters have a space between the lid and the top of the insert and the copper cylinder is not self-supporting. Deformations may jeopardise the integrity of the canister at the interface between the lid and the cylinder, and around the lead-throughs. The lid can be welded on as well (although the high temperature needed for a good weld may jeopardise the integrity of the lead-throughs).The lead-throughs are of proven design (for submarines) but have never been used by SKB before; their record of operation is, however, satisfactory long.

4.5.3 Alternative solutions

The aim of providing canisters in swollen bentonite for tests of canister retrieval can not be done in any other way.

However, details may face options. But the activities are mostly of practical nature and can be addressed in a conventional way by good engineering standard. This means that the most promising “alternative” is selected in the early phase, and there is little cause for assuming better result with a less promising “alternativ”.

5 SCOPE

5.1 Present status

At present the two deposition holes have been completed down to a depth of 8 m below the estimated rock floor (8.5 m below the concrete floor), and the next activity is to characterise them with respect to geology, geometry and geotechnical properties of the rock wall. The following activities have already been carried through:

- Excavation of the tunnel, which is an extension of the D-tunnel with 16 m. The tunnel width is 6 m and the height 6 m as well.
- Geological mapping of the tunnel.
- Positioning of the two deposition holes and coring of two holes in the centre of these.
- Registration of water inflow and hydraulic head in these two holes.
- Casting of concrete on the floor in order to obtain a flat floor.
- Coring of 7 about 10 m deep holes (Ø76 mm) for acoustic emission (AE) geophones, and of 8 holes (Ø60 mm) between 3 and 9 m deep around the periphery of the two deposition holes for rock mechanical instruments.
- Mapping of all cores and BIPS measurement in all 15 holes.
- Geological characterisation of the rock volume around the two deposition holes.
- Permanent installation of AE sensors including thermocouples and piezometres for measurement during boring and later on during heating.
- Permanent installation of biaxial stress sensors and strain gauges for measurement of rock mechanical response during boring and later on during heating.
- Installation of displacement gauges around the deposition holes for measurement of rock displacement upward during boring.
- Boring of the two deposition holes.

The activities have been planned and documented according to the Äspö HRL standard. Descriptions of scientific interest are found in Quality Plans and reports on results.

5.2 Project tasks

5.2.1 Characterisation

The general objectives for the characterisation programme of the test site are to provide:

- Basis for determination of the suitability of the two selected places for the deposition holes.
- Basis for possible engineering measures of artificial water saturation.
- Data on boundary and rock conditions to enable interpretation of the data collected during saturation.

This characterisation is executed in three stages: tunnel (Stage 1), pilot and exploratory holes (Stage 2) and deposition holes (Stage 3). Each stage is intended to contribute to more detailed information about the characteristics of deposition holes and boundary conditions needed for interpretation of the experimental data. The principle for evaluation of data in each stage is given in Table 5-1.

Table 5-1. Evaluation of data in the three characterisation stages.

STAGE	EVALUATION
Stage 1 (tunnel)	• basis for locating pilot holes and design of support of deposition hole plugs • basis for models
Stage 2 (pilot/instrument holes)	• data on hydraulic regime and design of artificial saturation • data for boundary conditions, predictions and monitoring during saturation
Stage 3 (deposition holes)	• characterisation of deposition holes and comparison with earlier models • data for models and monitoring

Today Stage 3 remains to be completed.

In addition to the planned characterisation work further geotechnical information is gained from the results of the study on crack formation during boring. This specific project on field measurements of the force the bore head applies to the rock wall and the consequent cracking this causes was namely carried through during boring of one of the two Canister Retrieval Test holes. The samples from the rock wall, that will be taken and analysed, will provide further information on rock properties.

5.2.2 Characterisation of deposition holes

Each deposition hole is characterised with respect to geometry and geology. Besides straightness and deviation from the vertical line, for which maximum values have been included in the boring contract, the volume of the hole and the pattern of water-conducting features are of concern. A specific programme for bore hole characterisation is composed and first tested in the supporting project "Test of Deposition Process" before being applied in the Canister Retrieval Test holes.

5.2.3 Scoping calculations

Scoping calculations will be made for design and boundary condition purposes.

Analysis of suitable heater power will be based on the calculations carried out for the Prototype Repository, which use the FEM-code ANSYS. That model is, however, also applied to the Canister Retrieval Test geometry and conditions in a simple way for supporting the analysis.

A concern is the hydraulic boundary condition around the canister positions, but with artificial water supply steady and homogeneous boundary conditions are obtained with respect to water distribution around the bentonite.

5.2.4 Prediction modelling

Prediction of the saturation of the bentonite, with due consideration to natural and artificial water supply, will be made by a coupled THM numerical analyse using the CLAYTECH/UNSATURATED model which is based on the ABAQUS code.

The analysis will continuously be compared with the data that are monitored in the deposition holes during operation.

5.2.5 Instrumentation

Suitable type of sensors have been investigated for the Prototype Repository and the Long Term Test of Buffer Materials. One recommendation made so far is to use two different types of sensors for the same type of measurements in the buffer. Another recommendation, from the Long Term Test, is to make the sensors in titanium due to the highly corrosive environment in reducing conditions at close to 100°C.

The configuration of measuring sensors in the bentonite will be determined in detail. Some additional thermocouples will be placed in the rock.

Canisters

The canisters will be equipped with sensors to measure temperatures. During operation the canister will be affected by mechanical loading that will change the condition for thermal distribution within the canister. The gap between the copper tube and the steel insert will decrease in time and thermal distribution is expected to improve. The aim of keeping a constant temperature on the canister´s surface then also requires temperature measurements on the surface of the canister.

Measurements in buffer

The instrumentation plan for the buffer is divided into two groups:

- Standard measurements in an even distributed pattern.
- Standard measurements concentrated to certain positions where detailed studies of the coupled THM-process are of interest.

Instruments will in the standard pattern be concentrated to three levels, i e to three blocks, covering both the whole blocks below the canister and the cylindrical ones around the canister. The sensors are placed along three symmetrically located lines from the centre and outward, see the schematic outline in Figure 5-1.

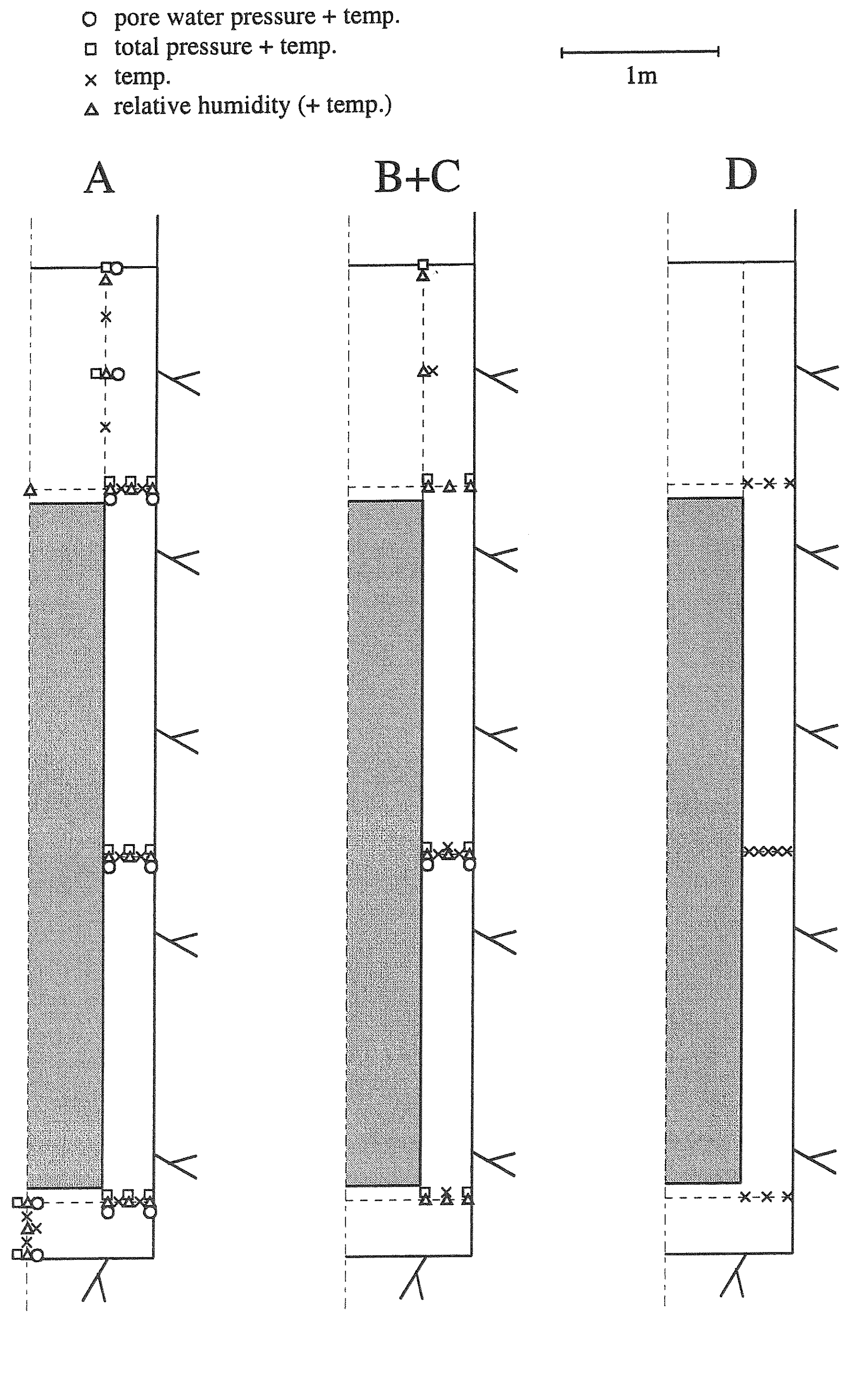

Figure 5-1 Location of instruments in four vertical sections

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Two alternatives for locating the vertical sections A-D i Figure 5-1 are shown in Figure 5-2. The feature of alternative 2 is that half of the hole is almost un-instrumented, and cables are not affecting the saturation process as thermocouples to this section can be drawn through the buffer from sections B or C.

Because the water for saturation is added in filter mats two measurement sections are placed just in front of a mat and two in between two mats.

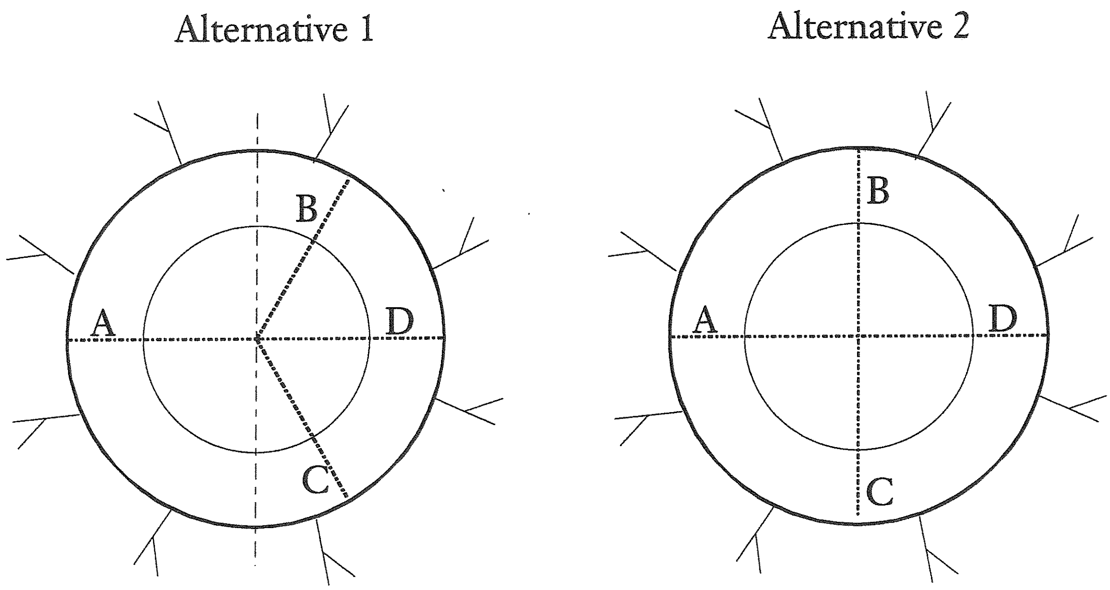

Figure 5-2 Location of vertical sections in relation to each other

Two main alternatives are considered for the location of these four vertical sections, see Figure 5-2.

Measurements of rock mechanical and hydraulic response

The instruments have already been installed.

5.2.6 Installation

A typical disposal sequence may be as follows

Preparatory works

- Pumping out water in hole
- Installation of drainage system. The bentonite blocks are very sensitive to water

which require that in-flowing water is pumped out from the deposition hole during installation.

- Installation of climate system. The humidity is measured to become too high in a hole with inflowing water, even if the water is pumped away, and the means of keeping the humidity down is to ventilate the hole during installation.
- Casting of the bottom slab in the deposition hole. The slab must be perfectly horizontal and stand a load of about 50 tons (canister and bentonite blocks)
- Installation of permeable mats for artificial water filling on the rock wall

Emplacement of bentonite blocks and deposition of canister

- Preparation of bentonite blocks, some for instrumentation.
- Gripping of blocks.
- Lowering of blocks. The blocks have to be placed very accurately. Installation of instruments in the prepared blocks. Cables/tubes are drawn up to the deposition tunnel and fixed against the deposition hole surface.
- “Cardano” movement and lowering of canister.
- Attachment of cables to heaters and to other instruments inside the canister, if inserted.
- Filling of water in the inner slot, if required. (Could also be done prior to deposition of the canister.)
- Emplacement of top blocks. Special consideration must be taken to handling of power supply cables etc.
- Filling of bentonite pellets in the outer slot. (Could also be done successively as the blocks are emplaced.)
- Filling of outer slot with water, if required.

Sealing

- Casting and anchoring of plug.

The sensitivity of the blocks to changes in air relative humidity requires that all blocks are prevented from coming in contact with the high humidity air in the tunnel. A special type of pallet is fabricated which has a air-tight cover around the block .

The bentonite blocks are prepared for instrumentation in an indoor controlled environment and transported down to the test site. Just before lowering the block, down into the deposition hole, the protecting cover will be removed and the blocks emplaced in the hole. Instruments are inserted once the block is in place in the hole.

5.2.7 Plug construction

The plug design is presented in Section 4.2.6. Ordinary concrete will be used.

5.2.8 Artificial water supply

The design work is presented in section 4.2.8. The installation of the permeable mats on the rock wall is made as part of the preparatory work

In order to preserve the natural ground water condition formation water will be added.

5.2.9 Climate control

A controlled environment is needed in order to maintain the bentonite blocks intact during the time after emplacement and up to the moment the sealing starts. The relative humidity in the deposition holes has been measured to 87% at which the blocks with a water ratio of about 17% are known to sorb water and swell. (The phenomenon was experienced during installation of the FEBEX experiment in the Grimsel URL.) The relative humidity has to be between 75-80% in order to prevent this from happen, and the needed reduction of relative humidity is planned to be obtained by conditioning of the air in the tunnel. The ordinary air at 420 m level is de-saturated and the received low-humidity air is blown into the part of the tunnel where the installation takes place; the separation is achieved by a plastic curtain covering the whole tunnel area. Passage in and out is not affected by this air seal.

5.2.10 Monitoring and testing

During operation, monitored data will continuously be analysed, in order to interpret the status and function of the buffer and compare the results with prediction models.

5.3 Supporting project tasks

The Canister Retrieval Test acquires support and information from other projects in the ÄHRL. Equipment is generally manufactured for use in several tests and testing of handling etc is carried out in projects which provide the results also to several tests. The main supporting projects work with:

- Canister manufacturing
- Selection of heaters
- Manufacturing of machine for emplacement of bentonite blocks
- Manufacturing of machine for deposition of canisters
- Testing of the deposition process

5.3.1 Canister manufacturing and selection of heaters

The heaters will be designed to generate heat for about 5 years. Selection of heater quality, design of heater configuration in the canister and the degree of redundancy is made in accordance with this need, which is within experienced time frames in other projects.

Canisters are manufactured in the ongoing development of canister technology, and the canisters are provided free of charge. One special consideration is, however, the need of a waterproof (water pressure about 4.5 MPa) lead-through in the lid for power and instrument cables inside the canister. No leakage into the canister can be allowed as the presence of water will jeopardises the function of the heater elements. The prime solution is a submarine device, which has been used for long.

The lid of the canister will be bolted and the seal maintained by the help of two o-rings in the lid. A second lid is manufactured which covers the lead-throughs as well as a 90 degree bend, so that the cables can be taken to the rock wall immediately above the canister and led to the tunnel floor along the rock wall. This additional lid has to be mounted on after that the canister has been installed.

5.3.2 Equipment for emplacement of bentonite blocks and deposition of canisters

The equipment will be delivered in due time for necessary tests (Test of Deposition Process) before the installation starts in the Canister Retrieval Test.

The unit for the bentonite blocks consists of a mobile gantry crane with a special tool for the bentonite blocks, which holds the blocks by means of bands. These bands are pulled out when the block has been placed in the deposition hole.

The equipment for disposal of the canister has a bed for the canister which can be moved in a "Cardano" fashion, i e allow tilting in parallel with lowering. The unit has no radiation shield and the canister can be under close observation during the whole disposal process. The unit can therefore be operated with a simple control system.

5.3.3 Test of the deposition process

The actual installation in both the Canister Retrieval Test and the Prototype Repository will face a number of practical issues which both concern the conditions in the deposition holes and the performance of the machines that are used. The objective is to pile up a column of bentonite blocks (each 0.5 m high) so that a centre hole is formed for disposal of the canister. Once the canister is in place the hole above the canister is filled with bentonite blocks and the hole is sealed with a concrete plug. Pellets and water are added in suitable ways before sealing. The main technical concern is to provide a vertical room for the canister with a minimum of tolerances for the lowering of the canister. The design of the bentonite buffer is assuming that a centre hole in the cylindrical blocks with a 20 mm larger diameter than the diameter of the canister is sufficient, but it has not been possible to verify this number in practise before. This matter will address several technical issues.

- Levelling of the bottom in the hole (millimetre deviation only from perfect horizontal is needed).
- Draining during deposition.
- Accurate placing of bentonite blocks on top of each other (the geometry of the blocks are not absolutely symmetric and vary with millimetres within each block and between blocks).

Additional issues are the matters of pellets and fresh water filling.

The technical solutions, the sequences and the performance of the equipments will be tested in-situ in a separate project (Test av deponeringsmetod) prior to installation with the objective of outlining construction methods and operative procedures. The deposition hole in the assembly hall will be utilised for this purpose.

5.3.4 Quality assurance

The test set-up involves handling of various products and installations. This calls for special efforts for co-ordinating not only the Canister Retrieval Test but also other experiments in the area. Special efforts are also needed to design a quality assurance program and quality control documents.

5.4 Time schedule

The Part 1 of the Canister Retrieval Test program is divided in two stages. Stage 1 Characterisation, Construction and Installation, and Stage 2; Monitoring.

A comprehensive time schedule for the main activities is shown in Figure 5-4:

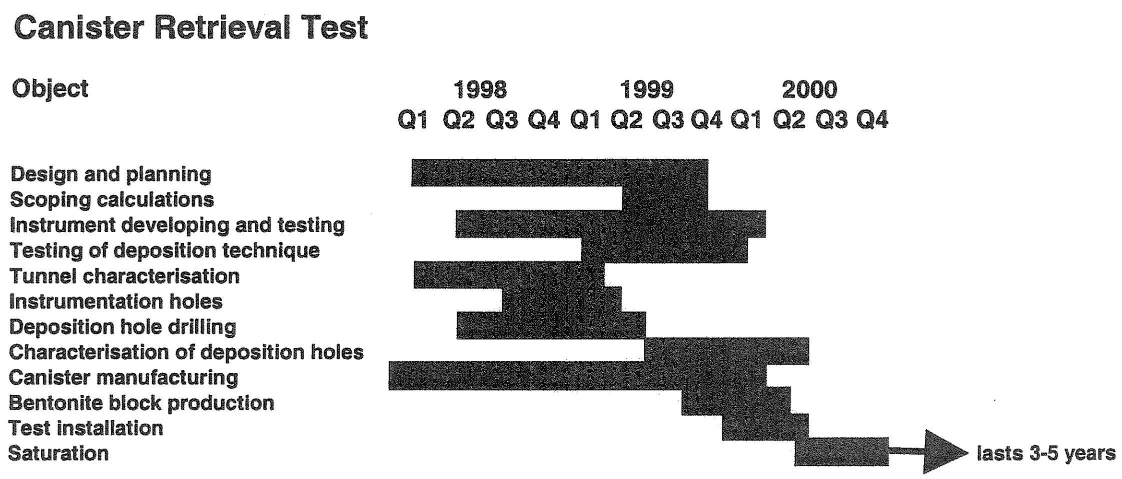

Figure 5-3 Master time schedule

6 PROJECT ORGANISATION AND RESOURCE REQUIREMENTS

6.1 Organisation

The Test will be organised in accordance with the guidelines given in the quality handbook for the ÄHRL project. The project manager for the Canister Retrieval Test is Christer Svemar, SKB ÄHRL. The Test will mainly be co-ordinated and organised by personnel at ÄHRL and participants with responsibilities within projects concerning the Engineered Barriers at ÄHRL. The Site co-ordinator in the Canister Retrieval Test is Åsa Johansson. Peder Thorshager, SCC, is engaged as Assistant Project Manager of Methods and Techniques, and Lars-Olof Dahlström, NCC, as Assistant. Project Manager of Science. An organisation plan is presented in Figure 6-1.

Gunnar Ramqvist (Assistant Project Manager for Methods and Techniques in the Prototype Repository) is engaged in technical support, when this is needed by the project, and in technical co-ordination on behalf of the Prototype Repository.

6.2 Data management

Data collected during characterisation and preparation will be filed in ÄHRL site database (SICADA). The data will be accompanied with a description of how they are collected and formatted. Task leaders are responsible for handling and quality assurance of all data. Responsible for filing and storing of data is the Data Manager at ÄHRL, Ebbe Eriksson.

Visualisation of monitored data is the responsibility of Thomas Karlsson, ÄHRL.

6.3 Reporting

The documentation will be made in the following three classes

- International Technical Documents (ITD)
- International Progress Reports (IPR)
- Technical Reports (TR) for final reporting

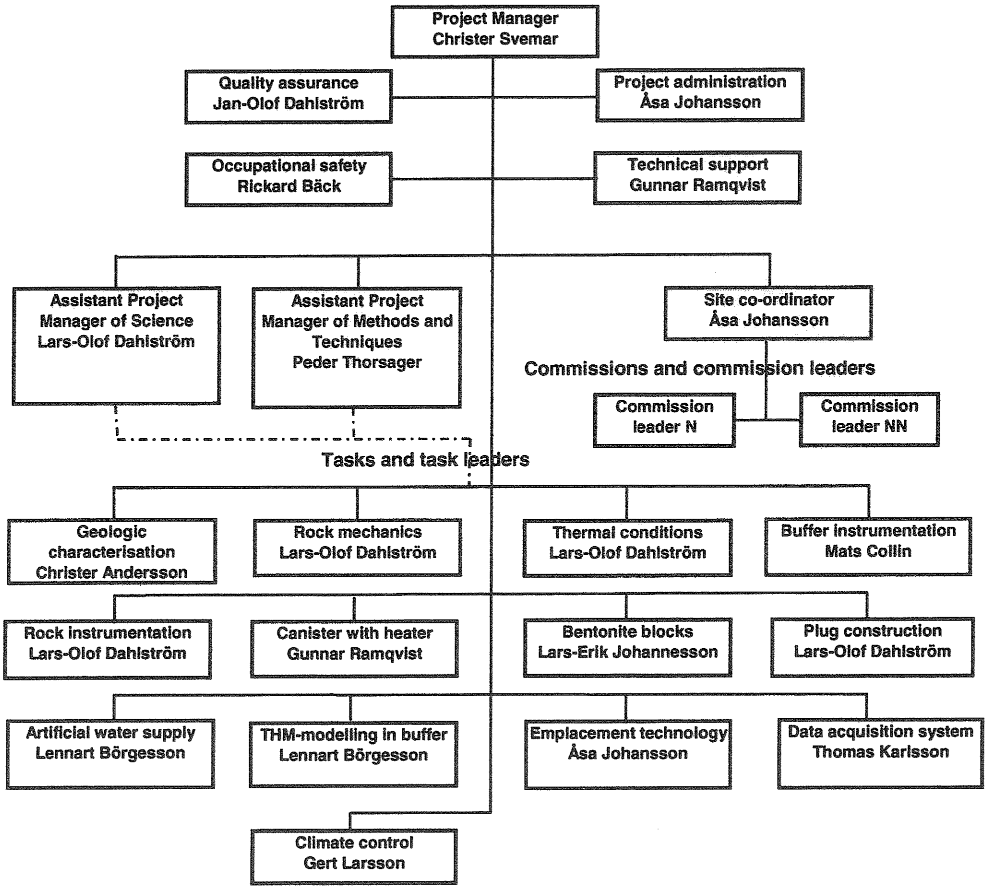

Figure 6-1. Organisation chart

Technical documents including a detailed activity plan and a quality plan will be made for each main task and precede the execution of work. Responsible for the technical documents are respective task leader for activities taking place outside the Canister Retrieval Tunnel (i e Äspö HRL), and the co-ordinator for activities taking place in the tunnel.

ITD (or sometimes R) will be produced, directly after completed work and are the responsibility of the task leader.

Progress Reports (R) will be produced after evaluation of each main activity.

A final report compiling the installation work, the test set-up "as built", will be produced when the Canister Retrieval Test starts to saturate (ready October 2000).

The responsible for the R Reports and the final reports (TR) is the Project Manager.

During monitoring technical documents should be produced regularly, and an International Progress Report is scheduled to be produced every six month, analysing monitored data for comparison with predictions.

6.4 Cost

The costs for completing installation in Part 1 is estimated to 19.5 Mkr, including tunnel excavation, deposition hole boring and scoping calculations. An additional 0.5 Mkr per year is estimated during monitoring for sampling, modelling and reporting.

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