International Progress Report

IPR-99-34

Äspö Hard Rock Laboratory

Prototype Repository

Test plan for subtask

Sampling and monitoring of microbial activities and chemical conditions during 20 years of operation

Ignasi Puigdomenech
Inorganic Chemistry, Kungliga Tekniska Högskolan

Karsten Pedersen
Department of Cell and Molecular Biology,
General and Marine Microbiology, Göteborg University

January 1999

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

Äspö Hard Rock Laboratory

Report no.	No.
IPR-99-34	F63K
Author	Date
Ignasi Puigdomenech Karsten Pedersen	Jan 1999
Checked by	Date
Christer Svemar	1999-12-15
Approved	Date
Olle Olsson	1999-12-21

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Keywords: Microorganisms, Microbiology, Chemistry, Chemical conditions, Water sampling, Gas sampling

ABSTRACT

The Prototype Repository is an SKB project to be conducted at the Äspö HRL, aiming at demonstration of technique for and function of the KBS-3 concept in full-scale. The Prototype Repository will have a duration of about 20 years.

The aim of this monitoring programme is to establish microbial activities and chemical conditions in the different parts of the Prototype Repository. This will allow:

- to follow the function of the Prototype Repository, and
- understand the processes occurring well enough to be able to predict reliably the performance of a future repository for spent nuclear fuel.

The following are some of the most important questions that the chemical and microbial programme will address:

- In situ determination of the O_2 disappearance rate in buffer and backfill.
- Registration of the redox potential distribution in backfill and buffer over time.
- Potential sulphate reduction rates in buffer and backfill with and without the addition of sulphate reducing bacteria.
- Salt precipitation from porewaters due to developing temperature gradients.
- Possible alterations of the organic carbon naturally present in bentonite.
- Assessment of possible bentonite colloid migration in groundwater from the deposition holes.
- Comparison of calculated copper corrosion values with measured values.
- Determination of copper corrosion products in the bentonite buffer.

The present document describes in some detail the monitoring techniques and procedures devised for waters in the different parts of the Prototype Repository site: the rock matrix, backfill in the tunnel, and the buffer in the deposition holes.

SAMMANFATTNING

Prototypförvaret är ett SKB-projekt som genomförs i Äspölaboratoriet. Målet är att demonstrera teknik för och funktion hos KBS-3-konceptet i fullstor skala. Prototypförvaret planeras vara i drift i ca 20 år.

Syftet med detta mätprogram är att bestämma mikrobiologisk aktivitet och kemiska förhållanden i de olika delarna av prototypförvaret. Detta möjliggör:

- Att registrera prototypförvarets funktion
- Lära känna processer som sker tillräckligt noggrant för att på ett tillförlitligt sätt kunna prediktera utvecklingen i ett framtid djupförvar för använt kärnbränsle

Följande frågor är de mest betydelsefulla, som det kemiska och mikrobiologiska programmet ska behandla:

- Bestämning in situ av O_2-haltens minskning med tiden i buffert och återfyll
- Mätning av redoxpotentialens förändring i återfyll och buffert med tiden
- Potentiell reduktionsgrad av sulfat i buffert och återfyll med och utan tillsats av sulfatreducerande bakterier
- Saltutfällning från porvatten till följd av temperaturgradientens utveckling
- Möjlig omvandling av naturligt förekommande organiskt kol i bentonit
- Bedömning av möjlig transport bort från deponeringshål av kolloider av bentonit i grundvatten
- Jämförelse av beräknad koppakkorosion med faktiskt uppmätt
- Bestämning av kopparkorrosionsprodukter i bentonitbufferten.

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1 INTRODUCTION

SKB is planning to dispose of spent nuclear fuel in a deep repository in granitic bedrock. The spent fuel will be placed in copper canisters, which in turn will be surrounded by a buffer (bentonite clay). At repository closure the underground tunnels will be filled with backfill material (a mixture of bentonite clay and crushed rock).

There is a need to test and demonstrate in full-scale the execution and function of the deposition sequence, and to demonstrate that it is possible to understand and quantify the processes which take place in engineered barriers and the surrounding host rock. This need has resulted in the decision of constructing a Prototype Repository, which will be conducted by SKB at the Äspö Hard Rock Laboratory.

The major objectives of the Prototype Repository are (Dahlström, 1998):

- To test and demonstrate the integrated function of the HLW repository components under realistic conditions in full-scale and to compare results with models and assumptions.
- To develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- To simulate appropriate parts of the repository design and construction processes.

To reach the proposed objectives, important processes will have to be monitored for long periods of time. The evaluation of the Prototype Repository will, therefore, be followed for about 20 years. Chemical conditions and microbial processes are included in the monitoring program because they are of importance for the stability of the copper canister and would influence actinide mobility, should a canister fail. This document proposes a scheme for the monitoring of such processes in the Prototype Repository, and it describes the methodology proposed for the sampling.

1.1 DESIGN OF THE PROTOTYPE REPOSITORY

The Prototype Repository will be located in the inner section of the TBM excavated tunnel, which has a diameter of 5 m and is located at about 450 m depth, see Figure 1. The length of the site is about 60 m.

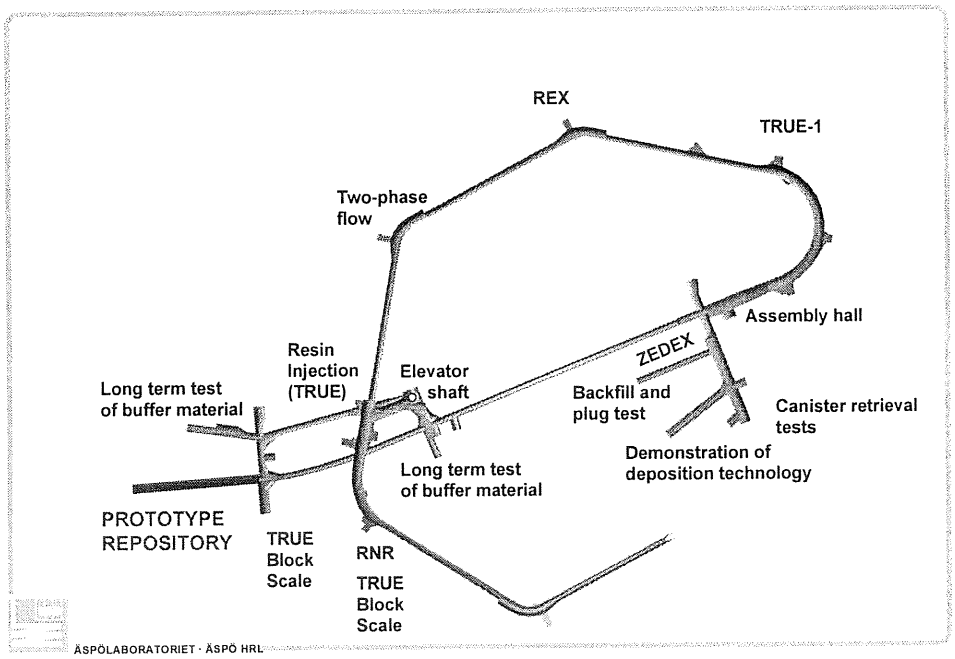


Figure 1. The Prototype Repository located in the tunnel system of the Äspö Hard Rock Laboratory.

The Prototype will have six deposition holes in full scale distributed in two sections, which will be separated by plugs as shown in Figure 2 and Figure 3. The inner section will contain four deposition holes that will be left for 20 years, while the outer section will contained two boreholes which will be decommissioned after about 5 years.

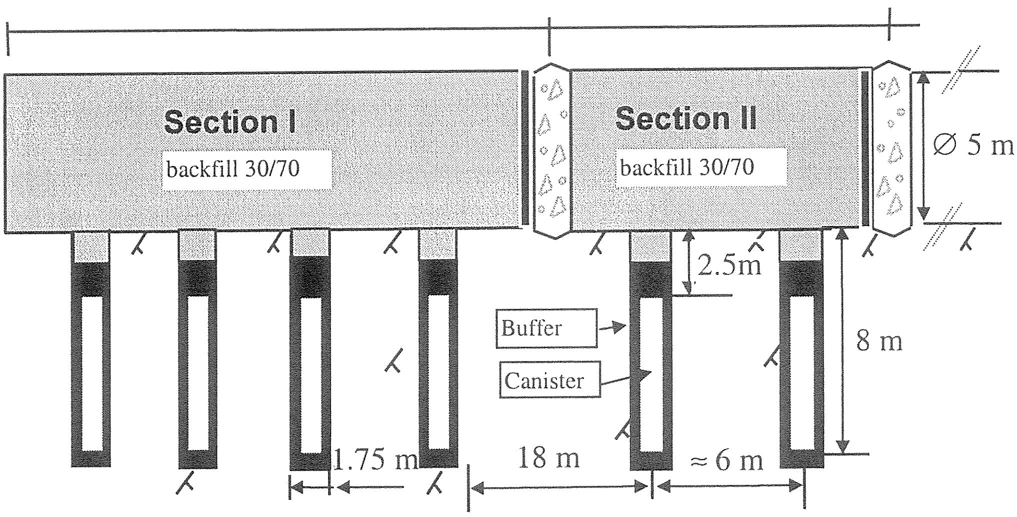


Figure 2. Schematic view of the Prototype Repository.

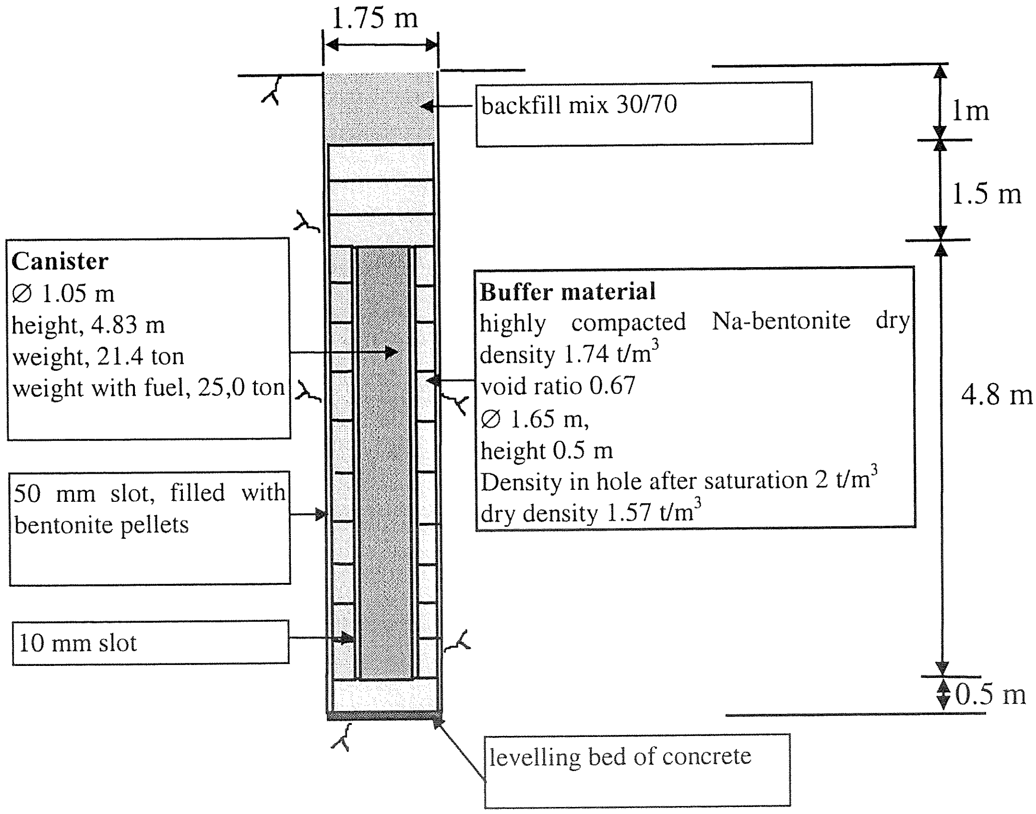


Figure 3. Schematic view of the deposition holes in the Prototype Repository.

1.2 RELEVANCE OF CHEMICAL AND MICROBIAL PROCESSES TO REPOSITORY PERFORMANCE

Both the chemical stability of backfill material and the corrosion rate of the canister are important areas of uncertainty in repository safety and performance assessment. These are processes that depend on the hydrochemical characteristics of the near field.

The solubility and migration characteristics of several radionuclides are highly dependent on the chemical composition of the groundwater. Other factors affecting radionuclide mobility are the hydraulic and mineralogical properties of the rock. A suitable description of the chemical environment is required in order to demonstrate the proper function of the engineered barriers of the Prototype Repository.

Current research tasks regarding microbial processes in the repository were recently reviewed and published (Pedersen, 1997) and that report is recommended for detailed information about microbial issues raised in this test plan. Chemical aspects of nuclear waste disposal have been surveyed in (Banwart et al., 1997; Laaksoharju and Wallin, 1997; Wikberg et al., 1993). Current research tasks are:

- Studies on copper corrosion under near-field conditions.
- Research on the hydrochemistry of granitic groundwaters.
- Exploration of the effects of $CaCO_3$ (calcite) precipitation on groundwater composition and flow.
- Studies on the removal of O_2 from a HLW: relative contribution from bacteria and rock-water reactions.
- Appraisal of energy sources and fluxes of energy that will be available for microorganisms in a HLW repository.
- Assessment of the influence from bacterial production and consumption of gases like carbon dioxide, hydrogen and methane on the performance of a HLW repository.
- Bacterial corrosion of the copper canisters, if any, will be a result of sulphide production. Two important objectives arise: Investigation of the survival of, and possible sulphide production by, sulphate reducing bacteria in the bentonite surrounding the canisters? It must be experimentally confirmed that bacterial sulphide production in the backfill and the surrounding rock does not exceed a performance safety limit.

Microorganisms have the capability to reduce important groundwater components such as sulphate to sulphide and to produce and consume gases. The documented presence of a deep biosphere (Pedersen, 1997; Pedersen and Karlsson, 1995) implies that relevant microbial reactions should be included in the performance assessment for a HLW repository. In conclusion, the repository will not be a sterile environment and microbial activity that influence the hydrochemical situation must, therefore, be studied. The following microbial issues have relevance for Prototype Repository performance:

- The HLW environment and the surrounding rock will not be sterile. Microorganisms will, at various rates, be active in biogeochemical processes of which several do not occur without them. They may influence the performance of a HLW repository in negative, neutral and positive ways. Six major influence areas were discussed in (Pedersen, 1997).
- Microorganisms have the capability to reduce important groundwater components such as sulphate to sulphide and to produce and consume gases. The documented presence of a deep biosphere implies that relevant microbial reactions should be included in the performance assessment for a HLW repository.
- The presence of active microorganisms in a HLW repository cannot be avoid and may be very beneficial for rapidly obtaining reducing conditions there. Microbial activity will thereby have a positive influence on the performance of a HLW repository and reduce the risk for oxygenic copper corrosion of the canisters.
- Microbial corrosion is an important process to consider in the performance assessment of a HLW repository because the canisters used are an absolute barrier to radionuclide dispersal, for as long as they

- remain intact. Copper/steel canisters are considered in the present Swedish spent fuel concept and especially the outer copper canister is an important protective barrier.
- The bentonite buffer around the copper canisters will be a hostile environment for most microbes due to the combination of radiation, heat and low water availability (Pedersen, 1997). Discrete microbial species can coup with each of these constrains and it is theoretically possible that sulphide producing microbes may be active inside a buffer, although the experiments conducted this far have shown the opposite.

2 OBJECTIVES

The objectives of the chemical and microbial monitoring are

- to follow the conditions in the near-field of the Prototype Repository.
- to perform simple tests that confirm physico-chemical or microbial processes occurring in the Prototype.

The final aim is to gain sufficient understanding of chemical and microbial processes to be able to predict reliably the performance of a future HLW repository.

These objectives will be achieved by monitoring microbial activity, microbial diversity and water quality in the rock, backfill and buffer of the Prototype Repository.

Several restrictions are imposed on the sampling/measuring:

- Minimal disturbance to the performance of the experiment and to other monitoring programs.
- The monitoring must reflect the *in-situ* conditions of pressure and temperature to avoid chemical changes of the water samples (degassing, precipitation, etc.).
- The equipment must function up to 20 years. Microbial contamination of the equipment to be used must be avoided due to the risk for clogging by microbial biomass. The equipment must not contain organic material that can be metabolised by bacteria. All equipment must be sterilisable.

2.1 EXPECTED OUTCOME

The sampling and analysis of waters from the Prototype Repository will allow the validation of important aspects in repository performance. These results will be supported by the preliminary characterisation and by the analysis of the Prototype on dismantling. The following are some of the most important questions that the chemical and microbial programme will address:

- In situ determination of the O_2 disappearance rate in buffer and backfill.
- Registration of the redox potential distribution in backfill and buffer over time.
- Potential sulphate reduction rates in buffer and backfill with and without the addition of sulphate reducing bacteria.
- Salt precipitation from porewaters due to developing temperature gradients.
- Possible alterations of the organic carbon naturally present in bentonite.
- Assessment of possible bentonite colloid migration in groundwater from the deposition holes.
- Comparison of calculated copper corrosion values with measured values.
- Determination of copper corrosion products in the bentonite buffer.

Furthermore, it will be possible to confirm that no unexpected detrimental processes occur under *in-situ* and full-scale conditions.

3 PROGRAMME CONCEPT

3.1 BACKGROUND

The sampling programme should be designed to take representative volumes from media with a wide variation of hydraulic conductivity. Owing to the characteristics of the buffer material, only small volumes of pore water are expected, and long sampling times will probably be involved. Therefore considerable planning and testing will be required to design the sampling equipment.

3.2 EXPERIMENTAL CONFIGURATION

Apparatus with mobile parts are prone to wear and tear, and therefore they have limited life expectancy. Two reasons indicate that the water sampling equipment should not involve movable parts inside the Prototype Repository: a) the expected long time span for the Test (about 20 years), and b) the geometry of the Prototype precludes any repairs or replacement of defective parts.

Waters will therefore be isolated in the different parts of the Prototype and transferred through plastic tubing to the adjacent tunnel, where they will be monitored and sent for analysis. In the case of groundwater sampling from fractures in the host rock, the natural hydrostatic pressure will prompt the transfer of fluids from the boreholes to the adjacent tunnel. In the case of the buffer and backfill, an inert gas (argon) will be used to gently push the collected water volumes through relatively thin tubes from the sampling location to the tunnel.

3.2.1 Materials

To prevent diffusion of gases and microbial degradation, only corrosion resistant metals (like titanium) or compact plastic materials, e.g. PEEK, will be used as tubing material to collect the Prototype Repository waters.

The operation of the Prototype will pose severe corrosion problems, due to the expected reducing conditions, the chloride contents of the waters, and the duration of the experiment.

Microbial contamination of the equipment must be avoided and it must, therefore, be possible to sterilise the equipment, either by heating or by rinsing with liquid disinfectants, such as chlorine dioxide or mixtures of ethanol and formaldehyde solution. The equipment must not contain organic material that can be metabolised by bacteria.

The equipment must function up to 20 years. Microbial contamination of the equipment to be used for investigations must be avoided due to the risk for clogging by microbial biomass. All equipment must therefore not contain organic material that can be metabolised by bacteria and be possible to sterilise before installation and during the 20 years of experiment time.

3.2.2 Sampling from the Bentonite Buffer

The buffer material in the Prototype Repository will consist of compacted bentonite. During the operation of the Prototype, the bentonite will adsorb groundwater and swell to achieve a proportion of about 20 % in weight of water. Laboratory studies have shown that bentonite has a large affinity for water, and therefore it is quite difficult to extract pore water from bentonite-water mixtures containing 20% water. For example, (Cuevas et al., 1997) used a pressure of 600 bar to extract pore waters in their study, while (Sasaki et al., 1995) used ultra filtration and ultra centrifugation.

Because the operating hydrostatic pressure for the Prototype Repository is expected to be between 30 to 45 bar, sampling of pore waters should pose no other difficulty than requiring long sampling times.

3.2.2.1 Sampling Points

To obtain some geometric indication of the hydrochemical stability of the buffer surrounding the canister, two deposition holes should be subjected to detailed monitoring. To keep tubing lengths to a minimum, these two holes should be the nearest to the plug in each of the two sections of the Prototype Repository.

These two deposition holes should be sampled with ten monitoring devices, each. A suggested spatial distribution of the sampling points for the deposition holes with detailed monitoring is shown in Figure 4.

Some of the sampling points will be located in the interface between the granitic host rock and the bentonite buffer, as indicated in Figure 4.

The remaining deposition boreholes will be monitored with two sampling points situated at increasing distances from the canister surface, cf. Figure 5.

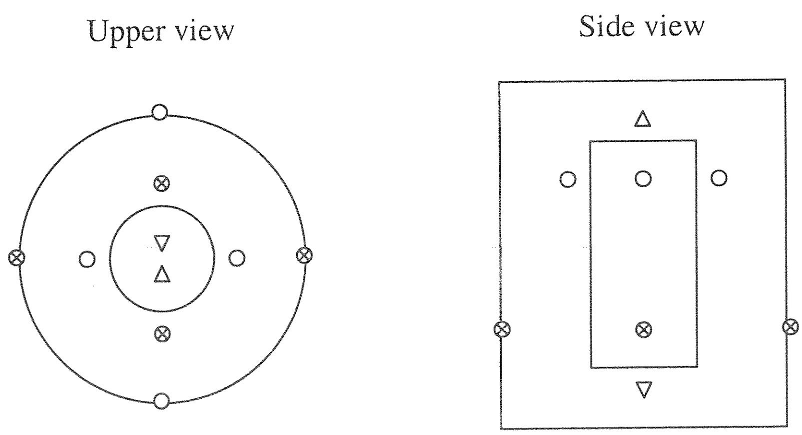


Figure 4. Schematic diagram indicating the suggested disposition for the sampling points for pore waters in the deposition holes with detailed monitoring.

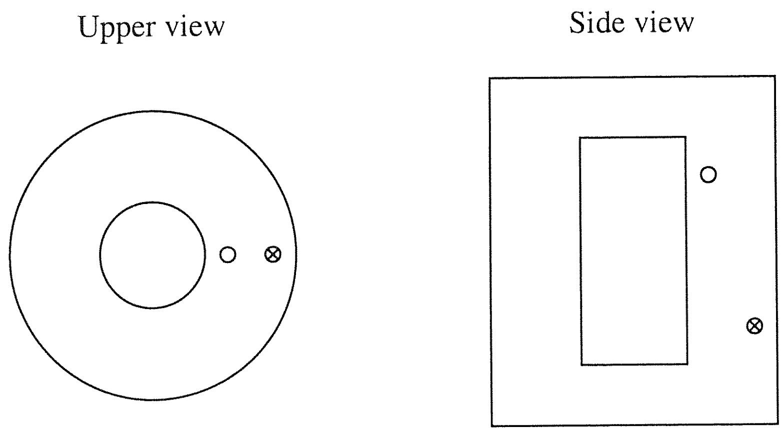


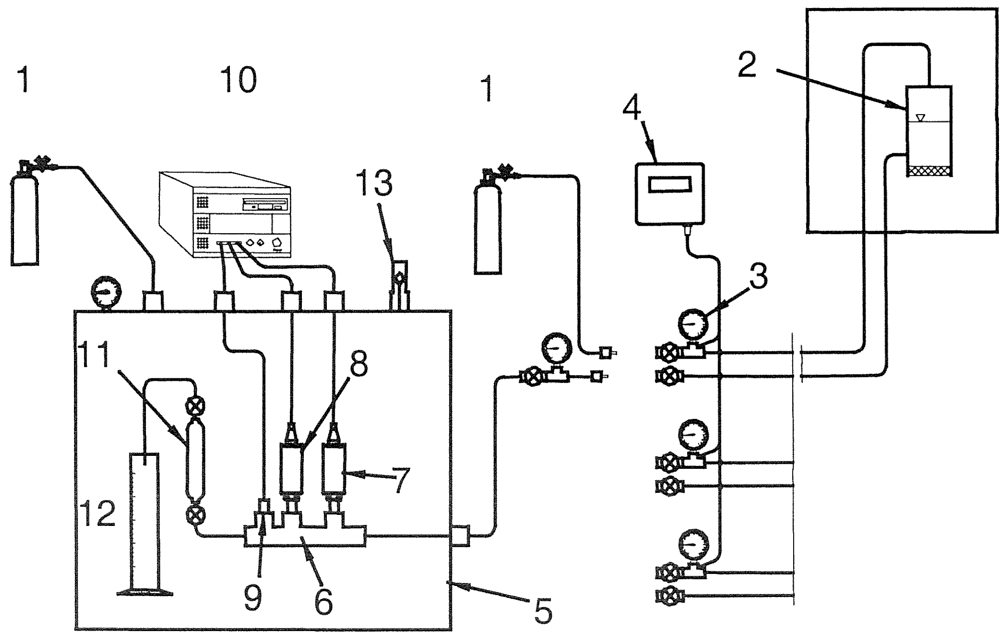
Figure 5. Schematic diagram indicating the suggested disposition for the sampling points for pore waters in the deposition holes with standard monitoring.

3.2.2.2 Sampling Equipment

A dual concept is proposed to collect porewaters from compacted bentonite buffer. Both methods rely in that the hydrostatic pressure surrounding the bentonite buffer will be ≥ 40 bar. The two concepts are:

- *Sampling vessels:* Small containers (≈ 5 cm^3) having a porous wall, and connected by thin tubing to a sampling station adjacent to the Prototype Repository. This method may be used as well to sample the gas phase before the buffer is completely saturated with water. This method allows to obtain the composition of the fluids as a function of time
- *Unattached thimbles:* Small containers (≈ 3 cm^3) having a porous wall on the top. Once the bentonite buffer is completely water-saturated, porewater will penetrate the vial through the porous lid. When the Prototype is dismantled, the vessels can be collected and the waters analysed. This method will only produce the "steady-state" porewater compositions prevailing when the Prototype Test is stopped.

The concept for the proposed "*Sampling Vessels*" equipment is illustrated in Figure 6. This type of sampling equipment for the buffer material consists of a container having some porous material at the bottom that will act as a filter. The approximate volume of this container is 5 to 10 millilitres. The pore water will penetrate the container due to the pressure difference. The collected fluid will be transferred to the adjacent tunnel through tubes that will be tight towards diffusion of gases.



1: Vessel for inert gas; 2: Sampler; 3: Pressure sensor; 4: Data collection unit; 5: Glove box; 6: Flow-through measuring cell; 7: pH probe; 8: E_H probe; 9: Temperature probe; 10: Data logger; 11: Sample cylinder; 12: Measuring cylinder (for excess flow); 13: Inert gas outlet.

Figure 6. Proposed concept for the sampling vessels and related equipment for bentonite porewaters (not drawn to scale).

The amount of water volume collected will be estimated by monitoring the increase in pressure of the inert gas that fills the vessel and tubing at the beginning of a sampling cycle.

The final design of the "*Sampling Vessels*" equipment will include the experience from the on-going Matrix Fluids project that will sample waters in low conductive bedrock at Äspö (Smellie, 1999).

The design for the "*Unattached Thimbles*" is illustrated in Figure 7. This method consists of introducing, in the bentonite blocks, slender cylindrical containers having a porous cap. These vessels will need relatively thick walls to withstand the swelling pressure of the bentonite. An inert material such as titanium should be chosen. The volume of the receptacle should be around 3 cm^3. Once the bentonite buffer is completely water-saturated, porewater will penetrate the vessel through the porous plug until the vessel is filled.

When the deposition hole has to be dismantled, the heaters in the copper canister will be switched-off, and the bentonite buffer will be allowed to cool-off. The water adsorbing capacity of the compacted bentonite will then perhaps increase, and the top portion of the water sampled in the vessels will then be re-adsorbed by the bentonite. When the bentonite is excavated, the unattached sampling vessels can be collected and the contained waters will be analysed.

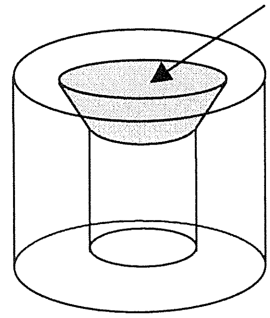


Figure 7. The unattached titanium "thimbles" for sampling buffer porewaters (not drawn to scale).

Although the "*Unattached Thimbles*" method will only produce steady-state porewaters prevailing when the Prototype Test is stopped, it has the advantage of simplicity over the "*Sampling Vessels*" method, where temperature gradients might induce processes that clog the connecting tubes when filled with porewaters.

3.2.2.3 Copper-Porewater Interactions

An interesting modification of the "*Unattached Thimbles*" technique would be to drill a short, slender vertical or sub-horizontal hole in one or several copper canister lid(s), and cover the lid with a porous filter, if possible of sintered copper. After bentonite saturation, the cavity would eventually fill with bentonite porewater. After the termination of the test, and dismantling of the Prototype, the canister lid can be inspected to identify corrosion products resulting from the interaction of copper and porewater in this artificial pit.

3.2.3 Sampling in the Backfill

The backfill material in the Prototype Repository will consist of a mixture of crushed rock and bentonite clay, in a proportion 70/30 weight %. It is expected that pore water from the backfill can be obtained in larger quantities and with shorter sampling times than when monitoring the buffer.

3.2.3.1 Sampling Points

A suggested spatial distribution of the sampling points for the backfill is shown in Figure 8. These locations are selected to obtain a geometric indication of the hydrochemical stability of the backfill.

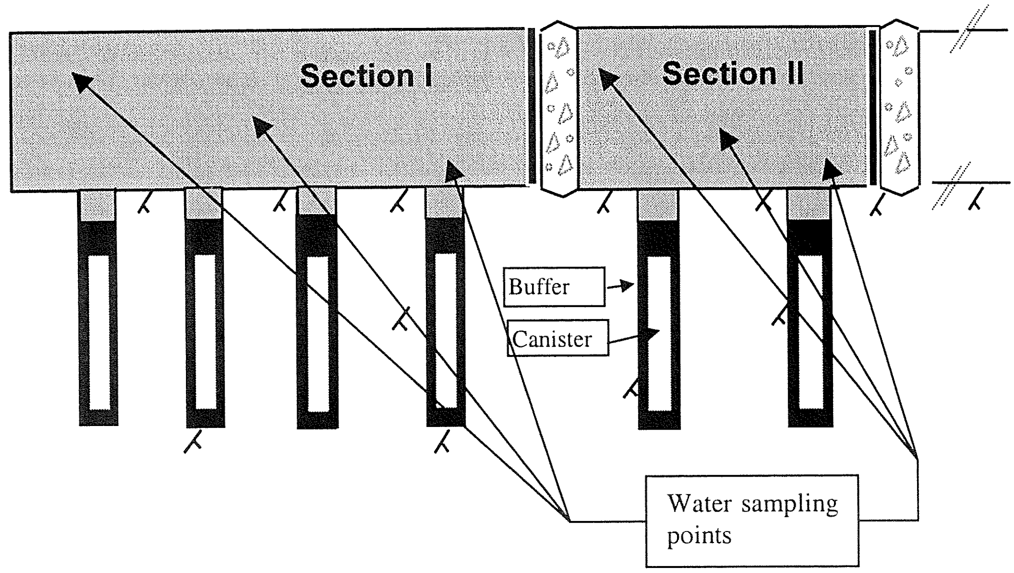


Figure 8. Schematic diagram indicating the suggested disposition for the sampling points for pore waters in the backfill.

3.2.3.2 Sampling Equipment

The sampling equipment for the backfill will be the similar to that used for the buffer, cf. Section 3.2.2.2. Possible differences might be the volume of the sampling vessel, and the type of filter.

3.2.3.3 Test of Cellulose Stability

Cellulose is degraded by contact with cement porewater. A major degradation product is isosaccharinic acid (ISA) which, at high pH, can form strong complexes with polyvalent cations. This can increase their solubility but ISA has itself a tendency to sorb in concrete (making it less harmful to the function of concrete as a barrier to radionuclide migration). Bacterial degradation of ISA has also been postulated. Cellulose is a normal component in low level radioactive waste. In a repository for spent fuel there is no cellulose present if not left as stray materials, for example debris of wood, paper etc.

The degradation of cellulose and sorption of ISA in concrete has only been demonstrated so far by laboratory experiments. The following experimental set-up will be used to corroborate these phenomena *in situ* in the backfill environment.

Samples of concrete and cellulose will be installed near the floor or, preferably, in a short (few dm) large diameter (1-2 dm) borehole in the floor of the tunnel. This will ensure that groundwater enters the samples. The samples can be formed by tissue of paper, cloth and thin pieces of wood placed separately between slabs of concrete. The cellulose/concretesandwich is placed in the whole on sand and covered with sand for protection and to ensure hydraulic conductivity.

Some of the cellulose samples will be separated from the concrete slabs by a few mm of bentonite to see if that stops concrete-porewater from migrating and degrading the cellulose.

The evaluation of this monitoring experiment is not trivial. ISA will, presumably, be found in the cellulose samples, some will be sorbed in concrete and some might leave the system or be decomposed (by bacteria). Analysis of ISA in concrete is difficult but valuable if possible. The cellulose samples need to be weighed their characteristics have to be recorded before the emplacement.

3.2.4 Sampling in the Host Rock

The chemical and microbial situation in the groundwater around the Prototype Repository must be monitored before installation of canisters, buffer and backfill. The microbiology of groundwater is prone to changes during the establishment of Prototype Repository equipment, and should, therefore, be analysed as close as possible to the start of the experiment. Boreholes and fractures transporting groundwater to the buffer and backfill should be sampled.

3.2.4.1 Sampling Points

To achieve a geometric assessment of the hydrochemical and microbial stability of the host rock in the vicinity of the Prototype, not less than eleven sampling points should be used. The sampling points should be arranged in a symmetrical disposition, as suggested in Figure 9. Appropriate boreholes will be selected for this groundwater sampling.

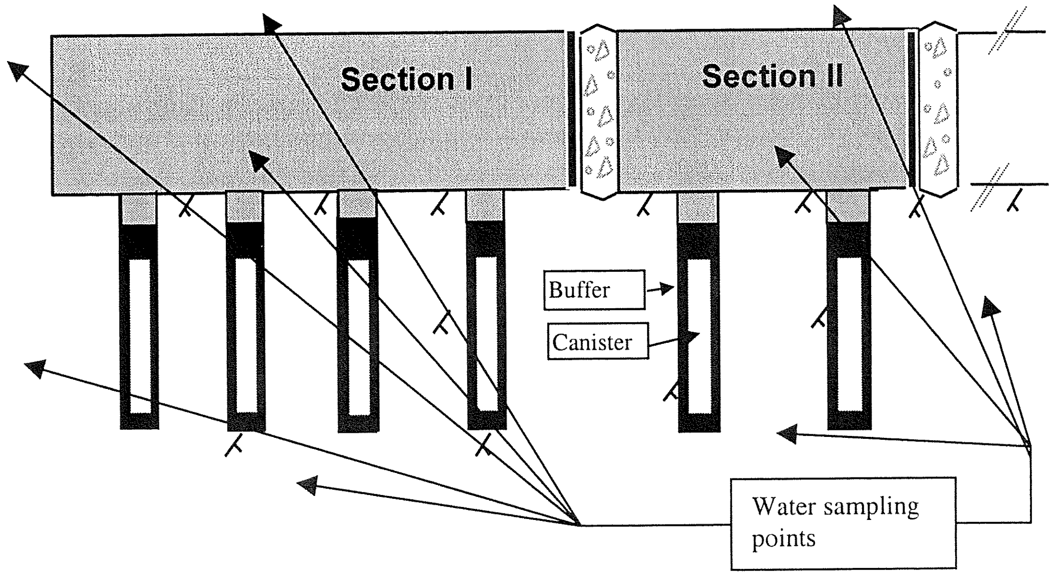


Figure 9. Schematic diagram indicating the suggested disposition for the sampling points of groundwater in the host rock.

3.2.4.2 Sampling Equipment

Packers will be installed to isolate the selected sampling points. Special care must be taken to select packers that remain tight for the long time periods (≥ 20 years) of operation of the Prototype Test.

3.3 PROBLEM AREAS

The following problems may arise during the water monitoring of the Prototype,

- The long-time duration of the Prototype Repository Test might result in leakages developing around the various packers.
- Potential contamination of samples during transportation from the prototype to the laboratory should be avoided. The samples should be collected under inert gas pressure in a glove box, and transported in sealed cylinders.

4 SCOPE OF THE SAMPLING PROGRAMME

The main target of the project is to monitor processes that may take place in the Prototype. Important chemical and microbial parameters are:

- Redox conditions: Eh and redox-buffering capacity
- Alkalinity and pH
- Salinity and main constituents: Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-
- Availability and concentration of corroding substances: sulphide, etc.
- Microbes
- Organic matter (DOC and TOC)
- Colloids
- Dissolved gases: oxygen, hydrogen, and methane
- Hydrogen and oxygen isotopes
- Other isotopes
- Survival of bacteria
- Migration of bacteria from the groundwater
- Microbial sulphate reducing activity
- Microbial oxygen consumption

It might not be possible to monitor all these parameters in the Prototype Repository waters. The analysis of organic matter, colloids, gases, and isotopes, will be given lower priority.

4.1 MAIN TASKS BEFORE BACKFILLING

A complete initial characterisation of the rock at the Prototype Repository site is required for a satisfactory interpretation of the data collected during the operation. The data from such a characterisation constitute the chemical and microbial "boundary" conditions.

The following tasks are involved:

- Mineralogical and chemical characterisation of the host rock surrounding the Prototype Repository site.
- Mineralogical and chemical characterisation of the fracture minerals from boreholes in the vicinity of the Prototype Repository site.
- Chemical sampling and analysis of groundwaters from the rock mass surrounding the Prototype Repository.
- Microbial sampling and characterisation of groundwaters from the rock mass surrounding the Prototype Repository.
- Mineralogical and chemical sampling of bentonite used as buffer in the deposition holes. One or two samples from each deposition hole are analysed. Special emphasis should be given to redox components: Fe(II)/Fe(III) ratio in the clay, organic material, pyrite and sulphides, etc. Another element of importance is of course the copper content. If

- bentonite pellets originate from a special shipping, they must be analysed as well.
- Microbial analysis of the bentonite. The same samples as indicated above must be analysed. Special emphasis should be given to fungi, which are known to develop on the surface of humid bentonite blocks, and could create migration paths for water and solutes (radionuclides) in the deposition holes.

4.2 MAIN TASKS DURING OPERATION

The following major tasks are foreseen:

4.2.1 Design, Testing, and Construction of Sampling Equipment

4.2.1.1 Buffer Material: Test and Design of "Traps" for Porewater Sampling

Objective: To design and manufacture traps (both attached and thimbles, cf. Section 3.2.2.2) for chemical water sampling in the buffer material. The vessels must be constructed so that the properties of the contained water to a minimal degree are influenced by the retrieving procedure.

The work has three parts

- Defining specifications of the functions during the saturation of the backfill and the retrieving. This moment also include the choice of material.
- Design and manufacturing of the trap.
- Testing of the reservoir in laboratory conditions during relatively short periods of time. The trap is mounted in bentonite and the system is pressurised in a chamber where the pressure gradient can be varied.

4.2.1.2 Testing the Transport of Fluids in Narrow Tubing

The objective is to ascertain if it is possible to transport small water volumes pushed by gas pressure through narrow tubing from the sample reservoir (located within the bentonite buffer) to a sample collector located outside the Prototype.

This work include choice of tubing material and driving gas, purchasing of material, connection of the test set-up and performing the test.

The test is to be done by connecting two tubes, ~ 30 m long, to a transparent cylinder. One tube is connected to a gas regulator and the other to a bag filled with silica gel. The bag is placed on an accurate scale. The cylinder is filled with water. The water is then pressed from the cylinder to the bag by means of gas. The weight of the bag is registered with time.

4.2.1.3 Construction of Sampling Equipment from Buffer Material

Aim: To design and test a sampling cylinder able to extract water from the saturated backfill material. The extracted water volume should then, through tubing, be transported to a unit for sampling and measuring unit.

The work is divided in three moments:

- Design and manufacturing of a sampling cylinder and a test of the cylinders ability to withstand high pressure.

  The material of the cylinder must be chemically inert and should not change its characteristics during time or due to high pressure. The properties of suggested materials are taken from the literature. In the design of the cylinder, the volume and the geometry are of great importance. This work is done in accordance with the views of involved chemists, microbiologists and the experts on bentonite.

- Designing/finding a suitable filters to mount on the sampling cylinder. Things to consider in this process, among others, are:
  - The area of the filter.
  - The filtering function regarding particles from the compacted bentonite.
  - Minimising the risk for ”clogging”.
  - The stability.

- Test in laboratory of the sampling cylinder prototype mounted in compacted bentonite.

  The test is done in a laboratory but should be as close to the expected ”real” conditions as possible. The sampling cylinder with its tubing should be mounted in the buffer material and enclosed in a pressure chamber with pressure-proof lead-through. In the pressure chamber, different hydraulic pressures can be generated.

  Before this test the following questions (among others) should be answered:
  - Development of a method to record the water volume in the cylinders over time.
  - Design of a method for sampling escaping gas from the bentonite via the cylinders.
  - Determine the degree of water saturation at which sampling of water should begin.
  - Determine the desired hydraulic gradient to be generated.
  - Develop a cleaning protocol for the equipment before start of the experiment and between sampling occasions.
  - Take a decision on the number of sampling to be performed during operation.

The test should make it possible to solve the following tasks:

- The sampling cylinder should extract water from the bentonite.
- The amount of water extracted over a given time should be predictable.
- Water must be transported from the cylinder to a mobile measuring-sampling unit.

4.2.1.4 Construction of Packer System for Chemical and Microbial Sampling of Water in Boreholes

Aim: Design of a multipacker system to make water sampling from different sections in a borehole possible.

The work is divided in two moments:

- Construction and manufacturing of a prototype multipacker system. The experiences gained from the construction of bentonite packers in the "Backfill and Plug Test" and from the PEEK packers constructed in the project "Ground Water Sampling from Low-Conductive Bedrock" will be taken advantage of.

  An important part of this work is a list of requirements among other things including materials, hydraulic conductivity intervals, type of tests (tracer dilution measurements), inclination of boreholes, number of tubes to the sampling sections, number of sections, maximum sampling flow, maximum differential pressure over the packers.

- Test of the system. The prototype multipacker system could either be tested in a borehole in the Äspö Laboratory or in a steel pipe on which connectors are mounted to simulate fractures. Through these connectors the pressures in the different sections can be controlled individually to test the maximum differential pressure and water supplied to make a functional test of the thin tubes passing through the packers.

4.2.1.5 Design of Permeable Filter Layers to Receive Gas/Water from the Backfill Material and Evacuate Fluids Through Tubing

Aim: To design, construct and test a permeable filter unit to be placed in the tunnel backfill in order to absorb water. It should then be possible to transport the water volume to a measuring and sampling unit outside the tunnel.

The work is suggested to be divided in two moments:

- Construction and manufacturing of the permeable filter unit. The permeable filter unit must be made of a material that is chemically and mechanically resistant and does not change during a time period of 5 – 10 years. The characteristics of the suggested materials are taken from the literature. The experiences gained in the "Backfill and Plug Test" project will be taken advantage of. Before the start of this moment the following questions ought to be answered:

- Design of a method for sampling escaping gas from the bentonite via the cylinders.
- Develop a cleaning protocol for the equipment before start of the experiment and between sampling occasions.
- Decide on the sampling protocol and flow rates during the sampling.

- Laboratory test of the permeable filter unit when mounted in the backfill material. This test is to be made in a laboratory but must be as close to the "real" conditions as possible. The permeable unit is contained in the backfill. The backfill is exposed to a hydraulic pressure to generate a sufficient gradient towards the permeable unit and the water escaping through the tubing is monitored. The layer and the tubing are examined at the end of the test.

4.2.1.6 Design of a Connection Panel for Emerging Tubing from the Sampling Points to the Mobile Measuring-Sampling Unit

Aim: To design a panel that in an intuitive and pedagogical way makes it possible to connect the mobile measuring and sampling unit to the tubing from the different measuring and sampling points emerging from the test set-up.

The work is divided into the following moments:

- Construction and manufacturing of a complete panel (prototype with connectors and pressure transducers for two sections). The panel is to be made in an intuitive and pedagogical way that minimises the risks of faulty engagements. Connectors and valves should be made in a way that eliminates the risk of contamination by irrelevant gases, fluid and microorganisms.
- Test of the "connecting the mobile measuring and sampling unit" concept. During the test cleaning and contamination risks should be considered.

4.2.2 Design, Construction and Testing of a Mobile Measuring-Sampling Unit

Aim: To construct and manufacture a mobile measuring and sampling unit adapted to the specific demands of the chemical and microbiological sampling in saturated buffer material. The measuring part of the unit consists of sensors for water chemical parameters (pH, Eh, temperature, etc).

The work is divided into the following parts:

- Construction and manufacturing of a mobile measuring and sampling unit. Measurement and sampling of the water coming from the sampling cylinders should be made in a way that minimises changes in its properties. A glove box will ensure sterile non-oxidising environment.

The low flow rates (and volumes) put special demands on the sensors and the sample containers. The cleaning is of outmost importance.
The construction is done in close co-operation with the experts in chemistry and microbiology involved in the project.

- Design of suitable signal processing (calibrating, logging and presentation) from the different sensors.
- Test of the measuring and sampling unit. This test is done inside the Äspö Laboratory in as authentic circumstances as possible.

4.2.3 Installation of Sampling Devices

The following equipment needs to be installed

- Packers in monitoring boreholes surrounding the Prototype. Tubing for sampling of groundwaters.
- Sampling reservoirs in the bentonite blocks. Tubing to collect gas and water samples.
- Sampling reservoirs in the tunnel backfill. Tubing to collect gas and water samples.
- Connection panel for the tubing emerging from the sampling points.
- Mobile Measuring and Sampling Unit.

4.2.4 Sampling During Operation Phase

Sampling will be performed when the sampling vessels have been filled, but not more than once every year from the backfill, and probably not more than once every 3-5 years from the buffer. The tests in 4.2.1 must be performed before a precise sampling plan can be set.

4.2.5 Evaluation and Interpretation of Data

Special modelling groups will be convened to evaluate the data from the geochemical and microbial perspectives.

4.3 MAIN TASKS DURING THE DISMANTLING OF THE PROTOTYPE REPOSITORY

A complete final characterisation of the Prototype Repository components is required for a satisfactory interpretation of the performance of the Prototype Repository.

The following tasks are involved:

- Mineralogical and chemical sampling of the bentonite used as buffer in the deposition holes. Several samples from each deposition hole are analysed. The following questions are of interest:
  - Comparisons of the ion exchange capacity and the mineralogy of the bentonite at start and end of the test.

    - Analysis of salt precipitation due to the heat gradient.
    - The redox components: Fe(II)/Fe(III) ratio in the clay, organic material, evidence for pyrite oxydation, etc.
    - Determination of the migration of copper into the bentonite and of possibly formed secondary copper mineralisations.
    - Evaluation of possibly performed tracer migration experiments.
- Characterisation of the surface of the copper canister: Search for evidence of localised corrosion.
- Analysis of survival of natural and possibly added microbial populations.
- Evaluation of the cellulose degradation test.
- Analysis of possible sulphate reduction
- Analysis of concrete plug dissolution and pH gradients in the bentonite caused by the concrete.

4.4 DOCUMENTATION

Each of the tasks described above will be systematically documented. This will basically take place in the form of Äspö HRL International Progress Reports (IPR) and International Technical Documents (ITD. The entire work will be summarised in the final reporting of the Prototype Repository results.

5 ORGANISATION

The responsibilities should be distributed as follows:

Prototype Repository:

Project Manager:	Christer Svemar
Assistant Project Manager Of Science:	Lars-Olof Dahlström
Assistant Project Manager of Methods and Techniques	Gunnar Ramqvist
Project Coordinator	Christer Andersson

Chemistry and Microbiology:

Sub-project Managers:	Karsten Pedersen Ignasi Puigdomenech
Design, Testing, and Construction:	Geosigma AB Clay Technolgy AB KTH Gothenburg University Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)
Mineralogy:	Clay Technolgy AB Terralogica AB
Groundwater sampling:	SKB Gothenburg University

This team will be extended as needed to fulfil the objectives of this test plan.

6 COSTS

MAIN TASKS BEFORE BACKFILLING (Section 4.1)	200 000 kr
MAIN TASKS DURING OPERATION (Section 4.2)	
Design, Testing and Manufacturing of Equipment (Section 4.2.1)	
Buffer Material (4.2.1.1)	
Design and Testing	50 000 kr
Manufacture	80 000 kr
Transport of Fluids in Narrow Tubing (4.2.1.2)	17 000 kr
Buffer Material: Sampling Cylinders (4.2.1.3)	
Design and Testing	76 000 kr
Manufacturing	370 000 kr
Packer System for Boreholes (4.2.1.4)	
Design and Testing	100 000 kr
Construction (11 sections)	360 000 kr
Backfill Material: Filter Layers (4.2.1.5)	
Design and Testing	45 000 kr
Construction	20 000 kr
Connection Panel (4.2.1.6)	
Design and Testing	65 000 kr
Construction	365 000 kr
Mobile Measuring-Sampling Unit (4.2.2)	380 000 kr
Installation (4.2.3)	400 000 kr
Sampling (4.2.4)	500 000 kr
Data Evaluation (4.2.5)	500 000 kr
MAIN TASKS DURING DISMANTLING (Section 4.3)	500 000 kr

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