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Äspö Hard Rock Laboratory

Planning Report for 2003

Svensk Kärnbränslehantering AB

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The Äspö Hard Rock Laboratory
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This report presents the planned activities for year 2003 with background, objectives, experimental concepts (where applicable), and scope of work. It details the programme for the Äspö Hard Rock Laboratory described in SKB's Research, Development and Demonstration Programme 2001, and serves as a basis for the management of the laboratory. The plan is revised annually. The activities are further detailed in activity plans for the Repository Technology department covering a time period of six years.

The role of the Planning Report is to present the background and objectives of each experiment. Thereby the Status Reports may concentrate on work in progress and refer to the Planning Report for more background information. The Annual Report will in detail present new findings and results.

Svensk Kärnbränslehantering AB
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Executive summary

General

The Äspö Hard Rock Laboratory (HRL) constitutes an important part of SKB's work to design and construct a deep geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. Most of the research is focused on processes of importance for the long term safety of a future deep repository. The underground part of the laboratory consists of a tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 450 m.

SKB's overall plans for research and development of technique during the period 2002-2007 are presented in SKB's RD&D-Programme 2001. The information given in the RD&D-Programme related to Äspö HRL is detailed in the Äspö HRL Planning Report. This plan is revised annually and the current report gives an overview of the planned activities for the calendar year 2003. Äspö HRL and the associated research, development and demonstration tasks, managed by the Repository Technology Department within SKB have so far attracted considerable international interest.

Technology

One of the goals for Äspö HRL is to demonstrate technology for and function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a real repository. It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. The experiments focus on different aspects of engineering technology and performance testing, and will together form a major experimental programme

The *Canister Retrieval Test*, located in the main test area at the 420 m level, is aiming at demonstrating the readiness for recovering of emplaced canisters also after the time when the bentonite is fully saturated. Bentonite blocks, bentonite pellets, and canisters with heaters have been implemented in one vertically bored test deposition holes in full repository scale. Artificial addition of water is provided regularly around the bentonite blocks and the test has been running for a little more than two years with continuous measurement of the wetting process, temperature, stresses and strains. There is a defect in the heaters caused by low resistance to earth which remain but the heaters have worked properly and a steady, but slightly reduced, power has been maintained and it has been decided to continue the test. The relative humidity sensors indicate that the bentonite between the rock and the canister is close to water saturation. Reporting of measurements and evaluation of the results will be done during 2003 as well as further modelling for increased understanding of the ongoing processes. Decision on when to start the retrieval tests is dependent on information of the degree of saturation.

The *Prototype Repository* is a demonstration of the integrated function of the repository and provides a full-scale reference for test of predictive models concerning individual components as well as the complete repository system. It is also a demonstration of the execution and function of the deposition sequence with state-of-the-art technology in full-scale. The layout involves altogether six deposition holes, four in an inner section and two in an outer. The tunnels are backfilled with a mixture of bentonite and crushed rock. The inner section was installed and a plug cast in 2001. A malfunction in the electrical insulation in heaters was discovered in early 2002 and due to this the installation of the two remaining canisters in the outer section was postponed. The malfunction has been dissolved and the installation in the outer section is now ready to start and the plan is to start the heating during 2003. Modelling teams will continue the comparison of measured data with predictions.

The *Backfill and Plug Test* is a test of the hydraulic and mechanical function of different backfill materials, emplacement methods, and a full-scale plug. The 28 m long test region is located in the ZEDEX drift. The inner part of the drift is backfilled with a mixture of bentonite and crushed rock and the outer part is filled with crushed rock. The test region is divided into sections by permeable mats, which are used for artifical addition of water to the backfill. At the end of 2002 the moisture measurements indicated that the entire backfill is completely water saturated and flow testing can therefore start during 2003 as planned. The flow testing will be complemented with supplementary modelling. In addition, data collection and reporting will be continued. The excavation of the backfill materials in the test region is planned to take place either in 2004 or 2005.

The *Long Term Test of Buffer Material* aims at validating models and hypotheses concerning physical properties in a bentonite buffer material and of related processes regarding microbiology, radionuclide transport, copper corrosion, and gas transport under conditions similar to those in a KBS-3 repository. The testing principle is to emplace “parcels” containing heater, central copper tube, pre-compacted clay buffer, instruments, and parameter controlling equipment in vertical bore holes with a diameter of 300 mm and a depth of around 4 m. At termination of the tests, the parcels are extracted. The water distribution in the clay is determined and subsequent well-defined chemical and mineralogical analyses as well as physical tests are performed. One parcel has been extracted and the bentonite material, copper coupons and tracer test material has been analysed and the results are presently being reported. The remaining four parcels are functioning well and water pressure, total pressure, temperature, and moisture content will be continuously measured and data stored every hour.

In the project *cleaning and sealing of investigation bore holes* the best available techniques for this are to be identified and demonstrated. Investigation bore holes are drilled during site investigations and detailed characterisation in order to obtain data on the properties of the rock. These bore holes must be cleaned and sealed, no later than at the closure of the deep repository. Sealing of the bore holes means that the conductivity in the bore hole is no higher than that of the surrounding rock. Cleaning of the bore holes means that instrumentation that has been used in the bore holes during long time periods, in a sometimes aggressive environment, is removed. A state of the art report summarising the developments of the techniques during the last 10-15 years has been put together. During 2003 activities related to preparation of bore holes to be used in field-tests, selection of suitable plugging materials, and selection of construction methods for the plugging will be started.

A project with the aim to qualify the use of *low pH cementitious products* (leachates below pH 11) for applications like structural cast concrete, shotcrete, rock bolting, and grouting in a repository is carried out by SKB, Posiva, and NUMO in co-operation.

Work with the repository performance has established that a pH below 11 in the pore water can be accepted to assure the long term repository performance and safety. It was, however, found more difficult than expected to find suitable injection grouts that penetrate fine fractures and a planned small field test has therefore been postponed. The present focus is put on finding suitable recipes for injection grouts. Thereafter, when or if suitable low-pH recipes have been developed, small field tests in Äspö HRL are planned to take place where both grouting and rock bolting will be tested.

Late 2001 SKB published an R&D programme for the *KBS-3 method with horizontal deposition* (KBS-3H). The program, which is carried through by SKB and Posiva in co-operation, was divided into four parts: Feasibility Study, Basic Design, Construction and Testing at the Äspö HRL, and Evaluation. The Feasibility Study has shown that the KBS-3H method is worth further development from a technical, economical, and long term safety point of view. The next phase, Basic Design, includes the technical development of the KBS-3H method, preparations for a future demonstration of the method at Äspö HRL, and studies of the barrier performance. The Basic Design phase will be reported late 2003.

The buffer's gas permeability shall be sufficient to allow the large quantities of gas that may be formed in a damaged canister to pass through. SKB has during several years performed a number of experiments with gas-injection on MX-80 bentonite. Today, there is relatively good understanding of the processes determining the gas transport. One remaining question is the importance of the scale. Therefore, the *Large Scale Gas Injection Test* will be carried out to verify the existing results from laboratory experiments. The experiments will be performed in a bored full-size deposition hole in the assembly hall at 420 m level in the Äspö HRL. A full-scale canister without heaters and a bentonite buffer will be installed and water will be artificially supplied. Gas injection tests start when the buffer is fully saturated, first with small gas volumes and finally with a volume corresponding to a damaged full-size canister. The project will be initiated in January 2003 and it is planned that the emplacement of canister and buffer take place during 2003.

The French organisation ANDRA intends to carry out a *Temperature Buffer Test* (TBT) at Äspö HRL in co-operation with SKB. The TBT aims at evaluating the benefits of extending the current understanding of the behaviour of engineered barriers at high temperatures (above 100°C). The test is located in the same test area as the Canister Retrieval Test. The design as well as the preparation of the site and deposition hole has been completed. The canisters with heaters are assembled, testing is ongoing, and a programme for predictive modelling has been established. The modelling group will issue a preliminary predictive modelling report in May 2003. Installation of the test is planned to commence and be finished in early 2003. The operation phase, including heating, artificial pressurised saturation of the buffer and monitoring of temperature, humidity, pressure and displacement, will start as the heaters are turned on.

Geo-science

Geo-scientific research is a natural part of the activities at Äspö HRL. Studies with the major aims to increase the understanding of the rock mass material properties and to increase the knowledge of measurements that can be used in site investigations are important activities.

In the *GeoMod Project* the existing geological, hydrogeological, rock mechanical, and hydrogeochemical models of Äspö will be updated by integrating new data collected since 1995. The updated models focus on the tunnel spiral volume from about 340 m to about 500 m. In addition, the development of a geothermal model will be integrated in the project. The gathered geo-scientific information will be provided to ongoing and coming experiments at Äspö HRL as bases for e.g. the identification of suitable experimental rock volumes and information for the setting of boundary conditions. The integration of the different disciplines will be worked on during 2003 and according to present plans an integration report will be written, reviewed and printed.

Rock stress measurements are performed at Äspö HRL with the aim to be able to make correct assessments of the *in situ* stress field from such measurements. A report will be published during 2003 which will be a major part of the strategy for rock stress measurements as suggested by the International Society for Rock Mechanics.

The objective with the work in the *Rock Creep Project* is to develop better conceptual models for the influence of the rock damaged zone and rock creep on rock stability. A literature study and scooping numerical modelling with a three-dimensional coupled hydromechanical computer code have been performed, which will be presented in a report during the first quarter 2003. The findings will be used to outline the scope of work for the rest of the year.

Äspö Pillar Stability Experiment is initiated at Äspö HRL to demonstrate the capability to predict spalling in a fractured rock mass and to demonstrate the effect of backfill (confining pressure) on the propagation of micro-cracks in the rock mass closest to the deposition hole. A new short tunnel will be excavated in Äspö HRL to ensure that the experiment is carried out in a rock mass with a virgin stress field. Two vertical holes at a distance of one metre will be drilled in the floor of the tunnel, to create the pillar, during autumn 2003. The pillar will be designed in such a way that spalling will occur when the pillar is heated. The heating of the pillar is planned to start early 2004.

The Hydro Monitoring System (HMS) registers at the moment the piezometric head in the underground in the Äspö HRL. By analysing the data on changes in the piezometric head at Äspö the *seismic influence on the ground water system* is expected to be established.

SKB has conducted a number of large field tests where *prediction of inflow* into tunnels or depositions holes has been a component. The results from these tests show that when going from a bore hole to a larger diameter hole, the inflow into the larger hole is often less than predicted. The explanation for this is not yet well understood. The aim with a new project concerning this issue is to make better predictions of the inflow of groundwater into potential deposition holes. During 2003 numerical modelling of water inflow will be carried out and the planning of a full-scale field experiment will begin.

One of the key issues in the process of selecting one site for detailed investigation is the utilisation of the available rock mass expressed as the number of acceptable canister positions. The main objectives of the *Canister position index* project are to find the factors that determine acceptance/non-acceptance of a deposition position, and to identify acceptable parameter values. A project group is established and a work programme launched. The expected interim result during 2003 is an identification of the important factors.

Different fracture zones/discontinuities represent inhomogeneities that need a certain distance of rock to the nearest canister in order to limit the negative effect the features may have on the repository performance. The aim with the *Respect Distance Project* is to identify the factors that determine the distances from a canister to the features and the measurable parameters that determine the values of the distances. A project group is established and a work programme launched for this project which will be run in co-operation between SKB and Posiva.

Natural barriers

At the Äspö HRL experiments, with the aim to increase the knowledge of the long term function of the repository barriers, are performed at conditions that are expected to prevail at repository depth. The bedrock with available fractures and fracture zones, its properties and on-going physical and chemical processes, which affect the integrity of the engineered barriers and the transport of radionuclides, are denoted the natural barriers of the deep repository. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The strategy for the on-going experiments is to concentrate the efforts on those experiments that are of importance for the site investigations. Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are one of the main purposes of the Äspö HRL. The programme includes projects with the aim to evaluate the usefulness and reliability of different models and to develop and test methods for determination of parameters required as input to the models.

A programme has been defined for tracer tests at different experimental scales, the so-called *Tracer Retention Understanding Experiments* (TRUE). The overall objectives of the experiments are to increase the understanding of the processes which govern retention of radionuclides transported in crystalline rock, and to increase the credibility in models used for radionuclide transport calculations. The work is presently performed in two projects; TRUE Block Scale Continuation and TRUE-1 Continuation. The objectives of the TRUE Block Scale Continuation project can be summarised as: "Improve understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure, and micro-structure". The activities during 2003 comprise complementary modelling in support of *in situ* tracer tests which will explore the possibilities to perform tests over longer distances and to introduce tracers in low–transmissive features of the background fracture population. The TRUE-1 Continuation project is a continuation of the TRUE-1 experiments, and the experimental focus is placed on the TRUE-1 site. The planned injection of epoxy resin at the TRUE-1 site will be preceded by complementary cross-hole hydraulic interference tests combined with tracer dilution tests. These tests are intended to shed light on the possible three-dimensional aspects of transport at the site. In addition, a methodology to estimate aperture using radon has been developed which is now tested at the site.

The *Long Term Diffusion Experiment* constitutes a complement to performed diffusion and sorption experiments in the laboratory, and is a natural extension of the experiments conducted as part of the TRUE experiments. The difference is that the longer duration (3-4 years) of the experiment is expected to enable an improved understanding of diffusion and sorption in the vicinity of a natural fracture surface. The experiment will be performed in a core stub with a natural fracture surface isolated in the bottom of a large diameter telescoped bore hole. The experimental set-up has been installed but the pre-test programme has been delayed.

Radionuclide retention experiments are carried out with the aim to confirm result from laboratory experiments *in situ*, where conditions representative for the properties of groundwater at repository depth prevail. The experiments are carried out in special borehole probes. Radiolysis experiments intended to investigate the influence of radiolysis on the migration of oxidised technetium in bentonite clay will be carried out during 2003 in the CHEMLAB 1 probe. The experiments where the migration of actinides in a natural rock fracture in a drill core will be studied in the CHEMLAB 2 probe are also planned to be run during 2003.

The findings of potential transport of solutes by colloids and access to more sensitive instruments for colloid measurements motivated a *Colloid Project* at Äspö HRL. The project comprises studies of the stability and mobility of colloids, measurements of the colloid concentration in the groundwater at Äspö, bentonite clay as a source for colloid generation, and the potential of colloids to enhance radionuclide transport. During 2003 borehole specific measurements will be performed to study bentonite as a colloid source. In addition, the planning of fracture specific experiments, with the aim to study changes in colloid content in groundwater prior and after the transport through a rock fracture, will begin.

Microorganisms interact with their surroundings and in some cases they greatly modify the characteristics of their environment. Several such interactions may have a significant influence on the function of a future deep repository for spent fuel. There are presently four specific microbial process areas identified that are of importance for proper repository functions and that are studied in *Microbe Project*. The process areas are: bio-mobilisation of radionuclides, bio-immobilisation of radionuclides, microbial effects on the chemical stability, and microbial corrosion of copper. During 2003 the planned work mainly comprises activities to study: the influence from three different microbial bio-films on the concentrations of gases (hydrogen, carbon monoxide, methane and carbon dioxide), sorption of selected radionuclides onto three different microbial bio-films, and parameters of importance for biological iron oxide systems (BIOS) formation.

The first phase of the *Matrix Fluid Chemistry* experiment increased the knowledge of matrix pore space fluids/groundwaters from crystalline rocks of low hydraulic conductivity, and this complemented the hydrogeochemical studies already conducted at Äspö. The first phase will be reported by early 2003. The second phase focuses on the small-scale micro-fractures in the rock matrix which facilitate the migration of matrix waters. The understanding of this migration of groundwater, and its changing chemistry, is important for repository performance. The scope of work for 2003 will for example be to extract and analyse additional matrix pore space waters and gases as well as groundwater, additional porosity measurements, conduct post-mortem on the core sample, and carry out long term *in situ* diffusion experiments.

An important goal for the activities at Äspö HRL includes projects with the aim to evaluate the usefulness and reliability of different models and to develop and test methods for determination of parameters required as input to the models. An important part of this work is performed in the *Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes*. The work in the Task Force is closely tied to ongoing and planned experiments at the Äspö HRL. Specified tasks are defined where several modelling groups work on the same set of field data. The modelling results are then compared to the experimental outcome and evaluated by the Task Force delegates. Currently active tasks are coupling between hydrochemistry and hydrogeology (Task 5) and performance assessment modelling using site characterisation data (Task 6). The main work in Task 5 has almost been finalised and a Summary Report and a Reviewers Report will be published during 2003. The work during 2003 within the Task Force focuses on Task 6.

Palaeohydrogeology is a relatively new term used as a common name for information from fracture minerals that is used for interpretations of past hydrogeochemical and hydrogeological systems. When the EU-project EQUIP, which concentrated on the formulation of a methodology for how to conduct a palaeohydrogeological study, ended in 2000 there was a need for continued fracture mineral investigations and model testing of the obtained results and therefore a new EU-project was initiated in the beginning of 2002. This project is called *PADAMOT* (Palaeohydrogeological Data Analysis and Model Testing) and includes further developments of analytical techniques and modelling tools to interpret data, but also focusing further research to investigate specific processes that might link climate and groundwater in low permeability rocks.

Äspö facility

An important part of the activities at the Äspö facility is the administration, operation, and maintenance of instruments as well as development of investigation methods. The main goal for the operation is to provide a safe and environmentally correct facility for everybody working or visiting the hard rock laboratory. This includes preventative and remedy maintenance in order to withhold high availability in all systems as drainage, electrical power, ventilation, alarm, and communications in the underground laboratory. Other issues are to keep the stationary hydro monitoring system (HMS) continuously available and to carry out the programme for monitoring of groundwater head and flow and the programme for monitoring of groundwater chemistry.

International co-operation

Eight organisations from seven countries participated in the co-operation at Äspö HRL during 2002. Most of the organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several of the organisations are participating in the experimental work as well as in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes.

SKB is through Repository Technology co-ordinating three EC contracts: Prototype Repository, Cluster Repository Project (CROP) and the project NET.EXCEL. SKB takes part in several EC projects of which the representation is channelled through Repository Technology in five cases: FEBEX II, BENCHPAR, ECOCLAY II, SAFETI and PADAMOT.

Environmental research

The experiments performed in Äspö HRL are not exclusively focused on radionuclide related processes but also on non-radioactive environmental issues. Äspö Environmental Foundation was founded 1996 on initiative of local and regional interested parties, with the aim to make the underground laboratory available for environmental research. SKB's economic engagement in the foundation will be concluded during 2003.

Äspö Research School was founded 2002 with the objective of providing conditions for today's and tomorrow's research concerning environmental issues. It has a special interest in the transport of pollutants and their distribution in rock, ground, water and biosphere. During 2003 detailed plans for the school activities will be worked out and the goal is to let four doctorial students begin their studies.

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1 General

1.1 Background

The Äspö Hard Rock Laboratory (HRL), in the Simpevarp area in the municipality of Oskarshamn, constitutes an important part of SKB's work to design and construct a deep geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. Most of the research is focused on processes of importance for the long term safety of a future deep repository.

The underground part of the laboratory consists of a tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 450 m, see Figure 1-1. The total length of the tunnel is 3600 m where the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The first part of the tunnel has been excavated by conventional drill and blast technique. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts.

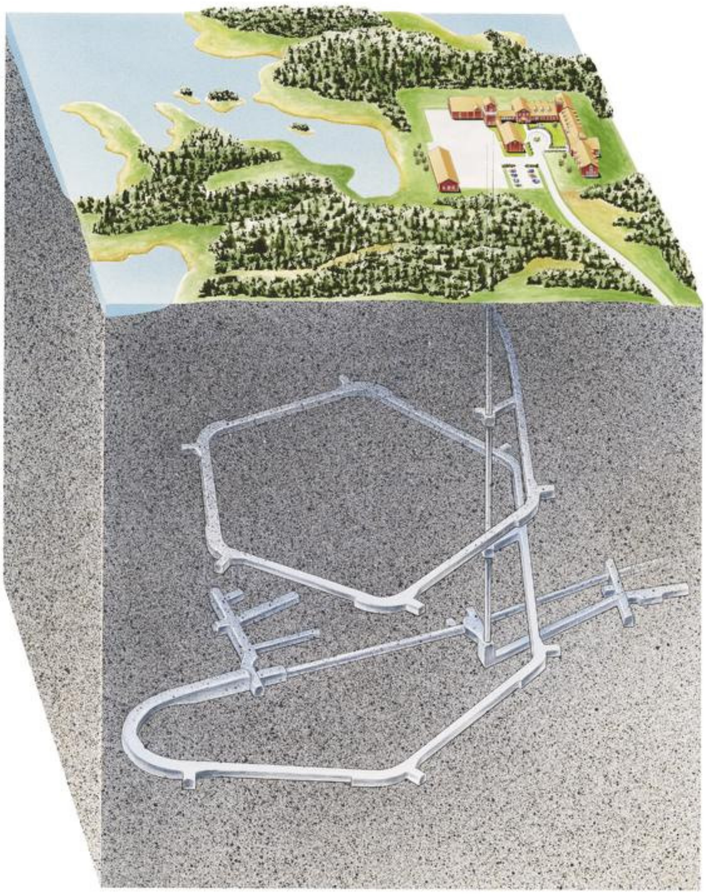

Figure 1-1. *Overview of the Äspö HRL facilities.*

The work with Äspö HRL has been divided into three phases: Pre-Investigation Phase, Construction Phase, and Operational Phase.

During the *Pre-Investigation Phase*, 1986-1990, studies were made to provide background material for the decision to locate the laboratory to a suitable site. The natural conditions of the bedrock were described and predictions made of geological, hydrogeological, geochemical etc. conditions to be observed during excavation of the laboratory. This phase also included planning for the Construction and Operational Phases.

During the *Construction Phase*, 1990-1995, comprehensive investigations and experiments were performed in parallel with construction of the laboratory. The excavation of the main access tunnel to a depth of 450 m and the construction of the Äspö Research Village were completed.

The *Operational Phase* began in 1995. A preliminary outline of the programme for this phase was given in SKB's Research, Development and Demonstration (RD&D) Programme 1992. Since then the programme has been revised every third year and the basis for the current programme is described in SKB's RD&D-Programme 2001 /SKB, 2001a/.

1.2 Goals

To meet the overall time schedule for SKB's RD&D work, the following stage goals were initially defined for the work at the Äspö HRL.

1. *Verify pre-investigation methods*. Demonstrate that investigations on the ground surface and in bore holes provide sufficient data on essential safety-related properties of the rock at repository level.
2. *Finalise detailed investigation methodology.* Refine and verify the methods and the technology needed for characterisation of the rock in the detailed site investigations.
3. *Test models for description of the barrier functions at natural conditions*. Further develop and at repository depth test methods and models for description of groundwater flow, radionuclide migration, and chemical conditions during operation of a repository and after closure.
4. *Demonstrate technology for and function of important parts of the repository system.* Test, investigate and demonstrate on full-scale different components of importance for the long term safety of a deep repository and to show that high quality can be achieved in design, construction, and operation of repository components.

Stage goals 1 and 2 have been concluded at Äspö HRL and the tasks are transferred to the Site Investigation Department of SKB which has began site investigations at two sites, Simpevarp in the municipality of Oskarshamn and Forsmark in the municipality of Östhammar.

In order to reach present goals the following important tasks are performed at the Äspö HRL:

- Develop, test, evaluate and demonstrate methods for repository design and construction, and deposition of spent nuclear fuel and other long-lived waste.
- Develop and test alternative technology with the potential to reduce costs and simplify the deep repository concept without sacrificing quality and safety.
- Increase the scientific understanding of the deep repository's safety margins and provide data for safety assessments of the long term safety of the repository.
- Provide experience and train personnel for various tasks in the deep repository.
- Provide information to outsiders on technology and methods that are being developed for the deep repository.

1.3 Organisation

SKB's work is organised into three main departments; Site Investigations, Technology, and Operation. All research, technical development, and safety assessment work is organised into the Technology department, in order to facilitate co-ordination between the different activities.

Repository Technology (TD), one of five departments organised under the Technology department, is responsible for development and testing of deep repository technology and *in situ* research on repository barriers at natural conditions. The unit is also responsible for the operation of the Äspö facility and the co-ordination of the research performed in international co-operation. The Repository Technology unit is organised in three operative groups, see Figure 1-2:

- *Technology and Science* is responsible for the co-ordination of projects undertaken at the Äspö HRL, for providing service (design, installations, measurements etc.) to the experiments undertaken at Äspö HRL, to manage the geo-scientific models of the "Äspö Rock Volume", and to maintain knowledge about the methods that have been used and the results that have been obtained from work at Äspö HRL.
- *Facility Operation* is responsible for operation and maintenance of the Äspö HRL offices, workshops and underground facilities, and for operation and maintenance of monitoring systems and experimental equipment at Äspö.
- *Administration, QA and Economy* is responsible for providing administrative service and quality systems.

The Äspö HRL and the associated research, development, and demonstration tasks are managed by the Director of Repository Technology. The International co-operation at the Äspö Hard Rock Laboratory is the responsibility of the Director of Repository Technology and SKB's International Co-ordinator.

Each major research and development task is organised as a project that is led by a Project Manger who reports to the head of Technology and Science group. Each Project Manager will be assisted by an On-Site Co-ordinator from the Site Office with responsibility for co-ordination and execution of project tasks at the Äspö HRL. The staff at the Site Office provides technical and administrative service to the projects and maintains the database and expertise on results obtained at the Äspö HRL.

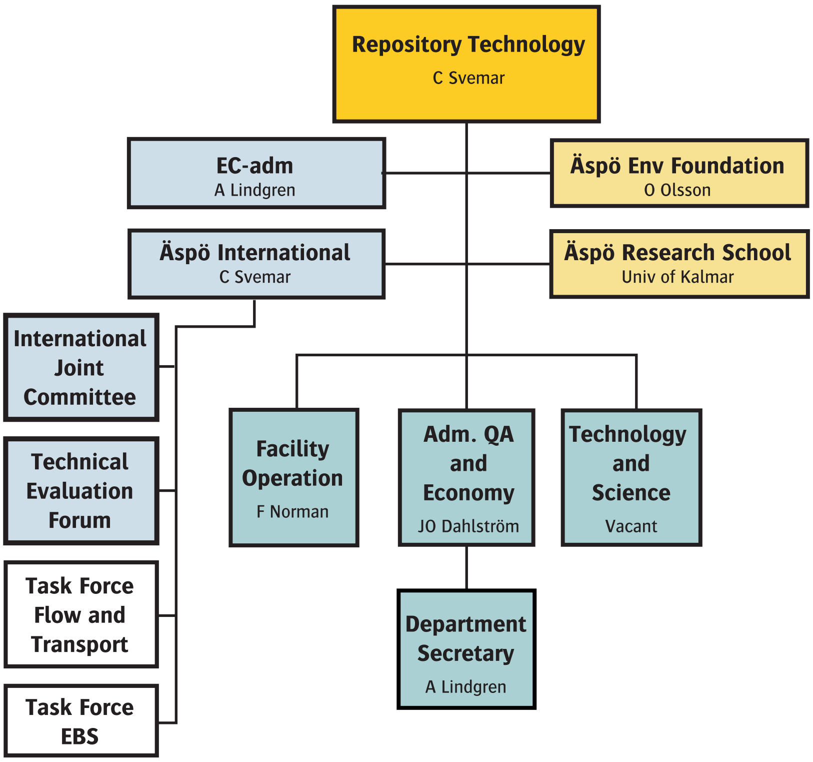

Figure 1-2. Organisation of Repository Technology and Äspö HRL.

1.4 Management system

SKB is since 2001 certified according to the Environmental Management System ISO 14001 and also to the Quality Management Standard ISO 9001.

The structure of the management system is based on procedures, handbooks, instructions, identification and traceability, quality audits etc. The overall guiding document for issues related to management, quality and environment are written as routines. The documentation can be accessed via SKB's Intranet, where policies, common routines for SKB as well as specific routines for Äspö HRL can be found.

Employees and contractors related to the SKB organisation are responsible that works will be performed in accordance with SKB's management system.

Project Model

SKB has developed a project model for the implementation of projects. The aim of the model is to create an effective and uniform management of all projects. According to this model each project shall have a project owner and a project leader shall be appointed. A project decision describing the aim of the project and the resources as well as a project plan shall be prepared.

Environmental management

SKB manage Sweden's spent nuclear fuel and radioactive waste in order to safeguard the environment and people's health in both the short and long term. This task is a key element of the national environmental objective of a safe radiation environment.

SKB make every effort to minimise their impact on the environment and the environmental work is goal-oriented and forms a natural part of all operations. Key assessment parameters for the selection of suppliers include security, environmental aspects and quality.

SKB are constantly developing and enhancing the security, the environmental and quality-control efforts to keep up with the company's development and with changes in circumstances. One of the cornerstones of both the existing operations and in the planning of new facilities is the efficient utilisation of available resources.

The guiding principles of SKB's operations can be described as follows:

- A high level of security at all our facilities.
- A low level of environmental impact.
- Efficiency.
- Meeting the demands imposed by legislation, statutes and regulations by a comfortable margin.
- Openness.

1.5 Reporting

Äspö HRL is an important part of SKB's RD&D-Programme. The plans for research and development of technique during the period 2002-2007 are presented in SKB's RD&D-Programme 2001. The information given in the RD&D-Programme related to Äspö HRL is detailed in the Äspö HRL Planning Report. This plan is revised annually and the current report gives an overview of the planned activities for the calendar year 2003. Detailed account of achievements to date for the Äspö HRL can be found in the Äspö HRL Annual Reports that are published in SKB's Technical Report series. In addition, Status Reports are prepared four times a year.

The highest report series is the TR (Technical Report) series with grey cover followed by IPR (International Progress Report) having a yellow cover. Reports in both those series may be referred to in other works and may be distributed to third party. ITD (International Technical Reports) and TD (Technical Reports) represent the lowest ranked series and are intended for facilitating quick distribution of results and constitute working material which may not be publicly referred to or spread to third party.

Basically joint international work at Äspö HRL as well as data and evaluations for specific experiments and tasks are reported in Äspö IPR. Information from Progress Reports is summarised in Technical Reports at times considered appropriate for each project. SKB also endorses publications of results in international scientific journals. Table 1-1 provides an overview of Äspö HRL related documents and the policy for review and approval.

Data collected from experiments and measurements at Äspö HRL are mainly stored in SKB's site characterisation database, SICADA.

Table 1-1. Overview of Äspö HRL related documents.

Report	Reviewed by	Approved by
SKB RD&D-Programme – Äspö HRL related parts	Director Repository Technology	SKB
Planning Reports – Detailed plans covering each calendar year	Contributors	Director Repository Technology
Annual Reports – Summary of work covering each calendar year	Repository Technology unit	Director Repository Technology
Status Reports – Short summary of work covering each 3 month period	Principal Investigators Project Managers	Director Repository Technology
Technical Reports (TR)	Project Manager	Director Repository Technology
International Progress Reports (IPR)	Project Manager	Director Repository Technology
Internal Technical Documents (ITD)	Case-by-case	Project Manager
Technical Documents (TD)	Case-by-case	Project Manager

1.6 International participation in Äspö HRL

The Äspö HRL has so far attracted considerable international interest. Eight organisations from seven countries participated during 2002 in the Äspö HRL in addition to SKB. The participating organisations are:

- Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA), France.
- Bundesministerium für Wirtschaft und Arbeit, BMWA, Germany
- Central Research Institute of Electric Power Industry (CRIEPI), Japan.
- Empresa Nacional de Residuos Radiactivos (ENRESA), Spain.
- Japan Nuclear Cycle Development Institute (JNC), Japan.
- Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (NAGRA), Switzerland.
- Posiva Oy, Finland.
- United States Department of Energy, Carlsbad Field Office (USDOE CBFO).

For each partner the co-operation is based on a separate agreement between SKB and the organisation in question. The international partners and SKB reached a joint decision to form the Äspö International Joint Committee (IJC). IJC is responsible for the co-ordination of the work arising from the international participation. The committee meets once every year. In conjunction with each IJC meeting a Technical Evaluation Forum (TEF) is held. TEF consists of scientific experts appointed by each organisation.

For each experiment the Äspö HRL management establishes a Peer Review Panel consisting of three to four Swedish or International experts in fields relevant to the experiment.

Specific technical groups, so called Task Forces, are another form of organising the international work. A Task Force on Groundwater Flow and Transport of Solutes in fractured rock has been working since 1992 and a Task Force on Engineered Barrier Systems has been initiated.

Some EC projects are co-ordinated by the Director of Repository Technology and administrated by the Repository Technology staff. Examples are EC projects concerning the Prototype Repository that has a direct coupling to the test set-up at Äspö, the CROP project that is coupled to experiments carried out in the Äspö HRL, and PADAMOT that has a strong coupling to radionuclide retention.

1.7 Allocation of experimental sites

The rock volume and the available underground excavations have to be divided between the experiments performed at the Äspö HRL. It is essential that the experimental sites are allocated so that interference between different experiments is minimised. The allocation of experimental sites within the Äspö HRL is shown in Figure 1-3.

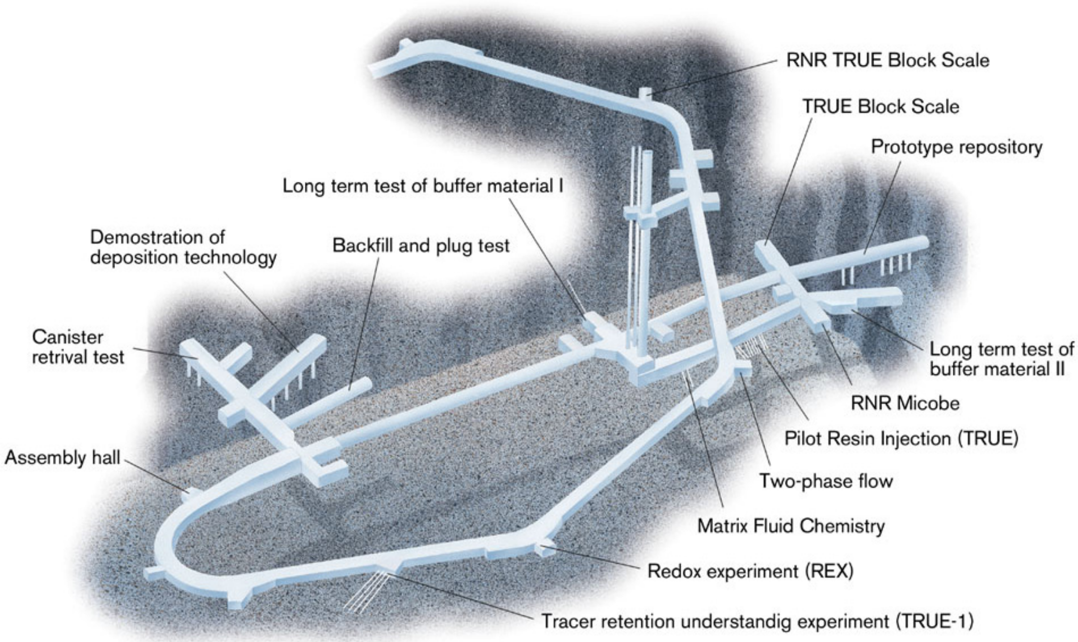

***Figure 1-3.** Underground excavations at the 300-450 m levels and allocation of experimental sites.*

1.8 Structure of this report

The information given in SKB's RD&D-Programme related to Äspö HRL is detailed on a yearly basis in the Äspö HRL Planning Report. The work planned during 2003 is described in six chapters in this report:

- Technology - demonstration of technology for and function of important parts of the repository system.
- Geo-science - experiments, analysis and modelling to increase the knowledge of the surrounding rock.
- Natural barriers – experiments, analysis and modelling to increase the knowledge of the repository barriers under natural conditions.
- Äspö facility – operation, maintenance, data management, and monitoring etc.
- International co-operation.
- Environmental research.

2 Technology

2.1 General

One of the goals for Äspö HRL is to demonstrate technology for and function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a real repository.

It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. The experiments focus on different aspects of engineering technology and performance testing, and will together form a major experimental programme.

With respect to technology demonstration important overall objectives of this programme are:

- To furnish methods, equipment and procedures required for excavation of tunnels and deposition holes, near-field characterisation, canister handling and deposition, backfill, sealing, plugging, monitoring and also canister retrieval.
- To integrate these methods and procedures into a disposal sequence, that can be demonstrated to meet requirements of quality in relation to relevant standards, as well as practicality.

With respect to repository function, the objectives are:

- To test and demonstrate the function of components of the repository system.
- To test and demonstrate the function of the integrated repository system.

The main experiments that are installed in Äspö HRL or under way are:

- Canister Retrieval Test.
- Prototype Repository.
- Backfill and Plug Test.
- Long Term Test of Buffer Material.
- KBS-3 method with horizontal deposition.
- Large Scale Gas Injection Test.
- Temperature Buffer Test.

2.2 Canister Retrieval Test

Background

The stepwise approach to safe deep disposal of spent nuclear fuel implies that if the evaluation of the deposition after the initial stage is not judged to give a satisfactory result the canisters may need to be retrieved and handled in another way. The evaluation can very well take place so long after deposition that the bentonite has swollen and applies a firm grip around the canister. The canister, however, is not designed with a mechanical strength that allows the canister to be just pulled out of the deposition hole. First the canister has to be made free from the grip of the bentonite before the canister can be taken up into the tunnel and enclosed in a radiation shield before being transported away from the deposition area.

The Canister Retrieval Test is aiming at demonstrating the readiness for recovering of emplaced canisters also after the time when the bentonite is fully saturated and has its maximum swelling pressure. The process covers the retrieval up to the point when the canister is safely emplaced in a radiation shield and ready for transport to the ground surface.

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. The following was defined to fulfil the aim of the Canister Retrieval Test:

- Two vertically bored test holes in full repository scale, which fulfil the quality requirements deemed necessary for the real repository.
- Careful and documented characterisation of the properties of these holes.
- Emplacement of bentonite blocks, bentonite pellets and canisters with heaters, and artificial addition of water. However, only one of the deposition holes has been used for implementation of the Canister Retrieval Test.
- Saturation of the buffer and heating of the canister under controlled conditions, with continuous measurement of wetting, temperature, stresses and strains.
- Preparations for testing of canister retrieval.

Boring of full-scale deposition holes and geometrical/geotechnical characterisation of holes as well as emplacement of bentonite and canister with heaters are made within sub-projects that concern also other tests in the Äspö HRL.

Experimental concept

The Canister Retrieval Test is located in the main test area at the 420 m level, and is separated into three stages:

Stage I: Boring of deposition holes and installation of bentonite blocks, canisters with heaters and instruments. The holes are covered in the top with a lid of concrete and steel.

Stage II: Measurement and evaluation of the saturation process of the bentonite and the evolution of the thermal regime.

Stage III: Test of freeing the canister from the bentonite, docking the gripping device to the canister lid and lifting of the canister up to the tunnel floor and into the radiation shield on the deposition machine (reversed deposition sequence).

The buffer was installed in the form of cylindrical blocks and rings of highly compacted Na-bentonite, with a full diameter of 1.65 m and a nominal height of 0.5 m. When the stack of rings was 5 m high the canister equipped with electrical heaters was lowered down in the centre. Cables to heaters were connected, and further blocks emplaced until the hole was filled up to 1 m from the tunnel floor. On top the hole was sealed with a plug made of concrete and a steel plate as cover. The plug was secured against heave caused by the swelling clay with 9 cables anchored to the rock. The tunnel was left open for access and inspections of the plug support (see Figure 2-1).

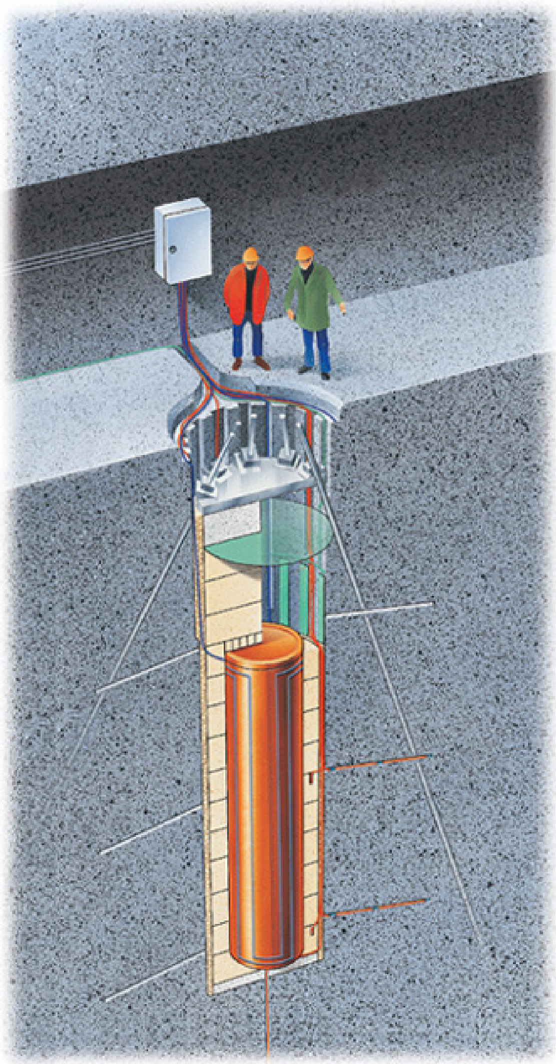

Figure 2-1. *Experimental set-up in Canister Retrieval Test.*

Artificial addition of water is provided regularly around the bentonite blocks by means of permeable mats attached to the rock wall. The design of the mats was done so that they are not disturbing the future test of retrieval.

Predicted saturation time for the test is 2-3 years in the 350 mm thick buffer along the canister and 5-10 years in the buffer below and above the canister. Decision on when to start the retrieval tests is dependent on information of the degree of saturation by instruments installed to monitor the saturation and swelling processes in different parts of the buffer. This instrumentation is similar to the instrumentation in the Prototype Repository and yields comparable information during the saturation period.

Present status

Two deposition holes were bored but only one has been installed, the reason being that only one robust method for freeing the canister is presently being considered to be tested in full-scale in Äspö HRL. The installation of the buffer material and the canister with instrumentation and heaters started mid September 2000 and was completed during October 2000 including the *in situ* casting of the concrete plug on top of the bentonite buffer. The heaters were turned on and the artificial watering of the buffer material started in October 2000.

The test has thus been running for a little more than two years with continuous measurement of the wetting process, temperature, stresses and strains. The general conclusion is that the measuring systems and transducers seem to work well with a few exceptions. Data reports are produced twice a year.

The relative humidity sensors indicate that the bentonite between the rock and the canister is close to water saturation although the wetting seems to be somewhat uneven and the total pressure has not reached the expected values yet. Some clogging of the filters may explain the inhomogeneous appearance.

In order to increase the rate of saturation the water pressure in the mats was increase in steps to 800 kPa during the autumn 2002 and in order to reduce the risk of heater failure the power of the canister was reduced from 2600 to 2100 W in September 2002. Back flushing of the mats has been done in order to avoid clogging.

The problems with the heaters caused by low resistance to earth noted in the last Planning Report /SKB, 2001b/ have remained but the heaters have worked properly and a steady power has been maintained but slightly reduced. It has been decided to continue the test with the reduced power as long as the heaters are operative.

Scope of work for 2003

The plan is to continue the artificial water saturation of the bentonite, to maintain the power of the canister at 2100 W, to maintain the water pressure 800 kPa in the mats and to continue the registration of sensor readings during the forthcoming three years (2003-2005). Reporting of measurements and evaluation of the results will be done as well as further modelling for increased understanding of the processes.

2.3 Prototype Repository

Background

Many aspects of the KBS-3 repository concept have been tested in a number of *in situ* and laboratory tests. Models have been developed that are able to describe and predict the behaviour of both individual components of the repository, and the entire system. However, processes have not been studied in the complete sequence, as they will occur in connection to repository construction and operation. There is a need to test and demonstrate the execution and function of the deposition sequence with state-of-the-art technology in full-scale. In addition, it is needed to demonstrate that it is possible to understand and qualify the processes that take place in the engineered barriers and the surrounding host rock. It is envisaged that this technology can be tested, developed and demonstrated in the Prototype Repository.

The execution of the Prototype Repository is a dress rehearsal of the actions needed to construct a deep repository from detailed characterisation to resaturation of deposition holes and backfill of tunnels. The Prototype Repository will provide a demonstration of the integrated function of the repository and provide a full-scale reference for test of predictive models concerning individual components as well as the complete repository system. The Prototype Repository should demonstrate that the important processes that take place in the engineered barriers and the host rock are sufficiently well understood.

The Prototype Repository is co-funded by the European Commission for a 42 months period starting September 2000 with SKB as Co-ordinator, see Section 6.8.

Objectives

The main objectives for the Prototype Repository are:

- To test and demonstrate the integrated function of the deep 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.

The evolution of the Prototype Repository should be followed for a long time, possible up to 20 years. This is made to provide long term experience on repository performance to be used in the evaluation that will be made after the initial operational stage in the real deep repository.

Experimental concept

The Prototype Repository should, to the extent possible, simulate the real deep repository system, regarding geometry, materials, and rock environment. This calls for testing in full-scale and at relevant depth.

The test location chosen is the innermost section of the TBM-tunnel at 450 m depth. The layout involves altogether six deposition holes, four in an inner section and two in an outer, see Figure 2-2. The tunnels will be backfilled with a mixture of bentonite and crushed rock (30/70). A massive concrete plug designed to withstand full water and swelling pressures will separate the test area from the open tunnel system and a second plug will separate the two sections. This layout will in practice provide two more or less independent test sections. Canisters with dimension and weight according to the current plans for the deep repository and with heaters to simulate the thermal energy output from the waste will be positioned in the holes and surrounded by bentonite buffer. The deposition holes are with a centre distance of 6 m. This distance is evaluated considering the thermal diffusivity of the rock mass and the fact that maximum acceptable surface temperature of the canister is 90°C.

The test arrangement should be such that artificial disturbance of boundary conditions or processes governing the behaviour of the engineered barriers and the interaction with the surrounding rock are kept to a minimum.

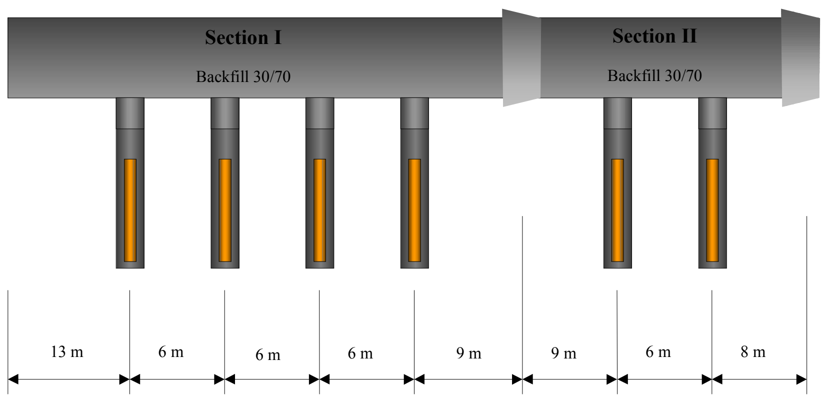

Figure 2-2. *Schematic view of the layout of the Prototype Repository (not to scale).*

Operation time for the experiment is envisaged to be at least 10 years, possible up to 20 years. Decision as to when to stop and decommission the test will be influenced by several factors, including performance of monitoring instrumentation, results successively gained, and also the overall progress of the deep repository project. It is envisaged that the outer test section will be decommissioned after approximately five years to obtain interim data on buffer and backfill performance through sampling. Instrumentation will be used to monitor processes and properties in the canister, buffer material, backfill and the near-field rock. The intention to minimise disturbance will, however, add restrictions to the monitoring possible.

Processes that will be studied include:

- Water uptake in buffer and backfill.
- Temperature distribution in canisters, buffer, backfill and rock.
- Displacements of canisters.
- Swelling pressure and displacement in buffer and backfill.
- Stresses and displacements in the near-field rock.
- Water pressure build up and pressure distribution in rock.
- Gas pressure in buffer and backfill.
- Chemical processes in rock, buffer and backfill.
- Bacterial growth and migration in buffer and backfill.

Present status

The inner section was installed and the plug cast in 2001. Heaters were turned on one by one during September-October 2001 and monitoring of processes was started and has yielded the expected data flow since then. A malfunction in the electrical insulation in heaters to all four canisters was discovered in early 2002 and the installation of the outer section was postponed until the cause of the malfunction had been found. This is now the case, as reported in Äspö Status Reports, and the installation is ready to start in March 2003.

Instrument installation in the rock and other preparatory works in the outer section have been completed and the site is ready for installation of bentonite blocks and canisters in the two holes.

Scope of work for 2003

The two holes in the outer section will be installed, the tunnel backfilled, the plug cast and the heaters turned on. The instrument readings in the inner section will continue and the data collection from the outer section be initiated.

Modelling teams will continue the comparison of measured data with predictions. The development of the buffer saturation process in the Canister Retrieval test is used for calibrating the mathematical models on the buffer behaviour.

2.4 Backfill and Plug Test

Background

The Backfill and Plug Test is a test of different backfill materials and emplacement methods and a test of a full-scale plug. It is a test of the hydraulic and mechanical function of the backfill materials and their interaction with the near-field rock. It is also a test of the hydraulic and mechanical function of a plug. The test is partly a preparation for the Prototype Repository.

Objectives

The main objectives of the Backfill and Plug Test are:

- To develop and test different materials and compaction techniques for backfilling of tunnels excavated by blasting.
- To test the function of the backfill and its interaction with the surrounding rock in full-scale in a tunnel excavated by blasting.
- To develop technique for building tunnel plugs and to test the function.

Experimental concept

The test region for the Backfill and Plug Test is located in the old part of the ZEDEX drift. Figure 2-3 shows a 3D visualisation of the experimental set-up. The test region can be divided into the following three test parts:

- The inner part filled with a mixture of bentonite and crushed rock (six sections).
- The outer part filled with crushed rock and bentonite blocks and pellets at the roof (four sections).
- The concrete plug.

The backfill sections were applied layer wise and compacted with vibrating plates that were developed and built for this purpose. It was concluded from preparatory tests that inclined compaction should be used in the entire cross section from the floor to the roof and that the inclination should be about 35 degrees.

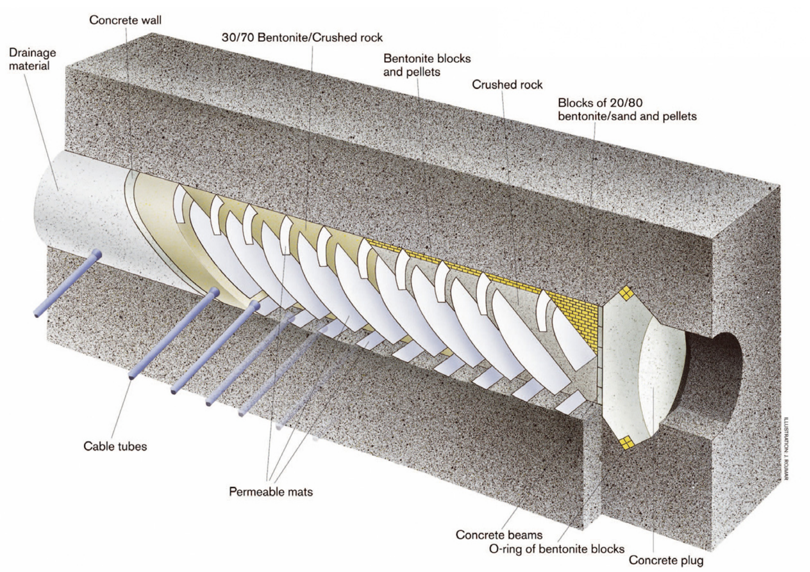

Figure 2-3. *Illustration of the experimental set-up of the Backfill and Plug Test.*

The inner test part was filled with a mixture of bentonite and crushed rock with a bentonite content of 30%. The composition is based on results from laboratory tests and field compaction tests. The outer part was filled with crushed rock with no bentonite additive. A slot of a few dm was left between the backfill and the roof. The slot was filled with a row of highly compacted blocks with 100% bentonite content, in order to ensure a good contact between the backfill and the rock, since the crushed rock has no swelling potential and may instead settle with time. The remaining irregularities between these blocks and the roof were filled with bentonite pellets.

The test region is about 28 m long and it is divided into sections by drainage layers of permeable mats in order to apply hydraulic gradients between the layers and to study the flow of water in the backfill and the near-field rock. The mats are also used for the water saturation of the backfill.

The backfill and rock were instrumented with piezometers, total pressure cells, thermocouples, moisture gauges, and gauges for measuring the local hydraulic conductivity. The axial conductivity of the backfill and the near-field rock will, after water saturation, be tested by applying a water pressure gradient along the tunnel between the mats and measuring the water flow. All cables from the instruments were enclosed in Tecalan tubes in order to prevent leakage through the cables. The cables were led through the rock to the data collection room in bore holes drilled between the test tunnel and the neighbouring Demo-tunnel.

The concrete plug is designed to resist water and swelling pressures that can be developed. It is equipped with a filter on the inside and a 1.5 m deep triangular slot with an “O-ring” of highly compacted bentonite blocks at the inner rock contact, see Figure 2-3.

The flow testing in the backfill is planned to start after saturation, when steady state flow and pressure have been reached.

Present status

The entire test set-up with backfill, instrumentation and building of the plug was finished in the end of September 1999 and the wetting of the 30/70 mixture through the filter mats started in late November 1999. Wetting of the backfill from the filter mats and the rock has continued during the years 2000 to 2002 and data from transducers has been collected and reported. In order to increase the rate of water saturation the water pressure in the mats was increased to 500 kPa at the turn of the year 2001/2002. At the end of 2002 the moisture measurements indicated that the entire backfill of both backfill types is completely water saturated.

Data reports are produced twice a year. Almost all transducers seem to work well so far.

Scope of work for 2003

Since the backfill is judged to be water saturated the flow testing will start in 2003 as planned. The starting-point is a water pressure of 500 kPa in all mats corresponding to the present situation. The leakage through the plug is at present 0.04 l min^{-1}. The strategy of the flow testing is in the first phase to successively decrease the water pressure in the mat sections starting with the mat at the plug. The flow from the mat section that still has 500 kPa pressure and the flow into the neighbouring mat section where the pressure just has been decreased will be measured. The water pressure must be kept equal in all three mats in each mat section in order to prevent water flow between the mats in a section. The pressure should be decreased in steps of 100 kPa and the hydraulic gradient kept for such long time that a steady flow could be observed.

The water flow to and from the two mats sections surrounding the tested backfill section will be measured separately in the three mats in the mat layers. If the measurements indicate that large air pockets are present in the backfill or mats it may be necessary to increase the water pressure in the mats to 1–2 MPa in order to reduce the influence of enclosed air.

When the test programme is finalised the pressure will successively be increased again starting from the mat at the plug implying that the water will flow in reversed direction. The time until equilibrium is estimated to be two weeks for each step but may be longer if unsolved air still exists in the pores.

In addition to the flow testing the following activities will be accomplished:

- Continued data collection and reporting of measured water pressure, water flow, total pressure and degree of water saturation.
- Maintenance of equipment and supervision of the test.
- Supplementary modelling of the flow testing and evaluation of results.

The flow testing is planned to continue until 2004 or 2005 and the excavation is planned to take place either in 2004 or 2005 depending on the results.

2.5 Long Term Test of Buffer Material

Background

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS-3 method the demands on the bentonite buffer are to serve as a mechanical support for the canister, reduce the effects on the canister of a possible rock displacement, and minimise water flow over the deposition holes.

The decaying power from the spent fuel in the HLW canisters will give rise to a thermal gradient over the bentonite buffer by which original water will be redistributed parallel to an uptake of water from the surrounding rock. A number of laboratory test series, made by different research groups, have resulted in various buffer alterations models. According to these models no significant alteration of the buffer is expected to take place at the prevailing physico-chemical conditions in a KBS-3 repository neither during nor after water saturation. The models may to a certain degree be validated in long term field tests. Former large scale field tests in Sweden, Canada, Switzerland and Japan have in some respects deviated from possible KBS-3 repository conditions and the testing periods have generally been dominated by initial processes, i.e. water uptake and temperature increase.

Objectives

The present test series aims at validating models and hypotheses concerning physical properties in a bentonite buffer material and of related processes regarding microbiology, radionuclide transport, copper corrosion and gas transport under conditions similar to those in a KBS-3 repository. The expression “long term” refers to a time span long enough to study the buffer performance at full water saturation, but obviously not “long term” compared to the lifetime of a repository. The objectives may be summarised in the following items:

- Data for validation of models concerning buffer performance under quasi-steady state conditions after water saturation, e.g. swelling pressure, cation exchange capacity and hydraulic conductivity.
- Check of existing models on buffer-degrading processes, e.g. illitization and salt enrichment.
- Information concerning survival, activity and migration of bacteria in the buffer.
- Check of calculation data concerning copper corrosion, and information regarding type of corrosion.
- Data concerning gas penetration pressure and gas transport capacity.
- Information, which may facilitate the realisation of the full-scale, test series with respect to clay preparation, instrumentation, data handling and evaluation.

Experimental concept

The testing principle for all planned tests is to emplace "parcels" containing heater, central tube, pre-compacted clay buffer, instruments, and parameter controlling equipment in vertical bore holes with a diameter of 300 mm and a depth of around 4 m, see Figure 2-4. The test series concern realistic repository conditions except for the scale and the controlled adverse conditions in three tests, see Table 2-1.

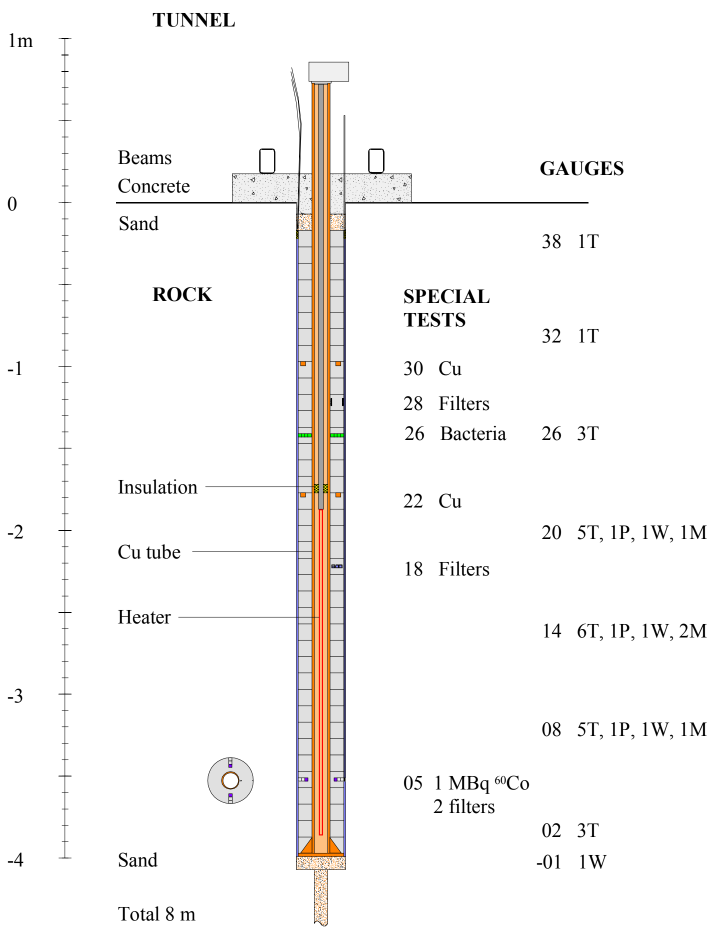

Figure 2-4. *Cross-section view of a standard condition parcel (S-type). The first figures in the columns "special tests" and "gauges" denote block number and second figures in the column "gauges" denote the number of sensors. T denotes thermocouple, P total pressure sensor, W water pressure sensor, and M moisture sensor.*

Adverse conditions in this context refer to high temperatures, high temperature gradients over the buffer, and additional accessory minerals leading to i.a. high pH and high potassium concentration in clay pore water. The central copper tubes are equipped with heaters in order to simulate the decay power from spent nuclear fuel. The heater effect are regulated or kept constant at values calculated to give a maximum clay temperature of 90°C in the standard tests and in the range of 120 to 150°C in the adverse condition tests.

Each parcel contains 25 thermocouples, 3 total pressure gauges, 3 water pressure gauges, 4 relative humidity sensors, 7 filter tubes, and 12 water sampling cups. The power is regulated and temperature, total pressure, water pressure and water content are continuously being measured.

At termination of the tests, the parcels are extracted by overlapping core drilling outside the original bore hole. The water distribution in the clay is determined and subsequent well-defined chemical, mineralogical analyses and physical testing are performed.

Table 2-1. Lay-out of buffer material test series.

Type	No.	max T, °C	Controlled parameter	Time, years	Remark
A	1	130	T, [K+], pH, am	1	pilot test, reported
A	0	120–150	T, [K+], pH, am	1	main test, reported
A	2	120–150	T, [K+], pH, am	5	main test, ongoing
A	3	120–150	T	5	main test, ongoing
S	1	90	T	1	pilot test, reported
S	2	90	T	5	main test, ongoing
S	3	90	T	>>5	main test, ongoing

A = adverse conditions
T = temperature
pH = high pH from cement
S = standard conditions
[K+] = potassium concentration
Am = accessory minerals added

Present status

The A0-bentonite material, copper coupons and tracer test material has been analysed and are presently being reported together with analyses and test results from the original material. The remaining four parcels are functioning well and only minor service was needed during the past year.

Scope of work for 2003

No new field activities are planned for during this period except control and calibration of the measuring equipment. Water pressure, total pressure, temperature and moisture in the four remaining parcels will be continuously measured and stored every hour. These data are being checked monthly, and the results are planned to be analysed more carefully and reported in April and October.

2.6 Cleaning and sealing of investigation bore holes

Background

Investigation bore holes are drilled during site investigations and detailed characterisation in order to obtain data on the properties of the rock. These bore holes must be sealed, no later than at the closure of the deep repository, so that they do not constitute flow-paths from repository depth to the biosphere. Sealing of the bore holes means that the conductivity in the bore hole is no higher than that of the surrounding rock. Cleaning of the bore holes means that instrumentation that has been used in the bore holes during long time-periods, in a sometimes aggressive environment, is removed.

Sealing of bore holes with cementitious materials is commonly used in construction work and can be performed with well-known techniques. Earlier studies, e.g. the Stripa project, have shown that sealing with cementitious material include a potential risk for degradation due to leaching and the sealing can not be guaranteed over time-periods longer than hundreds of years. Another opportunity is to use swelling clay materials, such as compacted bentonite blocks or bentonite pellets. Sealing with bentonite blocks has been tested in the framework of the Stripa project, in bore holes with a length of 200 m, with very promising results. A further development of this technique is however required to show that bore holes with lengths of up to 1 000 m can be sealed.

Since most of the investigation bore holes are instrumented, reliable technique is also needed to clean bore holes so that they can be sealed.

Objectives

The main objective of this project is to identify and to demonstrate the best available techniques for cleaning and sealing of investigation bore holes.

The project consists of two phases.

Phase 1 comprises:

- An inventory of known methods for sealing of bore holes with potential to be used for investigation bore holes. The inventory considers both cementitious materials and swelling clay materials.
- Performance of complementary laboratory experiments with sealing materials to obtain as high density and as low conductivity as possible.
- Investigation of the status of two instrumented bore holes at Äspö (KAS 06 and KAS 07).

Phase 2 comprises the following six issues:

I. Techniques for preparation of bore holes to be plugged. This issue comprises sealing and stabilisation of intersecting fracture zones, injection methods and packer techniques as well as identification and development of cement materials for minimum impact on smectite clay.

II. Selection of candidate plugging materials. Identification, development and testing of potential cement and clay materials and searching for other materials that can fulfil the criteria.

III. Selection of method for construction and application of plugs. Design of plugs with respect to borehole geometry, sealing rate and long term performance.

IV. Performance assessment. Conceptual modelling of short and long term performance of the plug. This issue also includes the planning of field tests.
V. Large-scale testing. Field tests of plug construction and performance.
VI. Evaluation, validation and assessment.

The work in Phase 2 will be made in two separate projects: Borehole cleaning (Issue I) and Borehole plugging (Issues II – VI).

Present status

A state of the art report summarising the developments of the sealing and cleaning techniques during the last 10-15 years has been put together. The report will be reviewed in the beginning of 2003 and printed thereafter.

Data from the two potential bore holes (KAS 06 and KAS 07) has been gathered to find out where in the holes the field tests can be performed.

Scope of work for 2003

The following activities are planned:

- A seminar will be held in February 2003, where representatives from the oil industry will participate.
- A Project Plan for Phase 2 will be compiled during spring 2003.
- Activities related to issues I, II and III will be started during 2003.

2.7 Low-pH cementitious products

Background

It is foreseen that cementitious products will be utilised in the construction of the underground facility of the final repository for spent nuclear fuel. The long term function and safety of the repository is quite dependent on the chemical conditions in the ambient rock. The use of standard construction cement paste will create pulses of pH in the magnitude of 12-13. Such high pH is detrimental and also complicates the safety analysis of the repository, as the effect of a high pH-plume should be considered in the evaluation. However, by using cementitious products that creates leachates below pH 11, these issues will never have to be resolved. Means to lower the pH are studied in order to decrease the initial peak in the leachate and to use silica to deplete the paste in Portlandite and lower the Ca/Si ratio of the cement paste in order to give a bulk paste with low pH. Adding ultra fine quartz also lowers the cement content.

Use of low-pH cement is foreseen for applications like structural cast concrete, shotcrete, rock bolting and grouting. It might also be possible that cement is used as one of the constituents in the backfill material. SKB and Posiva launched this feasibility study in December 2001 to qualify low-pH cement for practical application when constructing the repository. In 2002 NUMO from Japan joined the project.

Objectives

The original objectives were to:

- Achieve usable recipes of low-pH cementitious grouts for injection grouting and rock bolting.
- Test those grouts in a small field test.
- Compile influence of low-pH cement paste on function and safety of the deep repository.

Project concept

The project is performed in a number or work packages:

- Influences on the *repository performance*, including a compilation of knowledge concerning copper corrosion, fuel dissolution, radionuclide chemistry, and bentonite degradation. The study will be based on available information, i.e. no experimental studies will be carried out.
- *Basic understanding*, including leach tests and development of cement paste recipes. The low-pH products are based on a cement paste where the composition of normal cement paste is modified by the addition of silica. This will give a paste that during leaching theoretically will give pH <11.
- *Fabrication* of cement paste with pH <11 leachate. The fabrication of the components of low-pH cement paste can either be mixed traditionally or fabricated in a grinder. The project comprise the setting up of grinding equipment, testing of alternate grinding procedures and using alternate materials as well as measurements of influence on rheological properties and structural/chemical/physical state of the hardened paste.
- *Rock bolting*, including selection of appropriate mortar. According to present plans the following will be done: selection of suitable grouts, description of practical installation techniques, quantification of the rheological/chemical/physical properties of these grouts, small scale field tests, study of implications of low-pH rock bolt grouts on long term durability of rock bolts.
- *Grouting*, including laboratory experiments and demonstration of requirements on the grout and the geological conditions at the field site.
- A *small field test* is planned to take place in the Äspö HRL, where both grouting and rock bolting will be tested in a small scale. In order to make the grouting successful, a rock characterisation is included in this work package.
- Project managing and planning of a next stage.

Present status

The work with the repository performance has established that a pH below 11 in the pore water can be accepted to assure the long term repository performance and safety. It will, however, probably be necessary to put a limit on the quantities to be used. This study has been based on available information, i.e. no experimental studies were carried out. The study was finalised during 2002.

The work to select cement pastes for rock bolt grouting and injection grouting include a number of steps e.g. leach tests, investigations of structural and chemical variation of the un-leached and leached cement paste. Tests in a penetrability meter are another important step in the search for injection grouts.

It was more difficult than expected to find suitable injection grouts that penetrate fine fractures. The small field test that was planned to take place during 2002 has therefore been cut out from the project and the focus is put on finding suitable recipes for injection grouts.

Scope of work for 2003

According to present plans the development of recipes for cement based injection grout will continue.

Thereafter, when or if suitable low-pH recipes have been developed, a small field test is planned to take place where both grouting and rock bolting will be tested.

2.8 KBS-3 method with horizontal deposition

Background

The KBS-3 method based on the multi-barrier principle is accepted by the Swedish authorities and the government as base for the planning of the final disposal of the spent nuclear fuel. The possibility to modify the reference method and make serial deposition of canisters in long horizontal drifts instead of vertical deposition of single canisters in the deposition hole has been investigated since early nineties. One reason for proposing the change is that the deposition tunnels are not needed if the canisters are disposed in horizontal drifts and the excavated rock volume and the amount of backfill can be considerably reduced. Another reason is that it is easier to verify the quality of the near zone around the canister when the bentonite and the canister is assembled into a prefabricated disposal package in a reloading station.

Late 2001 SKB published an R&D programme for the KBS-3 method with horizontal deposition (KBS-3H) /SKB, 2001c/. The R&D programme is divided into four parts: Feasibility Study, Basic Design, Construction and Testing at the Äspö Hard Rock Laboratory, and Evaluation.

The R&D programme is carried through by SKB in co-operation with Posiva.

Objectives

The gains, due to smaller volume of excavated rock, in term of environmental impact in particular, but also cost, make the KBS-3 method with horizontal deposition (KBS-3H) an interesting variant, see Figure 2-5. Great efforts are, however, required to develop the variant.

The objective of the first part of the project, the Feasibility Study, is to evaluate if horizontal deposition is an alternative technique for deposition, and if so, to give SKB and Posiva a basis for continued evaluation of KBS-3H as a variant. The Feasibility Study focuses on differences compared to the reference concept KBS-3V. Highlighted tasks are the deposition technology and the barrier performance.

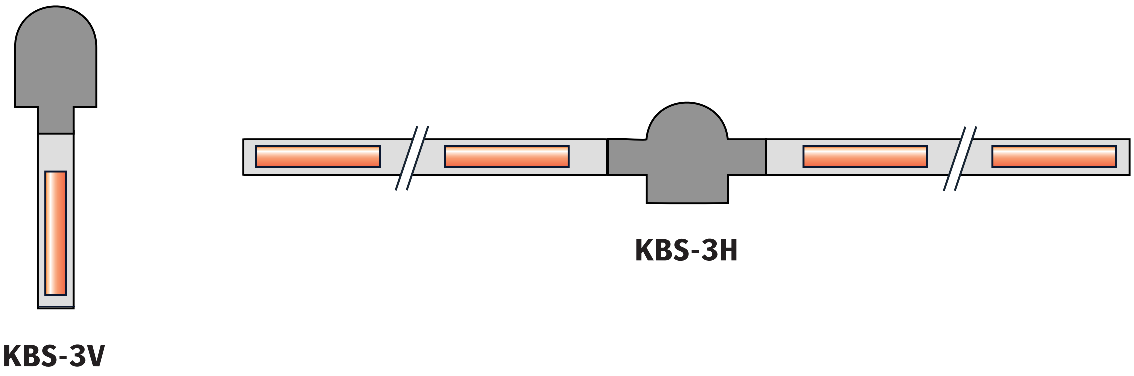

Figure 2-5. *Schematic illustrations of variants of the KBS-3 method.*

Present status

The Feasibility Study was finalised in October 2002 and reported to the SKB board in November. The results of the Feasibility Study show that the KBS-3H concept is worth further development from a technical, economical and long term safety point of view.

Different techniques for deposition of the prefabricated disposal packages have been evaluated and a technique where air cushions are used in order to make the deposition process safe and efficient has been chosen for further development. Two different techniques for boring of the deposition drifts have been studied and evaluated, TBM and the so-called Cluster technology. The performance of the buffer material in the KBS-3H has been studied and tested by experiments; preliminary results indicate that the perforated deposition container does not affect the sealing ability of the buffer material negatively. Other experiments indicate that there is a significant risk of erosion of buffer material during certain circumstances. The knowledge about the performance of the buffer material is not complete and further studies are necessary.

A buffer safety assessment has been performed during 2002 describing the differences with respect to buffer behaviour between horizontal and vertical emplacement. It also identifies and describes the most important questions to be solved within the R&D programme.

Scope of work for 2003

The decision to continue work within the R&D programme was taken by the SKB board in December 2002. The next phase in the R&D programme is called Basic Design and will be carried through in three different sub projects:

- Technical development of the KBS-3H concept.
- Preparations for a future demonstration of the concept at Äspö HRL.
- Studies of the barrier performance of the KBS-3H concept.

Work includes manufacturing of boring equipment and initial tests. It also includes tests of the type of air cushion device planned to be used for emplacement. Depending on the site elected in Äspö HRL for the demonstration area it may be necessary to excavate a niche from which the demonstration deposition drifts will be excavated.

The Basic Design phase will be reported late 2003.

2.9 Large Scale Gas Injection Test

Background

If there is a penetrating breach in the copper shell, water can run into the gap between the canister insert and the copper shell and further into the insert, where it can cause anaerobic corrosion with hydrogen gas and magnetite as corrosion products. Dissolved gas will slowly be transported through the buffer and it is very probably that a gas phase and a gas pressure will build up in the interior of the canister. It is very important that it can be shown that this gas pressure will not have a negative influence on repository performance. This means that the gas must be released without damaging the buffer or the surrounding rock.

The buffer's gas permeability shall be sufficient to allow the large quantities of gas that may be formed in a damaged canister to pass through. This gas passage must not lead to the formation of persistent gas-permeable channels or cavities in the buffer. A remaining uncertainty in the understanding of gas transport in the buffer material concerns the number, size and spatial arrangement of the gas-bearing fractures as well as the volume behaviour of the clay during gas injection. The experiments done to date indicate that the clay must expand (grow in volume) during gas transport and that changes in gas content must be balanced by an increased total volume. Furthermore, uncertainties remain concerning at what pressure the gas stops flowing and how this is dependent on the swelling pressure.

SKB has during several years performed a number of experiments with gas-injection on MX-80 bentonite. Today, there is relatively good understanding of the processes determining the gas transport. One remaining question is the importance of the scale. All bentonite experiments so far have been performed in the centimetre scale and the extrapolation of the results from these experiments to repository scale is unclear.

Therefore, the Large Scale Gas Injection Test (LASGIT) has been initiated to perform a number of large scale experiments to verify the existing results from the laboratory experiments.

Objectives

The aims of the project are to:

- Perform and evaluate full-scale gas injection tests based on the KBS-3 method.
- Give answers to questions related to up-scaling and their relative importance for gas transport and the function of the buffer.
- Give additional information on gas-transport processes.
- Give high quality data for testing and validation of models.
- Demonstrate that gas formation in the interior of a canister do not have marked negative consequences on the barriers in the repository.

Experimental concept

The experiments will be performed in a bored full-size deposition hole in a new tunnel at Äspö HRL. Water will be artificially supplied to the buffer at isothermal conditions. A full-scale canister without heaters and a bentonite buffer will be installed in the deposition hole. When the buffer is fully saturated the gas injection tests will start, first with small gas volumes and finally with a volume corresponding to a full-size canister. The LASGIT project is divided in the following phases:

- Characterisation of deposition hole.
- Construction, instrumentation and emplacement of full-scale canister.
- Instrumentation and emplacement of buffer.
- Construction and installation of laboratory for measurements.
- Artificial water supply to buffer.
- Gas-injection tests in steps.
- Evaluation, modelling and compilation of results.

Scope of work for 2003

The project will be initiated in January 2003. During 2003 it is planned that the drilling of test hole and full-size diameter hole will take place, emplacement of canister and buffer will be made, and after that the artificial water supply of the buffer will start.

The artificial water supply of the buffer will continue until the buffer is saturated. In 2006 it is foreseen that the bentonite buffer will be saturated and the gas tests can be performed.

2.10 Temperature Buffer Test

Background

The French organisation ANDRA intends to carry out a Temperature Buffer Test (TBT) at Äspö HRL in co-operation in SKB.

The scientific background to the project is that the Swedish design of storage facilities for spent fuel (KBS-3) and the Japanese design for vitrified waste ("H12" report) both limit the surface temperature of the packages to be below 100°C.

The variable nature of the French geological environment requires research to be carried out to relax the temperature constraints on the dimensioning of clay engineered barriers in order to produce more compact designs. Two possible approaches have been investigated:

- Allowing the temperature of the bentonite to exceed 100°C temporarily.
- Use of composite sand/bentonite engineered barriers.

Objectives

SKB will implement the TBT on ANDRA's behalf and will benefit from the experimental results. SKB will also have the opportunity to perform own gas-sampling test as an integrated part of the project.

The TBT aims at evaluating the benefits of extending the current understanding of the behaviour of engineered barriers to include high temperatures above 100°C and the experimental resources needed to achieve this.

Experimental concept

The Temperature Buffer Test is located in the same test area as the Canister Retrieval Test, which is in the main test area at the 420 m level. The principle design of the test is shown in Figure 2-6 and the experimental set-up in Figure 2-7.

The test will consist of five main phases: test design, test installation, operation, modelling, and dismantling.

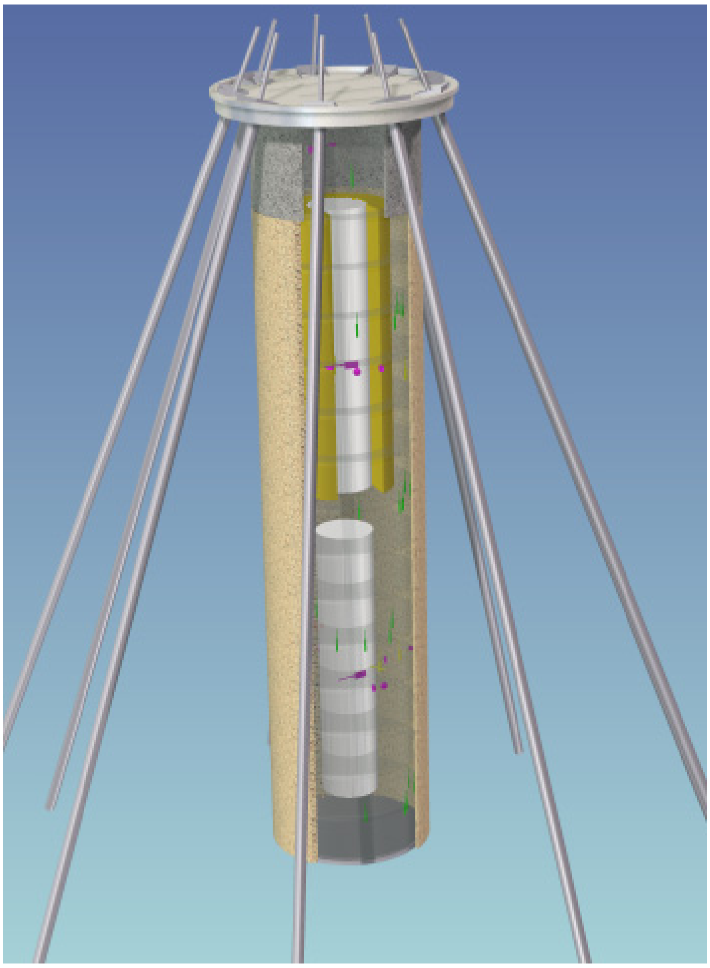

Figure 2-6. *Principle design of the Temperature Buffer Test.*

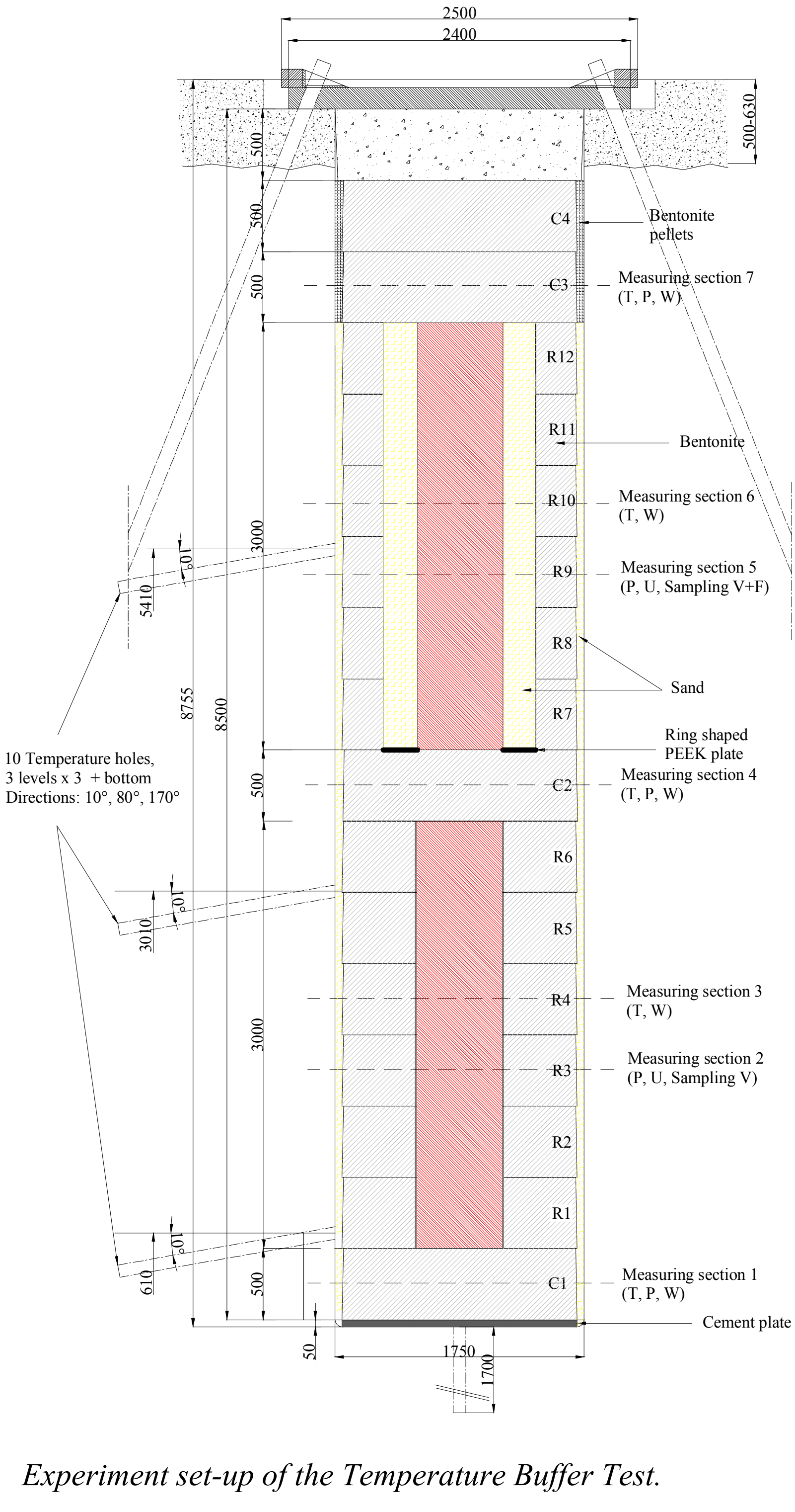

Figure 2-7. *Experiment set-up of the Temperature Buffer Test.*

Present status

The design has been finalised including instrumentation, electrical heaters, buffer materials, data acquisition, retaining system and artificial saturation.

Preparation of the test site and deposition hole is finished including erection of electrical cabinets, cutting of slots for cables, testing of the rock mass permeability, casting of concrete foundation and attaching of a steel cone mould.

The canisters with heaters are assembled and testing is ongoing and a programme for predictive modelling has been established.

Scope of work for 2003

Installation of the test is planned to commence in January 2003 and be finished in February 2003.

The operation phase will start as the heaters are turned on in conjunction with the final stage of the installation. The operation phase includes heating, artificial pressurised saturation of the buffer and monitoring of temperature, humidity, pressure and displacement.

The modelling group will issue a preliminary predictive modelling report in May 2003. Planning for the evaluation modelling will be performed during 2003.

2.11 New experimental sites

Background

Several large-scale experiments are discussed, which need new tunnels or themselves comprises tunnel excavation. But, the use of explosives is known to cause temporary disturbance in the hydraulic regime in the whole Äspö rock mass. In some cases the disturbance has been permanent. Another conflict with other experiments is that a penetration of a water-carrying fracture may change the hydraulic head in a large region around the place where the intersection takes place.

Objectives

The major aim is to find new experimental sites at Äspö HRL for three large-scale experiments that are in an advanced state of planning or under execution:

- Äspö Pillar Stability Experiment (APSE).
- Testing of low-pH grout.
- KBS-3 method with horizontal deposition (KBS-3 H).

Present status

One prime site has been selected for APSE and the characterisation of the rock is in progress. If the rock at this site fulfils the requirements for the experiment the planning of tunnel excavation can start.

The first testing of low-pH concrete will then be planned to take place during excavation of one part of this new tunnel.

The KBS-3H project is running the Basic Design phase during 2003, which among other things include location of a test site for boring of three tunnels with a diameter of 1.85 m. One of these is later planned to be used for testing of deposition equipment.

Scope of work for 2003

The work comprises:

- Planning and possible excavation of APSE tunnel.
- Testing of low-pH grout during excavation of a part of the APSE tunnel.
- Finding a suitable site for the KBS-3H experiment and excavation of a gallery for start of boring of the three KBS-3H tunnels.

2.12 Learning from experiences

Background

Several large-scale experiments have been installed and the methods and machines used provide experience for refinement and evaluation of limits of the methods applied.

Emplacement of buffer and canisters, and backfilling of tunnels have been experienced in Canister Retrieval Test, Prototype Repository and Backfill and Plug Test. These experiences are documented and the result analysed with respect to possible improvements as well as limits with respect to water inflows.

Objectives

The aim is to identify reference techniques for emplacement of buffer, canisters, backfilling, and closure.

Present status

Each experiment has been reported in installation reports.

Scope of work for 2003

The planned work comprises:

- Compilation of the results from almost ten years of performed engineering experiments in Äspö HRL.
- Compilation and evaluation of experience from emplacement of buffer and canisters, backfilling of tunnels, and estimation of acceptable water inflows for the applied methods.

2.13 Task Force on Engineered Barrier Systems

Background

A Task Force on Engineered Barrier Systems is still on stand-by while the prioritised work on modelling of THMC-processes in buffer during saturation is conducted on data from the Prototype Repository within the EC project.

Present status

On stand-by.

Scope of work for 2003

The scope is to carry out the modelling work in the Prototype Repository project. New tasks will gradually be defined together with international organisations taking part in the Äspö HRL co-operation.

3 Geo-science

3.1 General

Geo-scientific research is a natural part of the activities at Äspö HRL as a complement and an extension of the stage goals 3 and 4. Studies of the rock mechanical properties are performed in laboratory and field experiments as well as by modelling work.

The major aims are to:

- Increase the understanding of the rock mass material properties and also to increase the knowledge of measurements that can be used in site investigations.
- Identify those factors that determine the distance from a canister to different types of fracture zones/discontinuities and the measurable parameters that determines the values of the distance.
- Explain the results from previous tests that show that when going from a bore hole to a larger diameter hole, the inflow into the larger hole is often less than predicted.

The geo-scientific model of Äspö, based on information from the models developed for the different geo-scientific disciplines, will be updated and new data collected since 1995 will be integrated.

3.2 GeoMod Project

Background

Based on pre-investigations geological, hydrogeological, rock mechanical, and hydro-geochemical models were made over Äspö HRL. During the Construction Phase the models were successively updated based on characterisation data obtained from 1986 until 1995. This work resulted in the Äspö96 models /Rhén *et al.*, 1997/.

In the GeoMod Project the existing models will be updated by integrating new data collected since 1995. The major part of the new data has been collected during the operational phase for the different on-going experiments. The new data have been produced in the lower part of the Äspö HRL. The updated models focus on a volume including the tunnel spiral volume from about 340 m to about 500 m. In addition, the development of a geothermal model will be integrated in the project. This issue has earlier been run as a separate project.

Objectives

The objectives of the GeoMod Project are to:

- Describe the geo-scientific properties of the rock volume containing the tunnel spiral.
- Identify relevant geo-scientific processes to explain the geo-scientific properties.
- Define the boundary conditions of importance to the rock volume processes.
- Develop the methodology to integrate the knowledge from different geo-scientific disciplines.
- Develop a coherent integrated geo-scientific model of Äspö.

The gathered geo-scientific information will be provided to ongoing and coming experiments at Äspö HRL as bases for e.g. the identification of suitable experimental rock volumes, and information for the setting of boundary conditions. The development and refinement of the methodology and the tools for construction of geo-scientific models may also be applicable for the geo-scientific characterisation of a future repository site.

Present status

The models within each geo-scientific discipline has been assessed and results from the different projects conducted at Äspö has been utilised to modified or update the models. Draft reports are available from most of the geo-scientific disciplines.

A methodology for the integration of the different models has been developed where modelling results obtained in the different geo-scientific disciplines are compared.

Scope of work for 2003

Final reports describing the interactively constructed geo-scientific models will be prepared. These models will form the basis for an integrated site descriptive geo-scientific model. The integration of the different disciplines will be worked on during 2003 and according to present plans an integration report will be written, reviewed and printed.

3.3 Rock stress measurements

Objectives

To be able to make correct assessments of the *in situ* stress field from results from different types of rock stress measurement techniques it is important to know the limitations and shortcomings of the different measurement techniques.

Present status

Rock stress measurements with different techniques (bore probe, doorstopper and hydraulic fracturing) has been performed as well as numerical modelling of the over coring itself. Comparisons and conclusions have been made.

Scope of work for 2003

A report will be published that will be a major part of the strategy for rock stress measurements as suggested by the International Society for Rock Mechanics (ISRM).

3.4 Rock creep

The understanding of the material properties of rock and rock-mass are being developed. The objective with the work is to be able to develop better conceptual models for the influence of the rock damaged zone and rock creep on rock stability.

Present status

A literature study and scooping numerical modelling with a three-dimensional coupled hydromechanical computer code (3DEC) have been performed.

Scope of work 2003

The results from the modelling and the literature study will be presented in a report during the first quarter 2003. The findings will be used to outline the scope of work for the rest of the year.

3.5 Äspö Pillar Stability Experiment

Background

Very little research on the rock mass response in the transitional zone (accelerating frequency of micro-cracking) has been carried out. It is therefore important to gain knowledge in this field since the stress field around the canister holes is dependent on the spacing of the canister holes which finally determines the total length of the deposition tunnels. To optimise the repository design the length of the deposition tunnels shall be as short as possible.

Äspö Pillar Stability Experiment is therefore initiated at Äspö HRL as a complement to an earlier study at URL performed by AECL in Canada. AECL's experiment was carried out during the period 1993-1996 in an almost unfractured rock mass with high in situ stresses and brittle behaviour. The major difference between the two sites is that the rock mass at Äspö is fractured and the rock mass response to loading is elastic. The conditions at Äspö HRL therefore make it appropriate to test a fractured rock mass response to a load that will force the rock from an elastic response through the transitional zone to brittle behaviour where spalling will occur.

Objectives

The Pillar Stability experiment is a rock mechanics experiment which can be summarised in the following three main objectives:

- Demonstrate the capability to predict spalling in a fractured rock mass.
- Demonstrate the effect of backfill (confining pressure) on the propagation of micro-cracks in the rock mass closest to the deposition hole.
- Comparison of 2D and 3D mechanical and thermal predicting capabilities.

The project consists of two different work packages of which the first is the modelling and prediction work and the second is the excavation of rock and installation of instruments and heaters.

The project is divided into four different phases:

- Phase 1 is a feasibility study and preliminary design of the experiment. The expected outcome of the feasibility study is the location of the new tunnel, the experimental design and to demonstrate that the chosen design will give high stresses enough in the pillar. The feasibility study shall also give a rough estimation about what kind of instrumentation that will be needed.
- Phase 2 shall result in a final experiment design. Phase 2 also includes exploratory core drilling in the extension of the new experiment tunnel. When the test results from the cores in the proposed experiment location are ready they will be used for the numerical modelling. The numerical models will be completed and reported before the installation of the instrumentation starts.
- Phase 3 comprises all the work in the new tunnel including the instrumentation.
- Phase 4 comprises the heating part of the experiment. After completion of the experiment, compilation and analyses of sampled data will be summarised and reported.

Experimental concept

To achieve the objectives a new short tunnel will have to be excavated in Äspö HRL to ensure that the experiment is carried out in a rock mass with a virgin stress field. In the new tunnel a vertical pillar will be constructed in the floor. The pillar will be designed in such a way that spalling will occur when the pillar is heated.

To create the pillar two vertical holes will be drilled in the floor of the tunnel so that the distance between the holes is 1 m. To simulate confining pressure in the backfill (1 MPa), one of the holes will be subjected to an internal water pressure via a liner.

Convergence measurements, thermistors and an acoustic emission system will be used to monitor the experiment.

Present status

Numerical modelling has been performed by 2D and 3D tools to make predictions of the stress field in the pillar before and during the heating phase. The different tools give very similar results and predict that high stresses enough will be induced in the pillar to initiate the spalling process. Numerical modelling has also been used to specify the effect of the electrical heaters.

The monitoring systems including thermistors, different convergence measurement techniques and an acoustic emission system have been designed.

The confinement equipment, which will provide the 1 MPa pressure in one of the holes has been designed.

Compilations of earlier made rock stress measurements and determinations of mechanical parameters have been made and have been used for the numerical modelling.

Geological characterisation including: drilling, BIPS-logging, core mapping, density logging, flow logging and pressure build up tests has been performed in four bore holes at three different locations that initially were assessed to be suitable sites for the experiment. Rock stress measurements with the Bore probe have been performed in one of the holes located in the chosen preliminary site.

The preliminary site for the experiment has been selected at the 450 m level, see Figure 3-1. The building of a geological model for that site started in the end of 2002.

Scope of work for 2003

During 2003 the following main activities will be performed:

- In the first quarter the work performed during 2002 will be presented in the IPR- and R-report series.
- The geological model will be finished early in the year and shortly thereafter it will be decided if the chosen alternative is suitable for the purpose. The preliminary interpretation of the results looks promising.
- A full-scale test of the confinement equipment will be performed during the first quarter.
- The entrepreneurs for the tunnelling and boring of the large holes will be purchased. The tunnelling is planned from April through July. The tunnelling will be combined with a grouting experiment.
- Extensive geological characterisation of the rock volume around the tunnel will be performed before the final location of the pillar is chosen. The large holes will then be bored during the autumn. The acoustic emission system will monitor the rock mass response during the boring.
- The final instrumentation and the installation of the electrical heaters will be performed shortly after the large holes are finished in late 2003.

The remaining part of the year will be used for the final preparations before the heating of the pillar starts early 2004.

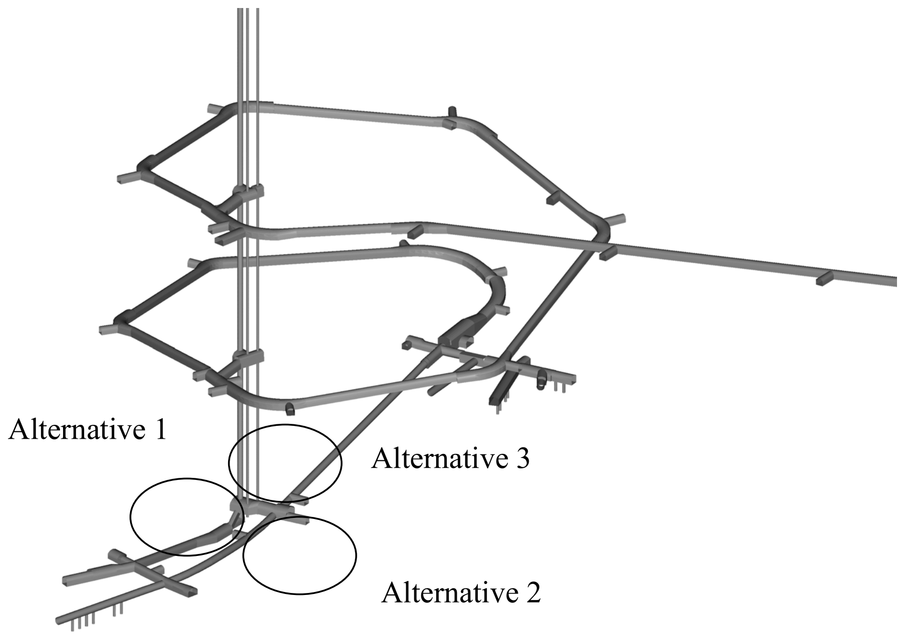

Figure 3-1. *Location of the preliminary site for the Pillar Experiment at the 450 m level in Äspö HRL (Alternative 3).*

3.6 Heat transport

Background

The deposit canisters generate heat due to radioactive decay. The temperature field in the repository depends on thermal properties of the rock and generated heat. The layout of the repository is dependent on the temperature field. The design criterion is the maximum temperature allowed on the surface of the canisters. A low thermal conductivity in the rock leads to a significantly larger distance between canisters than in the case of a high thermal conductivity.

Objectives

The aim is to develop a strategy for site descriptive thermal modelling and use the strategy to develop and test a thermal model for the Äspö Rock volume. The work includes measurements of thermal properties of the rock and examination of the distribution of thermal conductivities. Another objective is to analyse the thermal properties in different scales and clarify relevant scales for the thermal process by sensitivity analyses.

Present status

A report on the strategy for site descriptive thermal modelling is under preparation. The work with developing a site descriptive thermal model for Äspö HRL has been integrated in the GeoMod Project (c.f. Section 3.2).

The mineral distributions in rock samples documented in SKB's site characterisation database, SICADA, have been used to calculate the thermal conductivity of the samples. The thermal conductivities have been analysed statistically and divided into different rock types. Thermal data modelling has been used to analyse the influence on the canister temperature of changes in the thermal conductivity in the rock close to the canister. A relationship has been found between the thermal properties of specific rock types at Äspö and their density. This relationship has been tested to evaluate the thermal properties in fresh rock from density loggings (restricted to Fine-grained granite, Ävrö granite, and Äspö diorite at Äspö). These subjects are reported in "Thermal properties at Äspö HRL - Analysis of distribution and scale factors" (in preparation).

Uncertainties exist in the method used for determination of thermal properties. A comparison has been made between methods used by Posiva and SKB in order to examine and quantify these uncertainties. The comparison is reported in "Comparison of thermal properties measured by different methods" (in preparation).

Scope of work for 2003

- Development of site descriptive thermal model for Äspö HRL. See also the description of the GeoMod Project.
- Test of the thermal model. Prediction of the thermal function of the Prototype Repository and evaluation of thermal properties from backwards calculations.
- Scale factors of thermal properties. Clarify scale effects on thermal properties due to the measurement process and the actual process to be studied.
- Modelling of thermal properties from density and porosity loggings. A theoretical study based on existing material is planned to analyse limitations in the proposed empirical method and to study scale changes in thermal conductivity.

3.7 Seismic influence on the groundwater system

Background

The Hydro Monitoring System (HMS) registers at the moment the piezometric head in 409 positions underground in the Äspö HRL. An induced change of the head with more than 2 kPa triggers an intensive sampling. All measured data are stored.

Objectives

The data in the data base are assumed to bear witness of different seismic activities in Sweden but also abroad, dependent on the magnitude of the event. By analysing the data on changes in the piezometric head at Äspö connections to specific seismic events are expected to be established.

Present status

Data from the HMS are stored in the database pending analysis. In one case was the effect of seismic effects determined. This was in 1999, when the large earthquake in Turkey triggered the HMS approximately eight minutes after the actual event occurred.

Scope of work for 2003

Analyse data and document results with respect to:

- Blasts in Äspö HRL and the CLAB extension project.
- Earthquakes in Sweden and abroad.

3.8 Inflow predictions

Background

SKB has conducted a number of large field tests where prediction of inflow into tunnels or depositions holes has been a component; the Site Characterisation and Validation Test in Stripa, the Prototype Repository and the Groundwater Degassing and Two-Phase Flow experiments in Äspö HRL. The results from these tests show that when going from a bore hole to a larger diameter hole, the inflow into the larger hole is often less than predicted, and the explanation for this is not yet well understood.

The ability of predicting inflow is of importance from several aspects, such as:

- Evaluation of experimental results in the Äspö HRL. A good understanding of the mechanisms controlling inflow would improve the possibilities for good experimental set-ups and accurate result interpretation.
- Evaluation and comparisons between potential repository sites. It is desirable to be able to predict the inflow conditions into the excavations, already before the construction work starts, based on hydraulic measurements made in small diameter bore holes.
- Evaluation of the expected bentonite buffer behaviour. The amount of inflow into deposition holes will influence the time needed for saturation and also the expected performance of the buffer.
- Design and optimisation of the repository layout. Poor prediction of inflow could lead to less optimal design alternatives.

Objectives

The objectives for this project are:

- To make better predictions of the inflow of groundwater into deposition holes possible.
- To confirm (or refuse) previous observations of reduced inflow into deposition holes and tunnels compared with bore holes.
- To identify the different mechanisms determining the inflow, and quantify their importance.

Present status

During 2002 a workshop was held where the different potential mechanisms determining inflow rates were discussed. Based on previous field and laboratory test results, it was concluded that there is a need for further field investigations, with the aim of gaining experimental data under controlled conditions. A preliminary project plan for a large-scale field test at Äspö HRL has been prepared. The experiment is designed to test the influence of three different mechanisms judged to have a potential for causing the reduced inflow into deposition holes and tunnels:

- Stress redistribution.
- Blasting and boring.
- Two-phase flow.

The need for corresponding theoretical analyses of the processes has also been confirmed. Numerical analyses results may first be used in the further planning of field experiments and later as a tool for the interpretation of experimental results. The large-scale field test in combination with the development of inflow modelling concepts will provide knowledge necessary to improve the predictive capabilities.

Scope of work for 2003

A study including numerical modelling of inflow, using a three-dimensional coupled hydromechanical computer code (3DEC) will be carried out.

Within year 2003 the planning work for the full-scale field experiment will also begin.

3.9 Canister position index

Background

One of the key issues in the process of selecting one site for detailed investigation, i.e. rock excavation down to repository depth, is the utilisation of the available rock mass expressed as the number of acceptable canister positions out of the total number in the ideal pattern of deposition holes, when applying only the maximum temperature on the canister as a criterion.

Objectives

The main objectives are to find the factors that determine acceptance/non-acceptance of a deposition position, and to identify acceptable parameter values.

Present status

In the mid nineties some work was made regarding fractures and fracture propagation. A mathematical code for fracture propagation was analysed, a code which is more advanced today, but not to an extent that is needed for the purpose of Canister Position Index (CPI). A statistical method, BayMar, was also studied for distributing geo-data from a few positions over to the rock mass of interest.

Scope of work for 2003

A project group is established and a work programme launched. Results are planned to be reported in 2005. The interim result during 2003 is an identification of the factors of importance.

3.10 Respect distance

Background

Different fracture zones/discontinuities represent inhomogeneities that need a certain distance of rock between the feature and the nearest canister in order to limit the negative effect the features may have on the repository performance. In generic terms are there, by definition, three orders of features. The largest type is defined as the one that surrounds a deposition rock block. The second largest may intersect a deposition tunnel but not a deposition hole, and the third type may intersect also a deposition hole, and is consequently not a design-affecting feature.

Objectives

To identify those factors that determine the distance from a canister to the features and the measurable parameters that determines the values of the distance.

Present status

A rough distance of 100 m from the largest type of features has been assumed in SKB's performance assessments of deep repositories, and a couple of meters for the second type. No detailed analysis has been performed by SKB.

Posiva has been actively studying the issue for a fairly long period of time and has accepted to take the lead through the umbrella of the SKB and Posiva co-operation.

Scope of work for 2003

A project group is established and a work programme launched. Results are planned to be reported in 2005. The interim result during 2003 is an identification of the factors of importance.

4 Natural barriers

4.1 General

To meet Stage goal 3, experiments are performed to further develop and test methods and models for description of groundwater flow, radionuclide migration, and chemical conditions at repository depth.

Experiments, with the aim to increase the knowledge of the long term function of the repository barriers, are performed in Äspö HRL at conditions that are expected to prevail at repository depth. The bedrock with available fractures and fracture zones, its properties and on-going physical and chemical processes, which affect the integrity of the engineered barriers and the transport of radionuclides, are denoted the natural barriers of the deep repository. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The strategy for the on-going experiments is to concentrate the efforts on those experiments that are of importance for the site investigations. This focus implies the need to involve experts of different geo-scientific disciplines into the work in order to facilitate integration and spread information.

Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are one of the main purposes of the Äspö HRL. The programme includes projects with the aim to evaluate the usefulness and reliability of different models and to develop and test methods for determination of parameters required as input to the models.

The overall purposes are to:

- Improve the scientific understanding of the deep repository's safety margins and provide input data for assessments of the repository's long term safety.
- Obtain the special material needed to supplement data from the site investigations in support of an application for a siting permit for the deep repository.
- Clearly present the role of the geosphere for the barrier functions: isolation, retardation and dilution.

Isolation is the prime function of a deep geological disposal system such as the KBS-3. Isolation is obtained through the co-function of the natural and engineered barriers. The flow of water to the waste containment is largely determining the magnitude at which the corrosion of the canister and the dissolution of the waste form can take place. For a good isolation it is thus necessary to minimise the groundwater flow to the waste containment. Additional conditions that affect the isolation are the chemistry of the groundwater and the mechanical stability of the rock.

Retention of radionuclides is the second most important barrier function of the repository. Retention is provided by physical and chemical processes and will be provided by any system and process that interacts with radionuclides dissolved in the groundwater. Some elements are strongly retarded while others are escaping with the flowing groundwater.

Dilution is the third barrier function. It will take place in the rock volume surrounding the repository. The magnitude of dilution is very much depending on the site specific conditions. In the geosphere the dilution is caused by the dispersion in groundwater. No experiment at Äspö is focussing on dilution, although dilution is included in the biosphere safety assessment modelling.

The ongoing or planned experiments and projects are:

- Tracer Retention Understanding Experiments.
- Long Term Diffusion Experiment.
- Radionuclide Retention Experiments with CHEMLAB.
- Colloid Project.
- Microbe Project.
- Matrix Fluid Chemistry.
- Äspö Task Force on Groundwater Flow and Transport of Solutes.
- The EC project PADAMOT (Palaeohydrogeological Data Analysis and Model Testing).

4.2 Tracer Retention Understanding Experiments

Background

A programme has been defined for tracer tests at different experimental scales, the so-called Tracer Retention Understanding Experiments (TRUE) /Bäckblom and Olsson, 1994/. The overall objective of the defined experiments is to increase the understanding of the processes which govern retention of radionuclides transported in crystalline rock, and to increase the credibility in models used for radionuclide transport calculations, which will be used in licensing of a repository.

Objectives

The TRUE experiments should achieve the following general objectives:

- Improve understanding of radionuclide transport and retention in fractured crystalline rock.
- Evaluate to what extent concepts used in models are based on realistic descriptions of rock and whether adequate data can be collected during site characterisation.
- Evaluate the usefulness and feasibility of different approaches to modelling radionuclide migration and retention.
- Provide *in situ* data on radionuclide migration and retention.

During 2001, it was decided to collect all future TRUE work in two separate projects; TRUE Block Scale Continuation and TRUE-1 Continuation.

The overall objectives for both projects are to:

- Demonstrate and validate a process for defining the critical geologic element(s) for flow and transport/retention and their properties.
- Define, at different scales, the pore space (responsible for/necessary to explain) transport, diffusion, sorption and loss of tracer.
- Integrate experimental results from laboratory scale, detailed scale and block scale to obtain a consistent and adequate description of transport, to serve as a basis for modelling transport from canister to biosphere.

Although the experimental focus is placed on the respective TRUE experimental sites developed at the Äspö HRL, integration and co-ordination of experimental activities at, and between the sites is emphasised in the planned future work.

Experimental concept

The basic idea is to perform a series of *in situ* tracer tests with progressively increasing complexity. In principle, each tracer experiment will consist of a cycle of activities beginning with geological characterisation of the selected site, followed by hydraulic and tracer tests. A subsequent option is to characterise the tested pore space and analyse tracer fixation using epoxy resin injection. Subsequently, the tested rock volume will be excavated and analysed with regards to flow-path geometry and tracer concentration.

Together with supporting laboratory studies of diffusion and sorption characteristics made on core samples, the results of the *in situ* tests will provide a basis for integrating data on different scales, and testing of modelling capabilities for radionuclide transport up to a 100 m scale, see Figure 4-1. A test of the integration and modelling of data from different length scales and assessment of effects of longer time perspectives is made as part of Task 6 in the Task Force on Modelling of Groundwater Flow and Transport of Solutes, cf. Section 4.8.

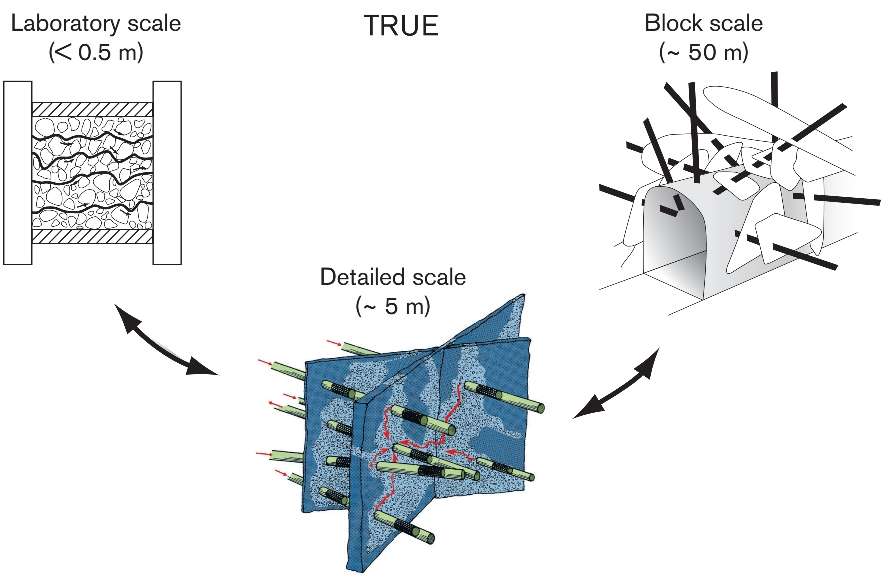

***Figure 4-1.** Schematic representation of transport scales addressed in the TRUE programme.*

Present status

The first *in situ* experiment (TRUE-1) performed on a detailed scale focused on an interpreted single fracture, was of limited time duration, and was primarily aimed at technology development, although comprehensive tracer tests using radioactive sorbing tracers were included. The final report on the First TRUE Stage was presented by Winberg *et al.* /2000/. The experiments conducted during the First TRUE Stage have also been subject to predictions and evaluations using an assortment of different modelling concepts within the framework of the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes /Elert, 1999; Elert and Svensson, 2001; Marschall and Elert (in preparation)/. In September 2001 the 4th International Äspö

Seminar was devoted to discussion of the TRUE-1 data and results, as well as relevant studies from elsewhere /SKB, 2001d/.

An experiment in the block scale, TRUE Block Scale Project, commenced in 1996. The experimental work was "officially" terminated in November 2000 but the pumping and sampling of the TRUE Block Scale Phase C tests was prolonged till the end of 2002. Evaluation and final reporting was completed in 2002. The TRUE Block Scale project is reported in a series of four final report volumes:

- Characterisation and model development /Andersson *et al.*, 2002a/.
- Tracer tests in the block scale /Andersson *et al.*, 2002b/.
- Modelling of flow and transport /Poteri *et al.*, 2002/.
- Synthesis of flow, transport and retention in the block scale /Winberg *et al.*, (in print)/.

The evaluation and reporting period was crowned by an International Seminar, held in Oskarshamn, November 2002, focused on the results and conclusions of the TRUE Block Scale Project.

Work in the detailed scale, including complementary cross-hole interference test, tracer dilution and tracer tests, has been performed at the TRUE-1 site as part of the TRUE-1 Continuation Project /Källgården *et al.*, 2002/.

4.2.2 TRUE Block Scale Continuation

The TRUE Block Scale Continuation (BS2) project has its main focus on the existing TRUE Block Scale site. The TRUE Block Scale Continuation is divided into two separate phases:

BS2a Continuation of the TRUE Block Scale (Phase C) pumping and sampling including employment of developed enrichment techniques to lower detection limits. Complementary modelling work in support of in situ tests.

BS2b Additional in situ tracer tests based on the outcome of the BS2a analysis. In situ tests are preceded by reassessment of the need to optimise/remediate the piezometer array. The specific objectives of BS2b are to be formulated on the basis of the outcome of BS2a.

Objective

The overall objective of BS2 can be summarised as: "Improve understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure, and micro-structure".

Special consideration is in this context put on the possibility to explore the role of more low-permeable parts of the studied fracture network, including background fractures.

Present status

Complementary field-work in terms of prolonged Phase C sampling and analysis has been performed as part of the TRUE Block Scale Continuation project /Byegård, 2002a/.

Scope of work for 2003

Complementary modelling in support of *in situ* tracer tests which will explore the possibilities to perform tests over longer distances and to introduce tracers in low–transmissive features of the background fracture population. In addition, modelling will explore the possibilities of improving process discrimination by using different pumping rates and non-sorbing tracers.

Complementary sorption laboratory experiments on site-specific materials from TRUE Block Scale site will be performed as part of the TRUE-1 Continuation project.

4.2.3 TRUE-1 Continuation

The TRUE-1 Continuation project is a continuation of the TRUE-1 experiments, and the experimental focus is here placed on the TRUE-1 site. The discussion and outcome of the 4th International Äspö Seminar (focused on the First TRUE Stage) re-emphasised the need for conducting the planned injection of epoxy resin at the TRUE-1 site. However, before conducting such an impregnation, some complementary cross-hole hydraulic interference tests combined with tracer dilution tests are foreseen. These tests are intended to shed light on the possible three-dimensional aspects of transport at the site. The planned tests would employ both previously used sink sections and some not employed in the already performed tests.

A complication for the scheduling of planned future work lies in the fact that the TRUE-1 and LTDE sites are hydraulically connected. In view of the urge for a relative hydraulic tranquillity on the part of LTDE, a priority for advancing LTDE has been set by SKB. Consequently, the resin impregnation at the TRUE-1 site will be postponed until vital parts of LTDE have been accomplished. According to the present plans resin injection will be possible 2006 at the TRUE-1 site.

Objectives

The objectives of TRUE-1 Continuation are:

- To obtain insight into the internal structure of the investigated Feature A, in order to allow evaluation of the pore space providing the observed retention in the experiments performed.
- To provide an improved understanding of the constitution, characteristics and properties of fault rock zones (including fault breccia and fault gouge).
- To provide insight into the three-dimensionality of the rock block studied as part of the First TRUE Stage such that the role and effects of the fracture network connected to Feature A on the performed tracer tests can be assessed.
- To test a methodology to estimate fracture aperture from radon concentration in groundwater and radon flux from geological materials.
- To provide quantitative estimates of the sorption characteristics of the altered rim zone and fault rock materials of fault rock zones.

The scope of work for identified remaining field and laboratory activities related to the TRUE-1 site includes:

- Complementary cross-hole interference, tracer dilution, and tracer tests with conservative tracers.
- Water sampling and analyses including analyses of radon concentration in groundwater and measurements of radon flux from various geological materials and subsequent evaluation.
- Characterisation of a number of typical fault rock zones of variable thickness. Injection of epoxy resin and subsequent sampling. Assessment of pore space and quantification of *in situ* porosity of fault gouge material.
- Batch sorption experiments on rim zone and fault gouge materials from the TRUE Block Scale site and from other locations along the access tunnel, including zones investigated as part of the Fault Rock Zone characterisation project.
- Injection of epoxy resin into the previously investigated Feature A, with subsequent excavation and analyses.

Present status

The pre-study compiling data from the TRUE-1 site has been reported /Källgården *et al.*, 2002/. The results of the complementary cross-hole interference, tracer dilution and tracer tests /Källgården *et al.*, 2002/ provided an explanation for the double peak in the STT-2 tracer test /Winberg *et al.*, 2000/, attributed to a branching of Feature A in bore hole KXTT4. In addition, a trace test with pumping in feature A and injection in neighbouring sections of Feature B showed no breakthrough from Feature B after 700 hours, indicating no evidence of a short-circuiting three-dimensional fracture network in the TRUE-1 target area.

In situ sampling and radon measurements at the TRUE-1 site have shown that very similar radon concentration is measured for different groundwater samples within a singular feature /Byegård, 2002b/. Laboratory experiments have shown that radon fluxes can be measured using a rather simple experimental set-up. Results obtained for the radon fluxes from generic fault gouge materials indicated no evidence of gouge materials being the dominant source of radon to the groundwater of conductive fractures.

During the past year alternative resin technologies have been discussed resulting in retaining an epoxy resin alternative also for this application. Four potential fault rock zone intercepts have been located along the Äspö access tunnel. At one of these (NE-2, L=1/600 m) drilling to collect samples for laboratory experimentation of epoxy optimisation and dye additives has been carried out.

Scope of work for 2003

The activities planned for 2003 are mainly:

- Continued test of methodology to estimate aperture estimations using radon. This includes investigation of the possibility of non-destructive radium measurements of intact rock samples using γ-spectrometry. Carrying out of an in situ experiment in a dipole flow geometry experiment in which water without dissolved radon is injected. The decrease in radon concentration obtained during the “breakthrough” of this water should provide confirmation of the basic principles assumed for the mechanisms of the radon flow. In addition, this includes evaluation of radon analyses carried out on groundwater sampled from the TRUE Block Scale site to confirm the finding of unique radon signatures in individual structures/fractures.

- Laboratory tests focused on suitable resin formulas including dye additives. Basic characterisation of identified potential fault rock zones including drilling of injection bore holes. Resin injection and start up of *in situ* sampling.
- Initiation of laboratory batch sorption experiments and associated geological characterisation.

4.3 Long Term Diffusion Experiment

Background

The Long Term Diffusion Experiment (LTDE) constitutes a complement to performed diffusion and sorption experiments in the laboratory, and a natural extension of the experiments conducted as part of TRUE-1 and TRUE Block Scale. The difference is that the longer duration (3-4 years) of the experiment is expected to enable an improved understanding of diffusion and sorption in the vicinity of a natural fracture surface.

Matrix diffusion studies using radionuclides have been performed in several laboratory experiments and also *in situ*. Some experimental conditions such as pressure and natural groundwater composition are however difficult to simulate in laboratory experiments. Investigations of rock matrix diffusion in laboratory scale imply that one uses rock specimens in which damage due to drilling and unloading effects (rock stress redistribution) may have caused irreversible changes of the rock properties. Matrix diffusion in non-disturbed rock is therefore preferably investigated *in situ*. Through the proposed experimental technique one will also obtain some information of the adsorption behaviour of some radionuclides on exposed granitic rock surfaces.

Scoping calculations, for the planned experiment, have been performed /Haggerty, 1999/ using the multi-rate diffusion concept which accounts for pore-scale heterogeneity. A test plan was drafted and presented at the combined TRUE 2/LTDE review meeting in March 1999. The review and desires of SKB redirected the experiment towards an assessment of diffusion from a natural fracture surface, through the altered zone into the intact unaltered matrix rock. The new direction resulted in a revision of the test plan from its final form /Byegård *et al*., 1999/.

Objectives

The objectives of the Long Term Diffusion Experiment project are:

- To investigate diffusion into matrix rock from a natural fracture *in situ* under natural rock stress conditions and hydraulic pressure and groundwater chemical conditions.
- To improve the understanding of sorption processes and obtain sorption data for some radionuclides on natural fracture surfaces.
- To compare laboratory derived diffusion constants and sorption coefficients for the investigated rock fracture system with the sorption behaviour observed *in situ* at natural conditions, and to evaluate if laboratory scale sorption results are representative also for larger scales.

Experimental concept

A core stub with a natural fracture surface is isolated in the bottom of a large diameter telescoped bore hole. In addition a small diameter bore hole is drilled through the core stub into the intact undisturbed rock beyond the end of the large diameter bore hole. A cocktail of non-sorbing and sorbing tracers are circulated in the test section for a period of 3-4 years after which the core stub is over-cored, and analysed for tracer content and tracer fixation, see Figure 4-2.

The experiment is focussed on a typical conductive fracture identified in a pilot bore hole (KA3065A02). A telescoped large diameter bore hole (300/196.5 mm) (KA3065A03) is drilled sub-parallel to the pilot bore hole in such away that it intercepts the identified fracture some 10 m from the tunnel wall and with an approximate separation of 0.3 m between the mantel surfaces of the two bore holes.

The natural fracture as seen on the surface of the stub is sealed off with a polyurethane cylinder and a peek lid, which constitutes a “cup-like” packer. The remainder of the bore hole will be packed off with a system of one mechanical and two inflatable packers. The small diameter (36 mm) extension is packed off using a double packer system leaving a 0.3 m section. The system of packers and an intricate pressure regulating system will be used to eliminate the hydraulic gradient along the bore hole.

During the circulation of tracer, samples of water will be collected at various times over the duration of the experiment. The redox situation in the circulation loop will be monitored continuously with a flow through cell, which will measures pH, Eh (three different electrodes) and temperature. Strategically positioned filters and on line preventive devices will safeguard that no build up of microbes in the loop occurs. After completion of tracer circulation, the core stub is over-cored, sectioned and analysed for tracer content.

The project also involves a variety of mineralogical, geochemical and petrophysical analyses. In addition, as in the REX project, a “replica” laboratory through diffusion experiment is planned on the corresponding “stub” material from the pilot bore hole.

The drilling of the telescoped large diameter experimental bore hole was performed with a high degree of interactivity between; careful iterative drilling in short uptakes (particularly in the inner part of the bore hole), BIPS imaging, core examination and on-site structural modelling/updating of structural model. Despite these the resulting stub turned out three times longer (150 mm) than originally planned. The situation was analysed in a series of *in situ* and laboratory measurements and modelling, which showed that the core stub effectively is disturbed throughout its entire length.

The 36 mm extension of the bore hole was drilled early October 2001. Comprehensive planning proceeded the drilling and development of the drilling procedure and updating of the descriptive structural model based on bore holes KA3065A02 and KA3065A03. The resulting structural model is shown in Figure 4-3.

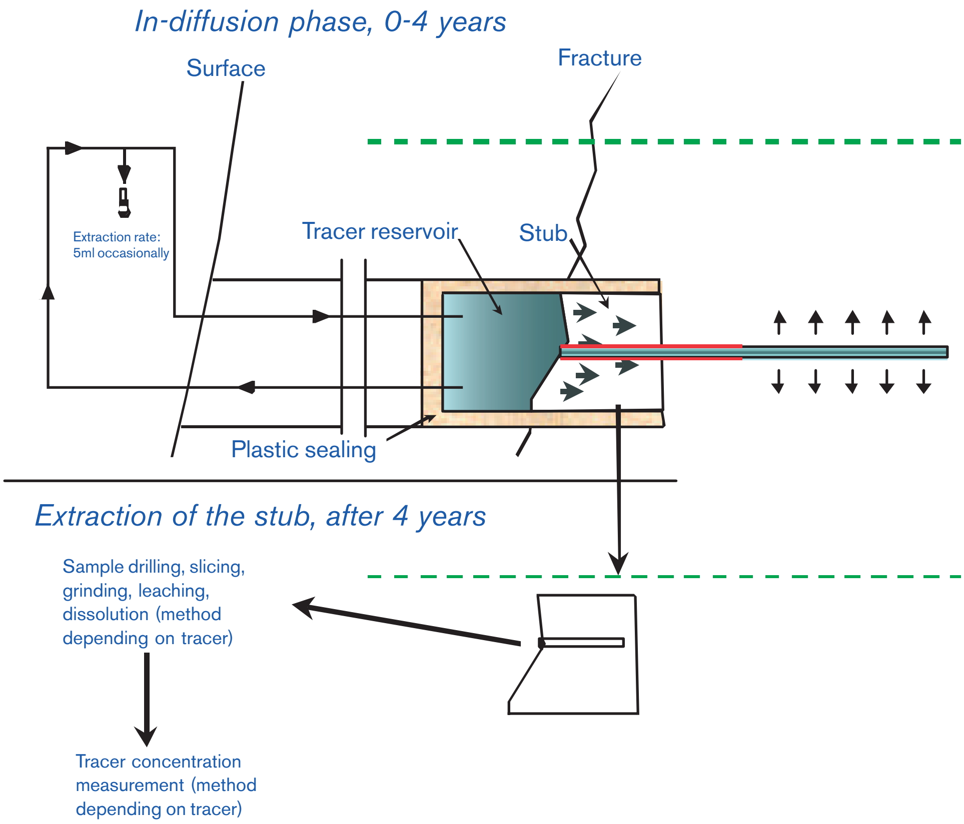

***Figure 4-2.** Schematic of LTDE experimental concept including injection bore hole in contact with a fracture surface, combined with excavation and penetration profile studies.*

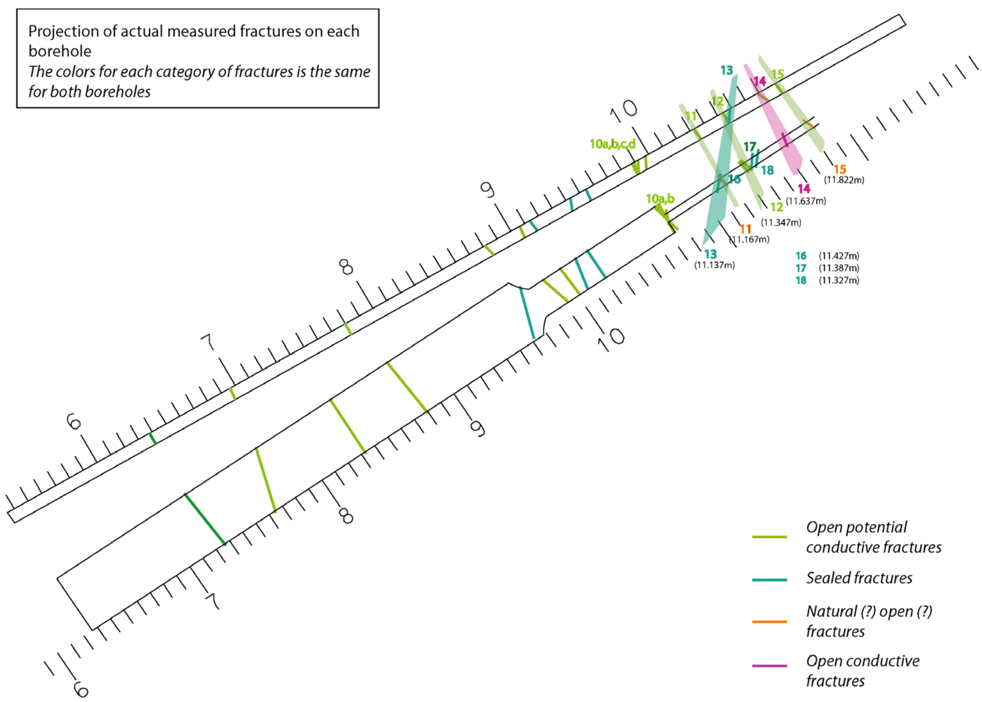

***Figure 4-3.** Plane view of interpreted structures in the interior of experimental telescoped bore hole KA3065A03.*

Present status

During the year, bore hole KA3065A03 has been instrumented with the full down-hole system including the double packer in the slim hole section. The experimental container has been equipped with the necessary electrical infrastructure and the infrastructure to enable pressure registration. In addition, two plexi-glass boxes including the pressure regulation equipment and the circulation, sampling and system state monitoring equipment have been installed.

The above described *in situ* activities have been complemented by construction and programming of the system which will enable online and remote monitoring of system states.

Planned initiation of a pre-test programme focused on system function control and simulation of various extreme situations and possible leakage scenarios have been delayed due to noted rust precipitates in the circulation loop. The origin of these precipitates is attributed to the simulated test bore hole used for a laboratory setup of the equipment. In addition, indications of unexpectedly high microbial activity in the bore hole may call for remediating actions.

Scope of work for 2003

The scope of work for 2003 includes:

- Performance of the planned pre test programme.
- FMEA #4.
- Start of circulation followed by addition of tracer (two injections foreseen).
- Mineralogical studies and start-up of replica experiment in the laboratory.

4.4 Radionuclide Retention Experiments

Background

Laboratory studies on the solubility and migration of long-lived nuclides e.g. technetium, neptunium, and plutonium indicate that these elements are so strongly sorbed on the fracture surfaces and into the rock matrix that they will not be transported to the biosphere until they have decayed. This very strong retention could well be an irreversible sorption process.

Laboratory studies of radionuclide retention under natural conditions are extremely difficult to conduct. Even though the experiences from different scientists are uniform it is of great value to be able to demonstrate the results of the laboratory studies *in situ*, where the natural contents of colloids, of organic matter, of bacteria etc. are present in the groundwater. A special borehole probe, CHEMLAB, has been designed for different kinds of *in situ* experiments where data can be obtained representative for the properties of groundwater at repository depth.

The results of experiments in CHEMLAB will be used to validate models and check constants used to describe radionuclide dissolution in groundwater, the influence of radiolysis, fuel corrosion, sorption on mineral surfaces, diffusion in the rock matrix, diffusion in buffer material, transport out of a damaged canister and transport in an individual fracture. In addition, the influence of naturally reducing conditions on solubility and sorption of radionuclides will be tested.

Objectives

The objectives of the radionuclide retention experiments are:

- To validate the radionuclide retention data which have been measured in laboratories by data from *in situ* experiments.
- To demonstrate that the laboratory data are reliable and correct also at the conditions prevailing in the rock.
- To decrease the uncertainty in the retention properties of relevant radionuclides.

Experimental concept

CHEMLAB is a borehole laboratory built into a probe, in which *in situ* experiments can be carried out under ambient conditions with respect to pressure and temperature, and with the use of natural groundwater from the surrounding rock. Initially one “all purpose” unit, CHEMLAB 1, was constructed in order to meet any possible experimental requirement. At a later stage, a simplified version the CHEMLAB 2 unit was designed to meet the requirements by experiments where highly sorbing nuclides are involved. Figure 4-4 illustrates the principles of the CHEMLAB 1 and CHEMLAB 2 units.

In the currently ongoing or already completed experiments the following are studied:

- Diffusion of cations (Cs^{+}, Sr^{2+} and Co^{2+}) and anions (I^{-} and TcO^{4-}) in bentonite.
- The influence of primary and secondary formed water radiolysis products on the migration of the redox-sensitive element technetium.
- Migration of actinides (americium, neptunium and plutonium) in a rock fracture.

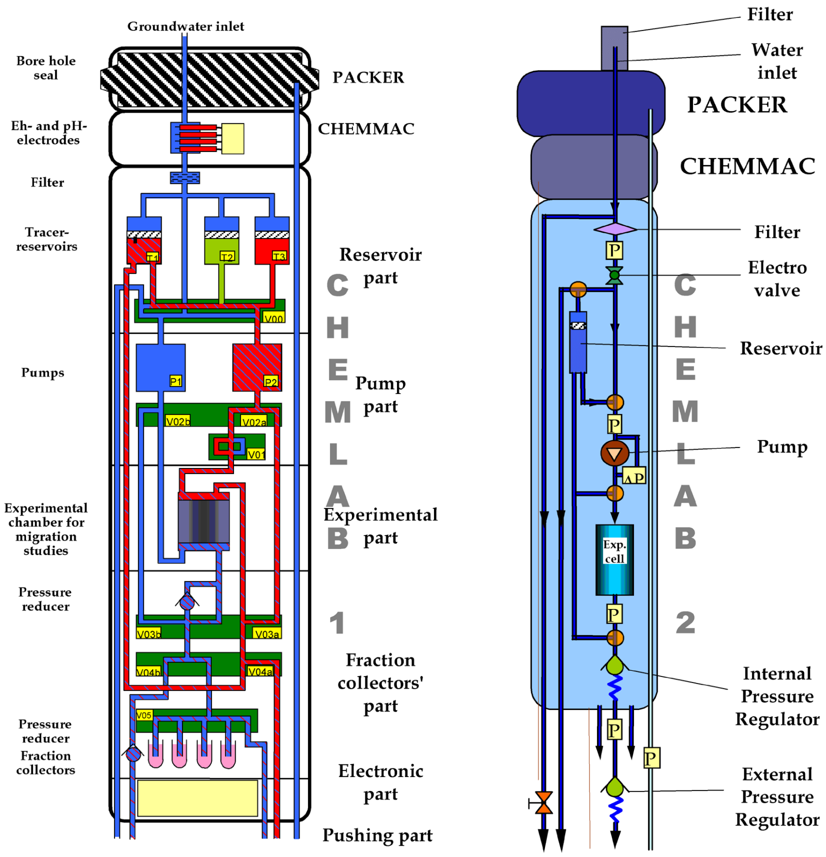

Figure 4-4. Schematic illustration of CHEMLAB 1 and 2.

Diffusion in bentonite

In the diffusion experiments compacted clay was placed between two filters in an experimental cell in CHEMLAB 1. A small volume of solution prepared from filtrated Äspö water and spiked with the radionuclide(s) used as tracers is transferred to the tracer reservoir. The tracers used were cations (^{134}Cs, ^{85}Sr, and ^{57}Co) and anions (^{131}I and ^{99}Tc). The diffusion experiments were carried out during 2001 and the results are reported in a final report /Jansson and Eriksen, 2001/.

Radiolysis experiments

Reduced technetium will be placed in a diffusion cell containing bentonite. In the experiment with primary formed water radiolysis products the technetium tracer is placed on an irradiation source at the bottom of the cell (direct irradiation). In the experiment with secondary formed products the technetium tracer will be placed inside the cell while an irradiation source will be placed outside the cell (indirect radiation).

Migration of actinides

Experiments on the migration of actinides, americium, neptunium and plutonium, in a natural rock fracture in a drill core are carried out in the CHEMLAB 2.

The rock samples are analysed with respect to the flow-path and to the actinides sorbed onto the solid material. Non-destructive and destructive techniques will be applied, such as x-ray computer tomography and cutting the samples after injection of fluorescent epoxy resin. The distribution of actinides along the flow-path will be determined from the abraded material gained by cutting, as well as by coupled laser ablation ICP-MS techniques of the slices.

Present status

Radiolysis experiments

The radiolysis experiments, in CHEMLAB 1, are intended to investigate the influence of radiolysis on the migration of oxidised technetium in bentonite clay. Due to delays in the final evaluation of the experiments on diffusion in bentonite, the start of the radiolysis experiments has been postponed.

Actinide experiments

During fall 2000 the first of several actinide migration experiments at Äspö was performed. Due to a failure in CHEMLAB 2 this actinide experiment was stopped in advance and the results have not yet been fully evaluated.

Scope of work for 2003

Radiolysis experiments

The radiolysis experiments are planned to be carried out in CHEMLAB 1 during 2003. According to present plans both the direct radiolysis experiment and the indirect radiolysis experiment will be carried out.

Actinide experiments

Experiments with actinides will be run during 2003 in CHEMLAB 2 in a drill core with a natural fracture along the core. The actinides are added to groundwater flowing through the fracture in the drill core in the sond.

The planning of additional experiments, where the natural groundwater passing through the CHEMLAB sond has been in contact with small fragments of spent fuel, will take place during 2003.

4.5 Colloid Project

Background

Colloids are small particles in the size range 10^{-6} to 10^{-3} mm. The colloidal particles are of interest for the safety of a repository for spent nuclear fuel because of their potential to transport radionuclides from a defect waste canister to the biosphere.

SKB has for more than 10 years conducted field measurements of colloids. The outcome of the studies performed nationally and internationally concluded that the colloids in the Swedish granitic bedrock consist mainly of clay, silica and iron hydroxide particles and that the mean concentration is around 20-45 ppb which is considered to be a low value /Laaksoharju *et al.*, 1995/. The low colloid concentration is controlled by the attachment to the rock, which reduces both the stability of the colloids and their mobility in aquifers.

It has been argued that e.g. plutonium is immobile owing to its low solubility in groundwater and strong sorption onto rocks. Field experiments at the Nevada Test Site, where hundreds of underground nuclear tests were conducted, indicate however that plutonium is associated with the colloidal fraction of the groundwater. The $^{240}Pu/^{239}Pu$ isotope ratio of the samples established that an underground nuclear test 1.3 km north of the sample site is the origin of the plutonium /Kersting *et al.*, 1999/.

The findings of potential transport of solutes by colloids and access to more sensitive instruments for colloid measurements motivated a Colloid Project at Äspö HRL The project was initiated by SKB in 2000 and is planed to continue until the end of 2006.

The participating organisations in the project are:

- INE/Forshungszentrum Karlsruhe, Germany.
- Posiva, Finland.
- SKB, Sweden.

Objectives

The aims and objectives of the Colloid Project are to study:

- The stability and mobility of colloids.
- Measure colloid concentration in the groundwater at Äspö.
- Bentonite clay as a source for colloid generation.
- The potential of colloids to enhance radionuclide transport.

The results from the project will be used mainly in the future development of safety assessment modelling of radionuclide migration.

Experimental concept

The Colloid Project comprises: laboratory experiments, background measurements, borehole specific measurements, and fracture specific measurements.

Laboratory experiments

The role of the bentonite clay as a source for colloid generation at varying groundwater salinity (NaCl/CaCl) was studied in laboratory experiments. Bentonite clay particles were dispersed in water solutions with different salinity and the degree of sedimentation was studied. The experiment investigated in detail the chemical changes, size distribution and the effects from Na versus Ca rich bentonite associated with colloid generation /Wold and Eriksen, 2002a; Karnland, 2002/.

Background measurements

The natural background colloid concentrations were measured in eight different bore holes, representing groundwater with different ionic strength, along the Äspö HRL-tunnel, see Figure 4-5.

The colloid content is measured on-line from the bore holes by using modified laser based equipment LIBD (Laser-Induced Breakdown-Detection) which has been developed by INE in Germany, see Figure 4-6. The advantage is that the resolution of this equipment is higher compared with standard equipments. It is therefore possible to detect the colloid content at much lower concentrations than previously possible /Hauser *et al*., 2002/. The outcome of these measurements was compared with standard type of measurements such as particle counting by using Laser Light Scattering (LLS) on pressurised groundwater samples /Wold and Eriksen 2002a/. Standard type of filtration and ultra filtration was performed on-line/at-line of the bore holes /Wold and Eriksen 2002b; Vuorinen 2002/. In addition, samples of groundwater /Mattsén 2002; Rantanen and Mäntynen 2002/, microbes /Pedersen, 2002b/ and humic material /Buckau and Wolf, 2002/ were collected from the selected bore holes in order to judge the contribution from these on the measured colloid concentration. The electrical conductivity was measured along the tunnel from water venues in order to reflect the variability of the groundwater composition, which can affect the colloid stability /Gurban, 2002/.

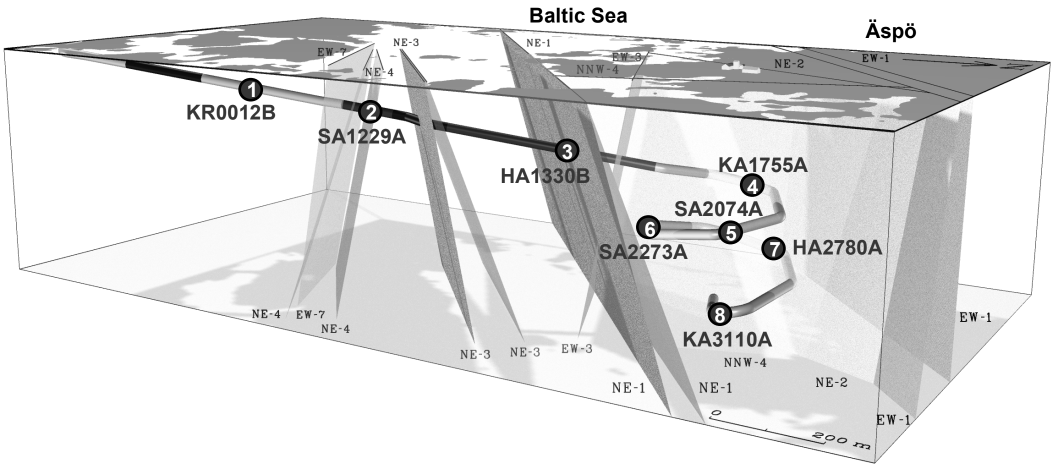

Figure 4-5. *The eight bore holes sampled for colloids along the Äspö tunnel.*

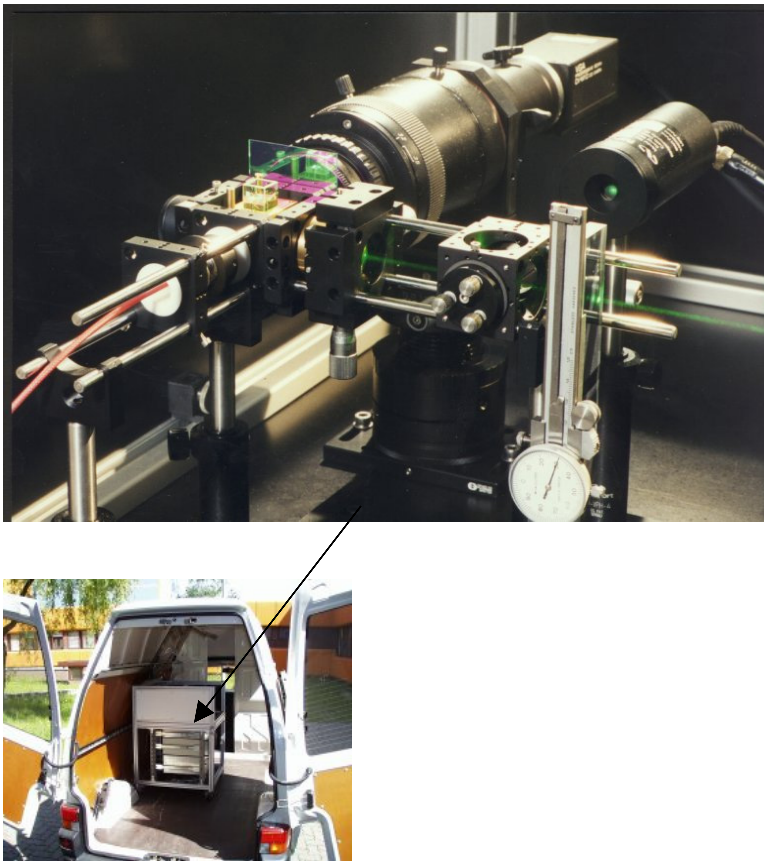

Figure 4-6. *Equipment for Lacer-Induced Breakdown-Detection (LIBD) of colloids (upper picture). The equipment is installed in a van in order to allow mobility and on-line measurements (lower picture).*

The results from the background measurements indicate that the natural colloid content is decreasing with groundwater salinity and depth (Figure 4-7). Natural colloidal particles consist of organics, inorganic colloids (clay, calcite, ironhydroxide) and of microbes. The microbe content is increasing with the content of organic carbon. Microbes form few but large particles, organic particles are small but can have a high concentration. The colloid content at Äspö is less than 300 ppb and at repository level it is less than 50 ppb /Laaksoharju *et al.*, 1995; Degueldre 2002; Hauser *et al.*, 2002; Wold and Eriksen 2002a; Vuorinen 2002; Gurban 2002; Wold and Eriksen 2002b; Mattsén 2002; Rantanen and Mäntynen 2002; Pedersen 2002b/.

Borehole specific measurements

The aim of the measurements is to determine the colloid generation properties of the bentonite clay in contact with the prevailing groundwater conditions at Äspö. For this purpose laboratory tests were carried out in order to optimise the "colloid reactor" (filter textile with bentonite clay) design. For the borehole specific measurements four bore holes along the Äspö tunnel and two bore holes at Olkiluoto in Finland will be investigated. The bore holes are selected so the natural variation in the groundwater composition at Fennoscandia is covered. The groundwater is in contact with the bentonite clay adapted in a container/packer equipment in the bore hole and the colloid content is measured prior and after contact with the bentonite clay. The bentonite reactor is 50 cm long and installed in bore holes with a diameter of 36 mm, see Figure 4-8. The colloid content is measured by using conventional filtering and ultra filtration.

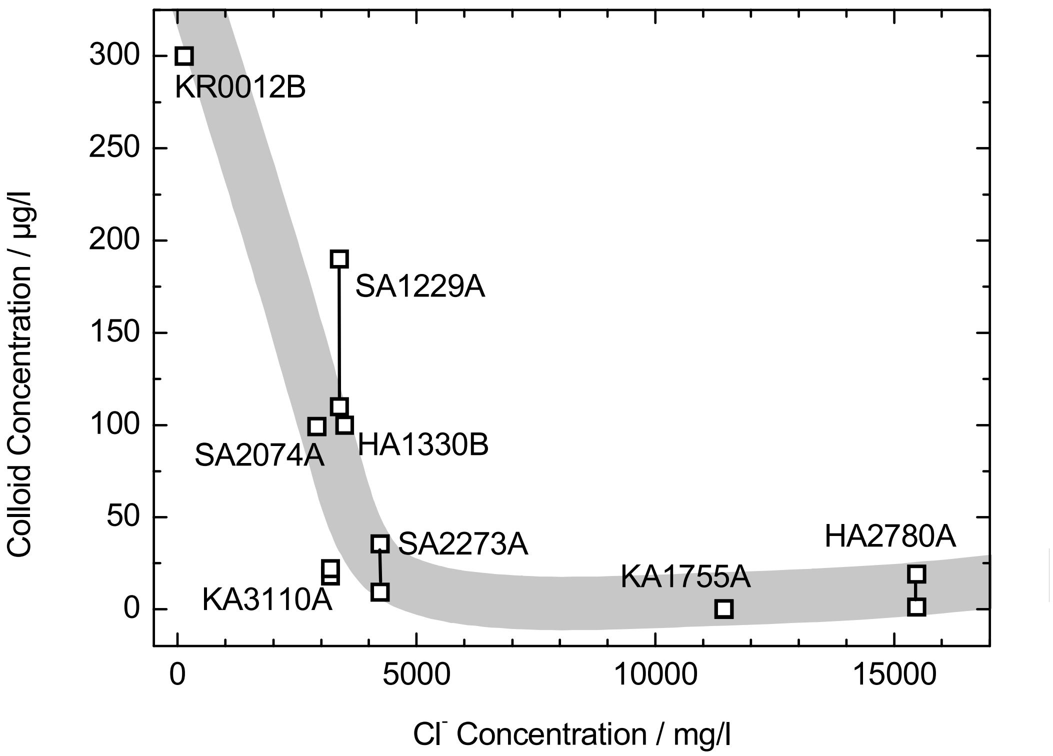

***Figure 4-7.** The natural colloid concentration is decreasing with groundwater salinity but also with depth at Äspö HRL /Hauser et al., 2002/.*

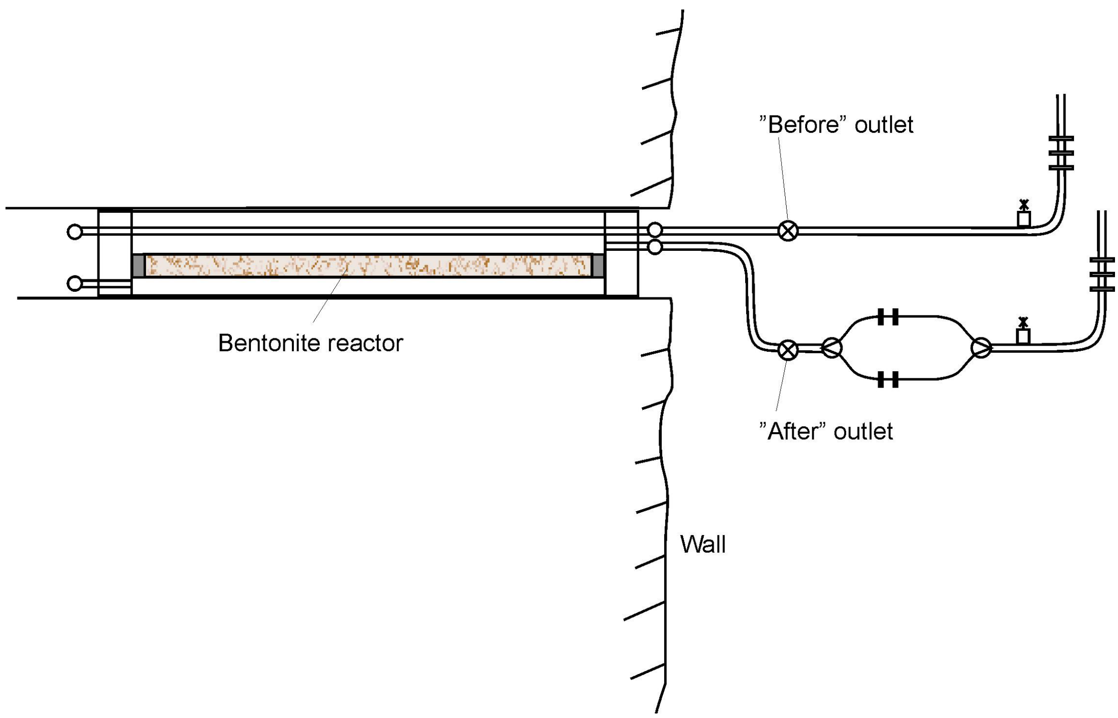

***Figure 4-8.** The natural groundwater is in contact with the bentonite clay surrounded by a filter textile. The water flowing by the reactor is sampled and analysed. A bypass allows colloid determination of the natural groundwater. The aim is to determine the colloid generation potential from the bentonite in contact with the water.*

Fracture specific experiment

A fracture specific experiment is planned within the Colloid Project during the time period 2003-2006. According to present plans two nearby bore holes intersecting the same fracture having the same basic geological properties will be selected for the fracture specific experiment at Äspö HRL. One of the bore holes will be used as an injection bore hole and the downstream bore hole will be used for monitoring. After assessing the natural colloid content in the groundwater, bentonite clay will be dissolved in ultra pure water to form colloidal particles. The colloids are labelled with a lanthanide (e.g. europium) and the fluid is labelled with a water conservative tracer. The mixture will be injected into the injection bore hole, see Figure 4-9. The colloidal content will be measured with laser (LIBD/LLS), the water is filtered and the amount of tracers is measured. The result of major interest is the changes in colloid content prior and after the transport through the fracture. The outcome of the experiment will be used to check performed model calculations and to develop future colloid transport modelling.

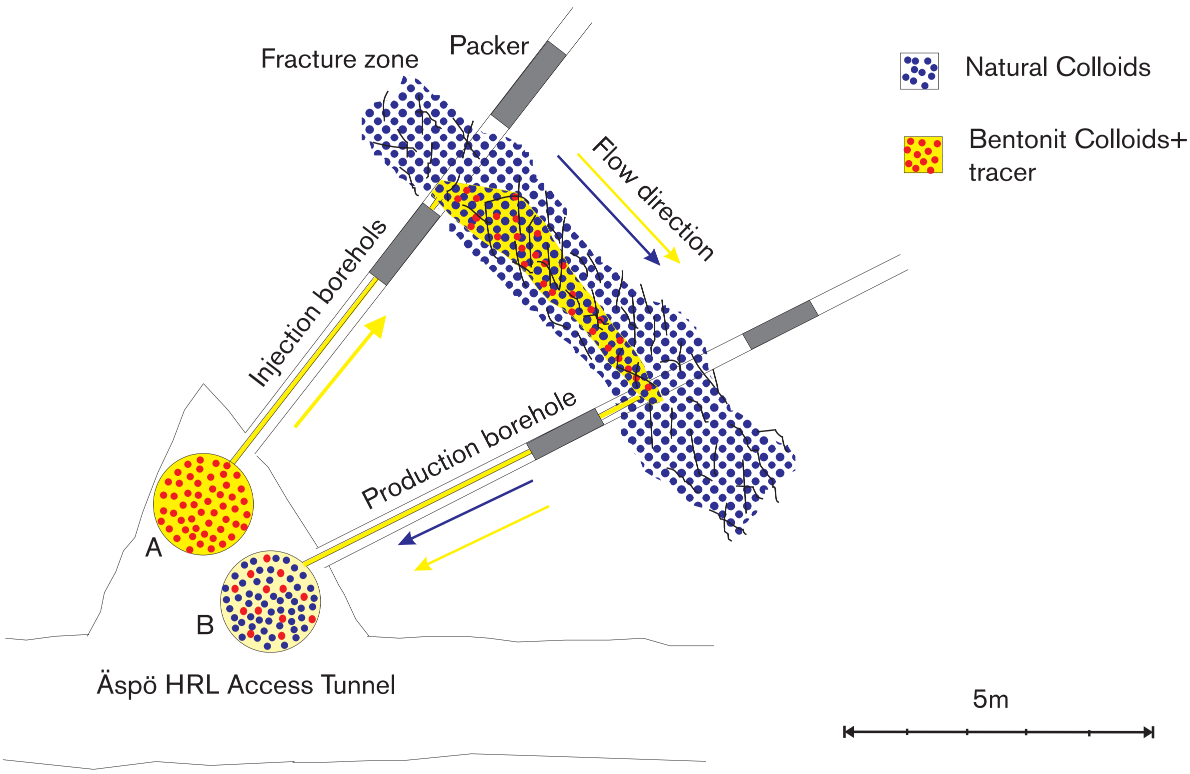

Figure 4-9. *Fracture specific measurement - injection of bentonite colloids and monitoring of the injected and natural colloids in the production bore hole.*

Present status

The following topics have been carried out:

- Laboratory experiments, January 2001 - March, 2002.
- Field measurements, background colloid content, October 2001 – March 2002.
- International Äspö Colloid workshop was held in March 2002 in Stockholm.
- Laboratory test concerning the design and optimisation of the colloid reactors, April 2002 – December 2003.

Scope of work for 2003

The following will be performed during 2003:

- Borehole specific measurements, January-May 2003.
- Status reporting of results from performed laboratory experiments and field measurements 2000-2003, March 2003.
- Status report concerning the borehole specific experiment, September 2003.
- Final reporting of the work performed 2000-2003, December 2003.
- Detailed planning for the fracture specific experiment, 2003-2006.

4.6 Microbe Project

Background

Micro-organisms interact with their surroundings and in some cases they greatly modify the characteristics of their environment. Several such interactions may have a significant influence on the function of a future deep repository for spent fuel /Pedersen, 2002a/. The study of microbial processes in the laboratory gives valuable contributions to our knowledge about microbial processes in repository environments. However, the concepts suggested by laboratory studies must be tested in a repository like environment. The reasons are several. Firstly, at repository depth, the hydrostatic pressure reaches close to 50 bars, a setting that is very difficult to reproduce in the microbiology laboratory. The high pressure will influence chemical equilibrium and the content of dissolved gases. Secondly, the geochemical environment of deep groundwater, on which microbial life depend, is complex. Dissolved salts and trace elements, and particularly the redox chemistry and the carbonate system are characteristics that are very difficult to mimic in a university laboratory. Thirdly, natural ecosystems, such as those in deep groundwater, are composed of a large number of different species in various mixes /Pedersen, 2001/. The university laboratory is best suited for pure cultures and therefore the effect from consortia of many participating species in natural ecosystems cannot easily be investigated there.

The limitations of laboratory investigations arrayed above have resulted in the construction and set-up of sites for microbiological investigations in the Äspö HRL tunnel. The main site is the MICROBE laboratory at the 450 m level. In addition, three more sites along the tunnel have been tested for their suitability for investigating important microbiology tasks.

There are presently four specific microbial process areas identified that are of importance for proper repository functions and that are best studied at the MICROBE sites.

They are: Bio-mobilisation of radionuclides, Bio-immobilisation of radionuclides, Microbial effects on the chemical stability, and Microbial corrosion of copper

Bio-mobilisation of radionuclides

It is well known that microbes can mobilise trace elements /Pedersen, 2002a/. Firstly, unattached microbes may act as large colloids, transporting radionuclides on their cell surfaces with the groundwater flow. Secondly, microbes are known to produce ligands that can mobilise soluble trace elements and that can inhibit trace element sorption to solid phases. The MICROBE sites intend to investigate the extent of bacterial dissolution of immobilised radionuclides and production of complexing agents under *in situ* conditions.

Bio-immobilisation of radionuclides

Micro-organisms can be either unattached or attached in deep groundwater systems. Data suggests that a large part of the microbes in groundwater is attached /Pedersen, 2001/. In the attached state, sorption of radionuclides to microbial cell surfaces will immobilise radionuclides and impose a retardation effect on possibly escaping radionuclides from a repository. A large group of microbes catalyse the formation of iron oxides from dissolved ferrous iron in groundwater that reaches an oxidising environment. Such biological iron oxide systems (BIOS) will have a retardation effect on many radionuclides. Typically, the microbes form stalks and sheaths that increase the volume of the iron oxides from densely packed inorganic oxides to a fluffy rust-like material with water contents of up to 99%. The microbes contribute to the exposure of a large oxide area to trace elements flowing by and the organic biological material adds a strong retention capacity in addition to iron oxides. At the MICROBE sites studies of the retention effects from microbial biofilms forming on groundwater conducting fracture surfaces and from the biological iron-oxidising systems (BIOS) are studied.

Microbial effects on the chemical stability

Micro-organisms can have an important influence on the chemical situation in groundwater /Haveman and Pedersen, 2002/. Especially, they may execute reactions that stabilise the redox potential in groundwater at a low and, therefore, beneficial level for the repository. It is hypothesised that hydrogen from deep geological processes contribute to the redox stability of deep groundwater via microbial turnover of this gas. Hydrogen, and possibly carbon monoxide and methane metabolisms will generate secondary metabolites such as ferrous iron and sulphide. These species buffer towards a low redox potential and will reduce possibly introduced oxygen. The MICROBE-450 m site is designed to investigate the extent of those processes.

Microbial corrosion of copper

Bio-corrosion of the copper canisters, if any, can be the result of microbial sulphide production. Two important questions have been identified and studied: Can sulphide-producing microbes survive and produce sulphide in the bentonite surrounding the canisters? Can microbial sulphide production in the surrounding rock exceed a performance safety limit? A series of laboratory and field experiments have indicated that this is not the case /Pedersen *et al.*, 2000a; 2000b/. However, the results have been criticised for not accounting for natural conditions such as high pressure and the natural population of sulphate reducing bacteria in deep groundwater. This issue is now addressed at the MICROBE-450 m site.

Objectives

The major objectives for the MICROBE sites are:

- To provide *in situ* conditions for the study of bio-mobilisation of radionuclides.
- To present a range of conditions relevant for the study of bio-immobilisation of radionuclides.
- To offer proper circumstances for research on the effect of microbial activity on the long term chemical stability of the repository environment.
- To enable investigations of bio-corrosion of copper under conditions relevant for a high deep repository for spent fuel.

Experimental concept

Four sites along the tunnel are in operation. However, the main site is the MICROBE-450 m site. That is where the research efforts are being focussed. Some tasks require settings that cannot be achieved at the 450 m site. Therefore, three additional sites have been identified along the tunnel.

The MICROBE-450 m site

The main MICROBE site is on the 450 m level in the F-tunnel. A laboratory container has been installed with laboratory benches, an anaerobic gas box and an advanced climate control system. Three core drilled bore holes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures at 12.7, 43.5 and 9.3 m are connected to the MICROBE laboratory via 1/8" PEEK tubing. The bore holes are equipped with metal free packer systems that allow controlled circulation of groundwater via respective fracture. Each bore hole has been equipped with circulation systems offering 500 cm^2 of test surface in each circulation for bio-film formation at *in situ* pressure and chemistry conditions, see Figure 4-10.

The BIOS-site at 2200A m tunnel length and the 907 m ditch site

Organic surfaces and iron oxides have been identified as important factors in radionuclide transport modelling. Several micro-organisms oxidise ferrous iron to ferric iron resulting in a mix of organic material (microbes) and iron oxides, here denoted BIOS (Biological Iron Oxide Systems). BIOS can be found everywhere along the Äspö HRL tunnel system. One particularly good site for investigations has been identified at tunnel length 2200 m, on the A-side. A vault is reaching about 10 m into the host rock perpendicular to the tunnel and it has a bore hole in the front that delivers groundwater rich in ferrous iron and iron oxidising bacteria. The bore hole has been connected to two 200 x 30 x 20 cm artificial channels that mimic ditches in the tunnel. The channels have rock and artificial plastic support that stimulate BIOS formation (Figure 4-11). Retention of naturally occurring trace elements in the groundwater by the BIOS is investigated.

At 907 m tunnel length, on the A-side, a small vault with a rescue chamber supports a ditch with groundwater that is rich in ferrous oxides and iron oxidising bacteria (Figure 4-12). This ditch is use as a natural analogue to the artificial BIOS channels at 2200 m. Growth characteristics of the BIOS are compared between the two sites.

The sulphur pond at 1127B m tunnel length

A unique ecosystem of sulphur oxidising bacteria exists at tunnel length 1127 m, on the B-side. The microbes oxidises sulphide to elemental sulphur and sulphate. Apart from being an intriguing site from a microbiological perspective, it also offers possibility to investigate microbial effects on the sulphur cycle in underground environments. It can be used to investigate microbial fractionation of sulphur isotopes. It will serve as an analogue for microbial influence on sulphur speciation in deep groundwater. Unfortunately, the pool has dried out during fall 2002. Possibly, this is because the extremely dry fall season (2002), but other reasons are also plausible, such as drilling and digging activities in the tunnel. Preliminary plans intend to open up the site by digging out the site down to the rock, but this remains to formally decide upon.

Present status

Three *in situ* pressure controlled temperature circulation systems (Figure 4-10) have been running since July 1st 2002 in the MICROBE-450 m laboratory. Biofilms have developed and reached about ten million cells per cm^2 test surface in December 2002.

Bentonite incubations with *in situ* populations at *in situ* pressure have been performed using KJ0052F03 groundwater. The purpose was to investigate the content of sulphate reducing bacteria in bentonite and their capability to produce sulphide under repository like conditions. The experiment will be decommissioned and analysed early spring 2003. Manuscript submission for the full experiment is also planned during 2003.

A Kappa 5 gas chromatograph (Trace Analytical, USA) equipped with a reductive gas detector (RGD) and a flame ionisation detector (FID) has been installed in the MICROBE-450 m laboratory. An on-line gas extractor has been constructed and installed in the laboratory as well. These two analytical components enable analysis of hydrogen and carbon monoxide down to about 1 ppb (RGD) and of methane, carbon dioxide, C_2H_6 C_2H_4 and C_2H_2 down to about 1 ppm (FID). A climate control system was installed concomitant with the chromatograph resulting in a high precision temperature controlled environment. The MICROBE-450 m site environment is shown in Figure 4-13.

A full BIOS biofilm growth series and associated trace element analysis have been preformed during 2002 on the 907 m and 2200 m sites. Manuscript production for publication has started and will be finalised during spring 2003.

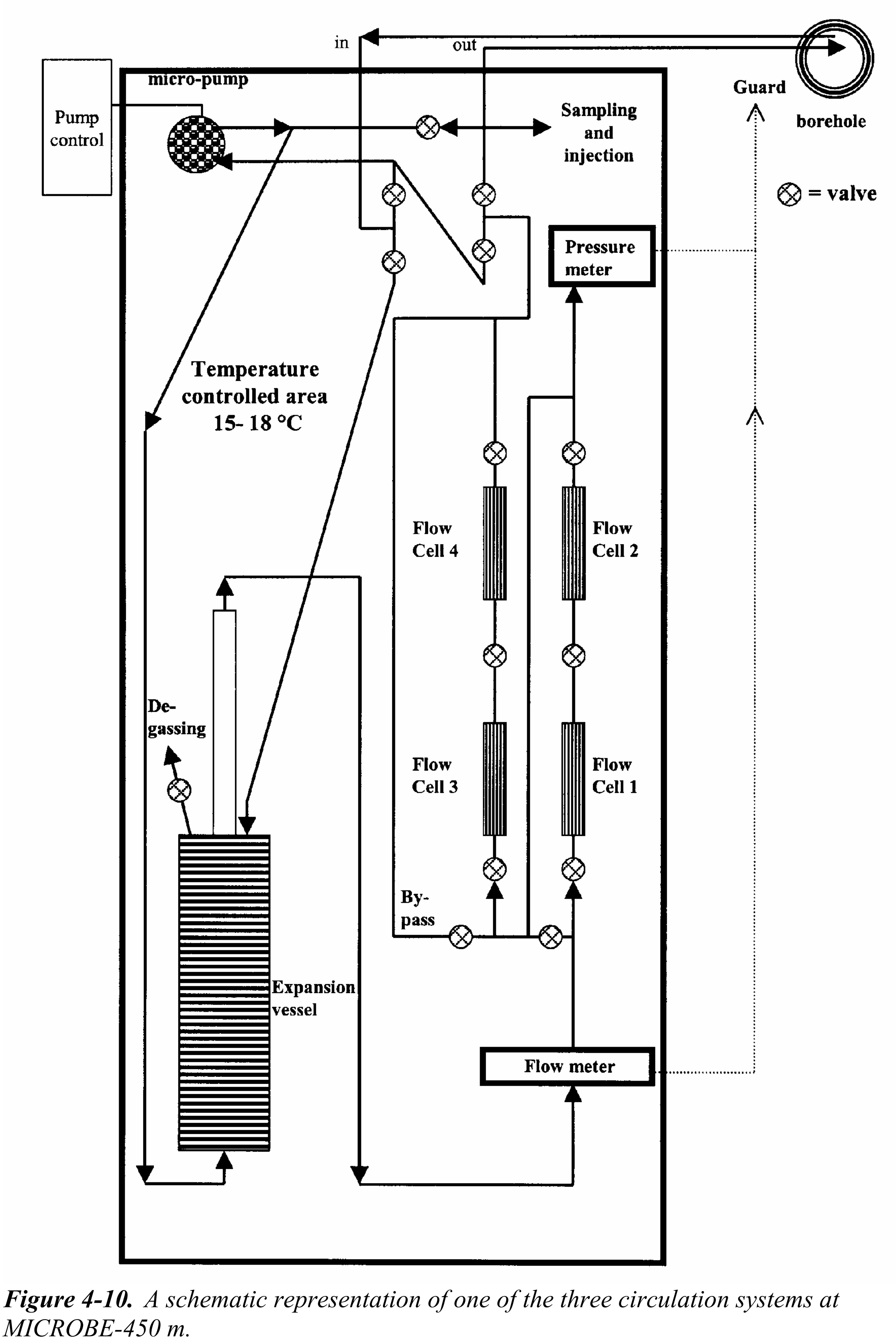

Figure 4-10. *A schematic representation of one of the three circulation systems at MICROBE-450 m.*

Figure 4-11*. Biofilms of* Gallionella ferruginea *develop on the plastic tube support in the channels at the 2200 m BIOS site. The fluffy character of the BIOS offers a huge surface area for trace element sorption. The support tube has a diameter of 25 mm.*

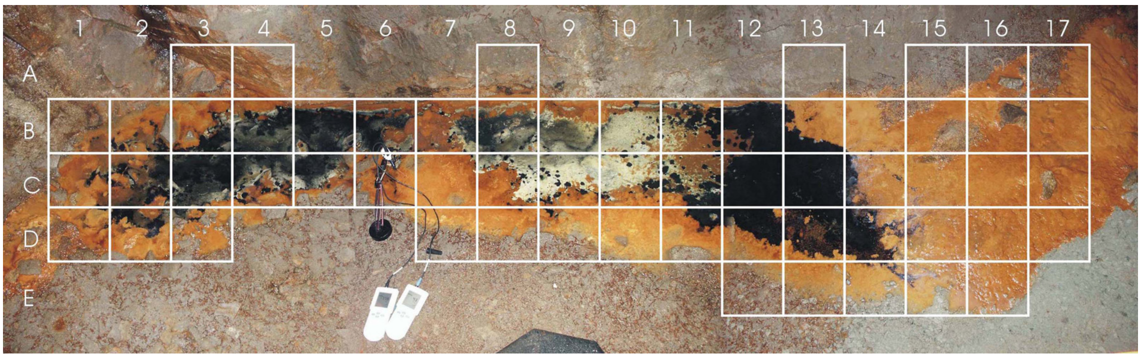

Figure 4-12. *The 907 m ditch site is characterised by a shallow, elongated water pond that overflows into the main tunnel ditch to the right in the image. Brown material is BIOS. The black colour is from iron sulphide precipitates and the white material is calcium carbonate. The overlaid grid creates an organised environment and enables pH, oxygen and redox measurements in three dimensions (Field instruments shown in the bottom of the figure). Grid size is about 20 x 20 cm.*

Figure 4-13. *The Microbiology Laboratory environment at the MICROBE-450 m site is equipped with three circulation systems (right), an anerobic box (forward), an in situ gas extractor, and a Kappa 5 gas chromatograph (right of the anaerobic box).*

Scope of work for 2003

The planned work for 2003 mainly comprises the following experiments:

- The influence from three different microbial biofilms (KJ0050F01, KJ0052F01 and KJ0052F03) on the concentrations of hydrogen, carbon monoxide, methane and carbon dioxide will be investigated. The results will be used for modelling long term microbial effects on the chemical stability of deep groundwater.
- Sorption of selected radionuclides onto three different microbial biofilms growing on glass slides (KJ0050F01, KJ0052F01 and KJ0052F03) will be studied.
- Parameters of importance for BIOS formation will be researched, using artificial channels on the 2200 m site. Flow rate, redox, oxygen concentration, type of support material, groundwater chemistry and different hydrodynamic configurations will be tested.
- Initial studies of microbial mobilisation of selected trace elements from solid surfaces will start during 2003. Nickel, vanadium and molybdenum are possible candidates.

4.7 Matrix Fluid Chemistry

Background

The first phase of the Matrix Fluid Chemistry experiment (1998-2002) increased knowledge of matrix pore space fluids/groundwaters from crystalline rocks of low hydraulic conductivity (K<10–10 ms^{-1}), and this complemented the hydrogeochemical studies already conducted at Äspö. This first phase will be fully reported by early 2003.

The second phase (2003-2006) will focus on the small-scale micro-fractures in the rock matrix ($K=10^{-12}$-10^{-9} ms^{-1}) which facilitate the migration of matrix pore space fluids/groundwaters. These groundwaters, via fracture networks of increasing hydraulic conductivity, eventually connect to groundwaters present in the more hydraulically conducting fractures in the surrounding bedrock ($K>10^{-10}$ ms^{-1}). Understanding this migration of groundwater, and its changing chemistry, is important to repository performance since such groundwater types may initially saturate the bentonite buffer material in the deposition holes. Such data may provide a more realistic chemical input to near-field performance and safety assessment calculations.

Objectives

The main objectives of the Matrix Fluid Chemistry second phase experiments are to:

- Determine the origin and age of the groundwaters in two micro-fracture systems identified from BIPS-imaging of the matrix bore hole.
- Establish whether present or past in- or out-diffusion processes have influenced the composition of the groundwaters, either by dilution or increased concentration.
- Determine the hydraulic properties of the rock matrix and the micro-fractures.
- Conduct additional porosity measurements on drill core samples from bore hole KA2599G01 (in the same matrix block close to the matrix bore hole) to complement the porosity data from the first phase.
- Carry out a long term *in situ* diffusion experiment in isolated sections of the bore hole already characterised in the first phase studies.

Experimental concept

The Matrix Fluid Chemistry experiment was designed to sample matrix pore space fluids/groundwaters from predetermined, isolated borehole sections. The bore hole was selected on the basis of: (a) rock type, (b) mineral and geochemical homogeneity, (c) major rock foliation, (d) depth in the tunnel, (e) presence and absence of fractures, and (f) existing groundwater data from other completed and on-going experiments at Äspö HRL.

Special equipment, see Figure 4-14, was designed to sample matrix fluids/groundwaters during the first phase of the experiment ensuring: (a) an anaerobic environment, (b) minimal contamination from the installation, (c) minimal dead space in the sample section, (d) the possibility to control the hydraulic head differential between the sampling section and the surrounding bedrock, (e) in-line monitoring of electrical conductivity and drilling water content, (f) the collection of fluids (and gases) under pressure, and (g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

This experimental equipment will be used also in the second phase to sample groundwaters from the micro-fractures and subsequently modified to measure the hydraulic parameters of the micro-fractures and the rock matrix, and finally to conduct the long term *in situ* diffusion experiment.

Present status

The present status of the Matrix Fluid Chemistry experiment is:

- Final reporting of the first phase (1998-2002) should be completed by March 2003. All technical data and interpretations are available as ITD reports.
- Matrix fluids/groundwaters and gases have been accumulating in the matrix borehole sections since the last sampling in October 2001.
- Drill core samples have been collected from bore hole KA2599G01 for the second phase porosity measurements.
- The laboratory permeability test, initiated in August 1999 at the University of Waterloo, is still on-going with still no sign of pore water movement.

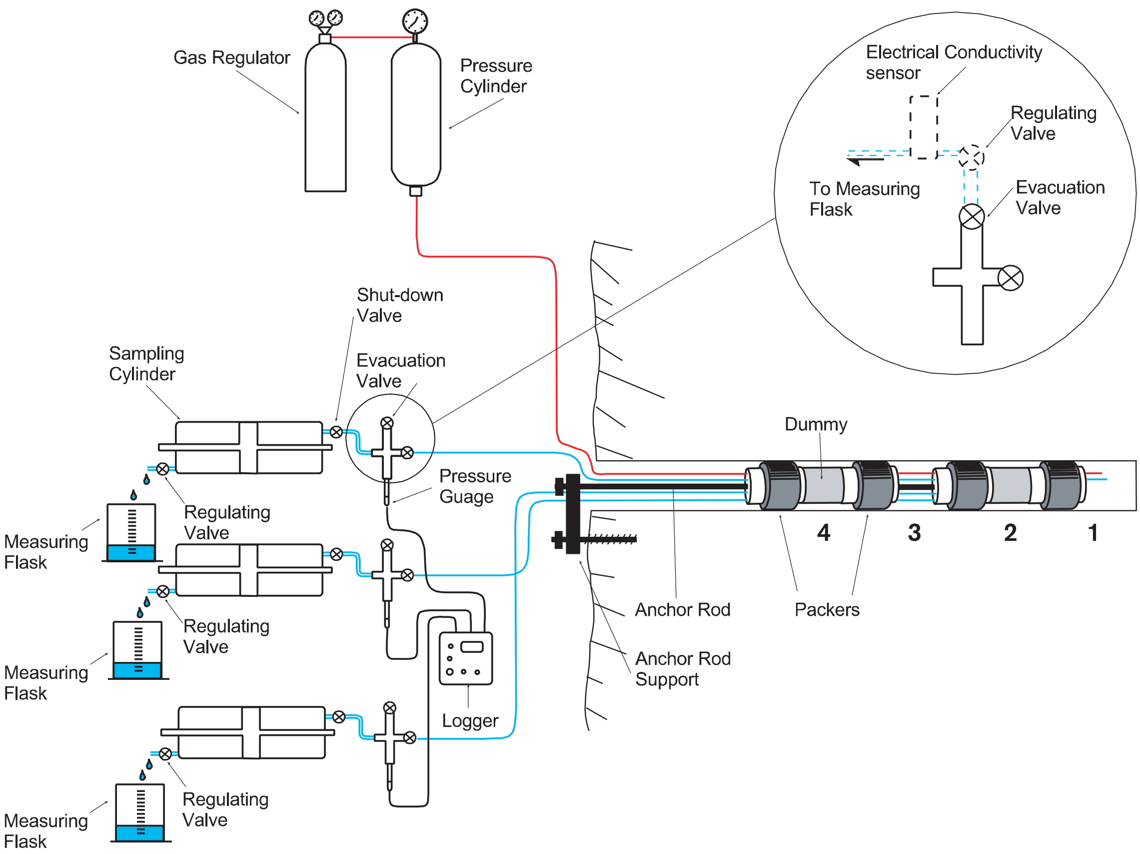

Figure 4-14. *Matrix Fluid Chemistry experimental set-up. Borehole sections 2 and 4 were selected to collect matrix fluid; sections 1-4 are continuously monitored for pressure.*

Scope of work for 2003

The scope of work for 2003 will be:

- To complete final reporting of the first phase study by May.
- To extract and analyse additional matrix pore space waters and gases from the same isolated borehole sections already sampled and documented in the first phase study, see Figure 4-15. This will supplement existing data from the first phase.
- To extract and analyse groundwaters and gases from micro-fractures identified from the first phase study.
- To measure the hydraulic parameters of the sampled borehole sections (both rock matrix and micro-fractures).
- To obtain additional porosity measurements to supplement those data from the first phase.
- To terminate the permeability test and conduct a post-mortem on the core sample.
- To carry out a long term *in situ* diffusion experiment in isolated rock matrix sections of the bore hole already characterised in the first phase study.

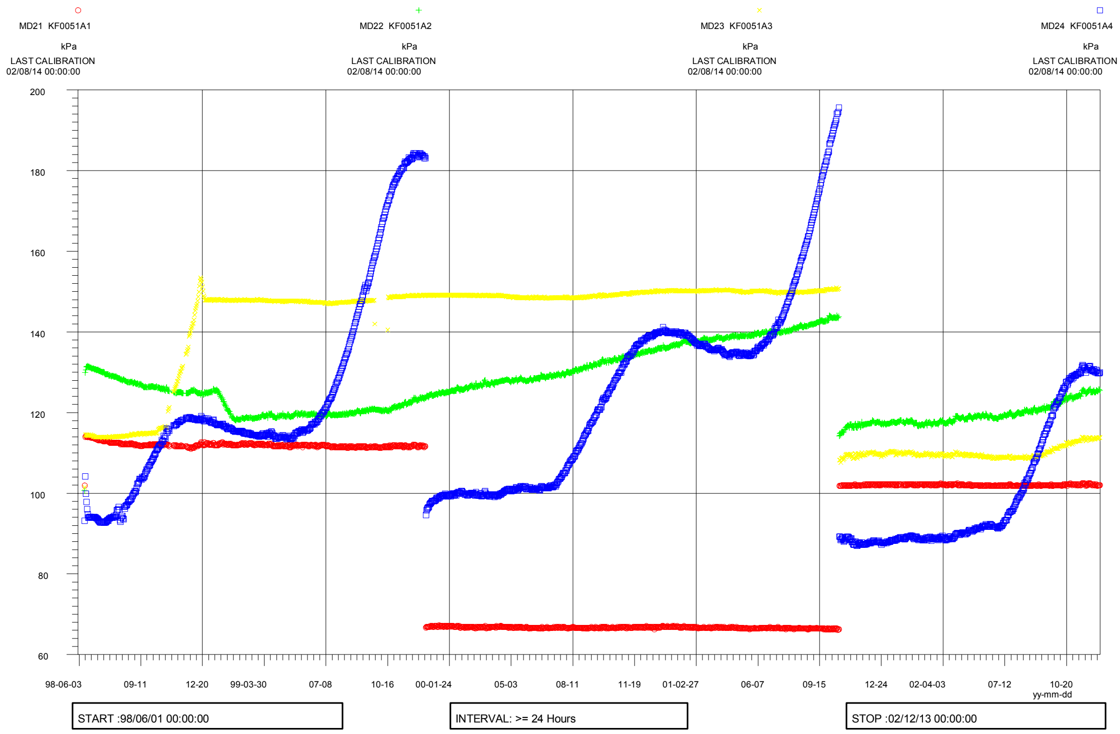

Figure 4-15. *Present status of the pressure monitoring curves for each of the four isolated borehole sections as from December 2002. Colours relate to borehole sections 1(red), 2 (green), 3 (yellow) and 4 (blue). Sections 2 and 4 were specifically demarcated for matrix fluid sampling. The break in the curves in December 1999 and October 2001 indicates the two sampling campaigns when sections 1 and 4 (first) and sections 1 to 4 (second) were opened for sampling. Pressure increases in sections 2, 3, and 4 indicate accumulating water and gas.*

4.8 The Task Force on Modelling of Groundwater Flow and Transport of Solutes

Background

An overall objective of the defined experiment is to increase the understanding of the processes which govern retention of radionuclides transported in crystalline rock and to increase the credibility in the computer models used for radionuclide transport and groundwater flow. A Task Force on Modelling of Groundwater Flow and Transport of Solutes has been created at the Äspö HRL to serve as a forum for consultation and discussion of conceptual and numerical modelling of groundwater flow and radionuclide transport

The Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes was initiated in 1992. The group consists of eight organisations from seven countries. A Task Force delegate represents each participating organisation and the modelling work is performed by modelling groups. The Task Force meets regularly about once to twice a year. Different experiments at the Äspö HRL are utilised to support the Modelling Tasks. To date modelling issues and their status are as follow:

Task 1: Long term pumping and tracer experiments (LPT-2). Completed.

Task 2: Scooping calculations for some of the planned detailed scale experiments at the Äspö site. Completed.

Task 3: The hydraulic impact of the Äspö tunnel excavation. Completed.

Task 4: The Tracer Retention and Understanding Experiment (TRUE), 1st stage. On-going.

Task 5: Coupling between hydrochemistry and hydrogeology. On-going.

Task 6: Performance Assessment (PA) Modelling Using Site Characterisation (SC) Data (PASC). On-going.

Objectives

The Äspö Task Force is a forum for the organisations supporting the Äspö Hard Rock Laboratory Project to interact in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock. In particular, the Task Force shall propose, review, evaluate and contribute to such work in the project. The Task Force shall interact with the principal investigators responsible for carrying out experimental and modelling work for Äspö HRL of particular interest for the members of the Task Force.

Much emphasis is put on building of confidence in the approaches and methods in use for modelling of groundwater flow and migration in order to demonstrate their use for performance and safety assessment.

Present status

The 16th International Task Force meeting, hosted by SKB at Äspö was held June 11-13, 2002. About 35 attendees from eight countries participated in the meeting. Status of the overall evaluation of Task 4 was presented. The modelling groups presented results of Task 6A, 6B and 6B2. A workshop was held regarding Task 5 at the end of the meeting.

The work within the Task Force has been in progress after the meeting. Minutes of the 16^{th} International Task Force meeting has been distributed according to the Task Force send list. Proceedings of the 16^{th} International Task Force are near ready for publishing on the new Task Force web site at SKB. In the planning group, telephone meetings are held on a regular basis. The report of the overall evaluation of the modelling conducted in Task 4 is near to be complete. All the Task 5 modelling reports are published. Task 5 Summary report and Task 5 Reviewers report are near to be finalised. Drafts of the modelling reports regarding Task 6A, 6B and 6B2 have been prepared. Final draft of the Task 6C report has been distributed as well as modelling data of Task 6D, to delegates and modelling groups.

Scope of work for 2003

The main objectives targeted to be accomplished during 2003 are summarised below:

- Complete the overall evaluation of the modelling conducted in Task 4 and publish a report.
- Complete and publish the Task 5 Summary report.
- Complete and publish the Task 5 Reviewers report.
- Complete and publish the Task 6C report.
- Produce the final modelling report for Task 6A (modelling selected tracers used within TRUE-1) and 6B (modelling selected tracers used within the TRUE-1 programme with new performance assessment relevant boundary conditions and time scales). Task 6B2 will be included in the same report if performed by modelling group.
- Produce modelling reports of Task 6D.
- Delivery of data of Task 6E to modelling groups.
- Organise the 17^{th} International Task Force meeting, hosted by NAGRA in Switzerland.
- Organize a workshop regarding Task 6.

4.9 PADAMOT

Background

Palaeohydrogeology is a relatively new term used as a common name for information from fracture minerals that is used for interpretations of past hydrogeochemical and hydrogeological systems. The need for such interpretations has become evident in the geological/hydrogeological modelling of sites within the radwaste programmes of several countries and therefore an EU founded 3 year project with the name EQUIP (Evidences from Quaternary Infills for Palaeohydrogeology) was started in 1997. The EQUIP project was concentrated on the formulation of a methodology for how to conduct a palaeohydrogeological study; what minerals to use, what analyses to perform, and also the preferred sequence in which the different analyses should be carried out. Each participating country also carried out analyses within their selected sites. Within the Swedish study the selected site is Äspö and the drill cores used was from the pre-investigation bore holes KAS02, KAS03 and KAS04. Some samples from the 1700 m deep bore hole KLX02 from the nearby mainland Laxemar were also included. The study was concentrated on calcite as this mineral relatively quickly responds to changes in groundwater chemistry. However, information from Fe-oxides and sulphides has also been included when possible.

When the EQUIP project ended in 2000 /Bath *et al.*, 2000/ there was a need for continued fracture mineral investigations and model testing of the obtained results and therefore a new EU-project was initiated in the beginning of 2002 running to the end of 2004. This project is called PADAMOT (Palaeohydrogeological Data Analysis and Model Testing).

Objectives

The objectives for the PADAMOT project includes a) further developments of analytical techniques that exploit the rapid advances in instrumental capabilities especially for quantitative microanalyses for trace elements and isotopes for dating, b) developing modelling tools to interpret such data quantitatively and to relate this both to water-rock reactions at the scale of mineral crystals and also to evolution of the groundwater systems at larger scales, and c) the focusing of further research to investigate specific processes that might link climate and groundwater in low permeability rocks.

The Swedish part of the PADAMOT study will concentrate on the two work packages WP2 (Palaeohydrogeological characterisation of sites) involving applications of several analytical techniques on fracture filling calcites dominantly from KLX01, and WP 5, which deals with Performance Assessment applications of palaeohydrogeological data and modelling.

Present status

The present status is that the work has continued from the base created in the EQUIP study, with sample preparation and analyses of the samples from drill core KLX01. The KLX01 bore hole is situated on the mainland (Laxemar) west of the location for the Äspö HRL. The hydrogeological inflow character is a little bit more pronounced in the area of this bore hole. The groundwater end-members are the same as those identified at Äspö (present Meteoric water, Baltic Sea water, Glacial water, and Brine water). However, the Baltic Sea component is relatively small (<15%) whereas the glacial component is significant in some samples (around 30% according to M3 modelling carried out within the Task 5 programme).

Compared with the fracture calcite samples from drill cores from the entire Äspö the fracture samples from the KLX01 drill core may thus reflect a deeper influx of meteoric water and past melt water (that may in the upper part possibly have been oxygenated).

The basic idea behind the sampling/analysis programme is therefore to distinguish and characterise the possible recent low temperature calcites and this is made by using stable isotope analyses, microscopy and trace element analyses. Based on these analyses a number of samples for detailed micro-scale studies are select.

Within the project, 44 samples have been chosen ranging in depth from 3 to 1056 m depth. Bulk analyses of stable carbon and oxygen isotopes in fracture carbonates have been carried out. From the sampled and analysed calcites, approximately 25 samples were selected for trace element analyses using ICP-MS on leachates from the samples in order to avoid in mixing of silicates. Eighteen samples have been analysed for Strontium isotopes and thin section preparation is ongoing.

In 2-3th of October a workshop was held in Brussels on the theme of Palaeohydrogeology organised by the PADAMOT co-ordinators. In addition to a good discussion about how to optimise palaeohydrogeological investigations the workshop provided possibilities to discuss knowledge exchange, which was acknowledged.

Scope of work for 2003

The characterisation work will continue with SEM/EDS studies, uranium series analyses. Studies of morphology and zoning will be performed by BGS (British Geological Survey).

5 Äspö facility

An important part of the Äspö facility is the administration, operation, and maintenance of instruments as well as development of investigation methods. Other issues are to keep the stationary hydro monitoring system (HMS) continuously available and to carry out the programme for monitoring of groundwater head and flow and the programme for monitoring of groundwater chemistry.

5.1 Facility operation

Background

The main goal for the operation is to provide a safe and environmentally correct facility for everybody working or visiting the hard rock laboratory. This includes preventative and remedy maintenance in order to withhold high availability in all systems as drainage, electrical power, ventilation, alarm and communications in the underground laboratory.

Present status

The plant supervision system has considerably increased the possibility to run the facility in a safe and economic way. The availability in the underground-related systems (ventilation, hoist, lightning, pumps etc.) has been almost 98% during 2002.

An automatic registration and object-monitoring system with the benefit to increase personnel safety underground was taken into operation for testing during 2002. Considerable problems with the system quality have delayed the project. The system will, however, according to present plans be taken into operation during 2003. Work on increased fire safety was also of concern during 2002 and safety-related education and fire fighting training was held in co-operation with the local fire brigade.

The long term rock control and reinforcement programme, initiated in year 2000, has been continued to ensure safe and reliable rock conditions.

The energy consumption at the facility was decreased with 3.5% despite the hot summer and an increase in number of personnel.

The decision to host the staff of the site investigation project resulted in a need for additional office space besides the offices that were provided in the temporary barracks. The work with new offices in the existing building was started in September and the design of an additional extension in the ventilation building has been finalised and the construction work has started.

A new storage facility for underground equipment was taken into operation during spring. It is located adjacent to the ramp portal.

Road works has been performed on the road through Ävrö village.

Scope of work for 2003

Safety of the personnel is of concern and safety-related education and fire fighting training in co-operation with the local fire brigade will be held. A new fire hazard analysis for the underground facility will be carried out. The aim is to assess safety and identify necessary improvements. The long term rock control and reinforcement programme will be continued.

The work with new offices in the in the ventilation building will be finalised in addition to the work spaces already supplied in temporary barracks and in the existing building. The temporary barracks will be phased out as offices but they will be reused underground or as stores.

One goal is to further increase the availability in the underground-related systems (ventilation, hoist, lightning, pumps etc.) during 2003. The main goal is to reach an availability of 99% during 2004.

A goal for the environmental work is to decrease the energy consumption with 5%. This can be done by trimming the underground ventilation system but also by informing the staff about energy saving activities.

The goal for the working environment, in addition to the present plan for this, is to install air conditioning e.g. in the chemistry laboratory. Parking lots with gravel surfacing will be coated with oil gravel to decrease the present dust problems.

The maintenance and service of equipments, installations and vehicles shall be of high quality. Installations and measurement systems shall be controlled and documented.

5.2 Hydro Monitoring System

Background

The Hydro Monitoring System (HMS) collects data on-line of groundwater head, salinity, electrical conductivity of the water, Eh, and pH. The data are recorded by numerous transducers installed in bore holes. The system was introduced in 1992 and has evolved through time, expanding in purpose and ambition. The number of bore holes included in the network has gradually increased and comprise bore holes in the tunnel and in Äspö HRL as well as surface bore holes on the islands of Äspö, Ävrö, Mjälen, Bockholmen and some bore holes on the mainland at Laxemar.

Weekly quality controls of preliminary groundwater head data are performed. Absolute calibration of data is performed three to four times annually. This work involves comparison with groundwater levels checked manually in percussion drilled bore holes and in core drilled bore holes, in connection with the calibration work.

As an effect of the excavated tunnel, the groundwater levels in the core drilled bore holes in the vicinity of the tunnel have been lowered up to 100 meters. Because of this the installations in the bore holes, e.g. the stand pipes (plastic tubes) in the open bore holes have been deformed. This makes it sometimes impossible to lower pressure transducers in the tubes or to lower manual probes for calibration purposes. Development and testing of new types of tubes is in progress. An evaluation of the groundwater monitoring system used at Äspö HRL is needed before a new similar system will be set up at candidate sites for the deep repository.

Measuring system

To date the monitoring network comprises bore holes of which many are equipped with hydraulically inflatable packers, measuring the pressure by means of transducers. The measured data are relayed to a central computer situated at Äspö village through cables and radio-wave transmitters. Once a year the data are transferred to SKB's site characterisation database, SICADA. Manual levelling is also obtained from the surface bore holes on a regular basis. Water seeping through the tunnel walls is diverted to trenches and further to 21 weirs where the flow is measured.

Scope of work for 2003

The activities during 2003 comprise operation, maintenance and documentation of the HMS system including implementation of some new bore holes in the system. Equipment that is out of order will be exchanged or renovated.

5.3 Programme for monitoring of groundwater head and flow

Background

The monitoring programme is a support to the experiments undertaken in the HRL and meets the requirements stipulated by the water rights court. The HMS implemented in the Äspö HRL and on the nearby islands is used to supply data to the programme for monitoring of groundwater head and flow.

Objectives

The scope of maintaining such a monitoring network has scientific as well as legal grounds:

- It is a necessary requirement in the scientific work to establish a baseline of the groundwater head and groundwater flow situations as part of the site characterisation exercise. That is, a spatial and temporal distribution of groundwater head prevailing under natural conditions (i.e. prior to excavation).
- It is indispensable to have such a baseline for the various model validation exercises, including the comparison of predicted head (prior to excavation) with actual head (post excavation).
- It was conditioned by the water rights court, when granting the permission to execute the construction works for the tunnel, that a monitoring programme should be put in place and that the groundwater head conditions should continue to be monitored until the year 2004 at the above mentioned areas.

Scope of work for 2003

The measuring points from the previous year will be maintained and no additional points are planned.

5.4 Programme for monitoring of groundwater chemistry

Background

During the Äspö HRL Construction Phase, different types of water samples were collected and analysed with the purpose of monitoring the groundwater chemistry and its evolution as the construction proceeded. The samples were obtained from bore holes drilled from the ground surface and from the tunnel.

Objectives

At the beginning of the Operational Phase, sampling was replaced by a groundwater chemistry monitoring programme, aiming at a sufficient cover of the hydrochemical conditions with respect to time and space within the Äspö HRL. This programme is designed to provide information to determine where, within the rock mass, the hydrogeochemical changes are taking place and at what time stationary conditions are established.

Scope of work for 2003

The annual water sampling campaign is scheduled to take place in September – October.

6 International co-operation

6.1 General

Eight organisations from seven countries participated in the co-operation at Äspö HRL during 2002. The agreements, which were ending in 2002 are re-negotiated, in US with USDOE instead of USDOE CBFO. During 2003 negotiations will start with one further organisation, Ontario Power Generation of Canada. Most of the organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several organisations are participating in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes, which is a forum for co-operation in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock.

The international organisations are taking part in the projects and experiments described in Chapters 2, 3 and 4 ("Technology", "Geo-science" and "Natural barriers"). The co-operation is based on separate agreements between SKB and the organisations in question. The participation by JNC and CRIEPI is regulated by one agreement. The participation of each organisation is given in Table 6-1. In the following sections a description of the scope of work for 2003 to be performed by the different organisations is given.

Table 6-1. International participation in the Äspö HRL projects during 2003.

Projects	ANDRA	BMWA	ENRESA	JNC	CRIEPI	NAGRA	Posiva
Technology							
Prototype Repository (EC-project)	X	X	X	X	X		X
Backfill and Plug Test			X				
Long Term Test of Buffer Material							X
Low-pH cementitious products							X
KBS-3 method with horizontal deposition							X
Large Scale Gas Injection Test							X
Temperature Buffer Test	X		X				
Geo-science							
Äspö Pillar Stability Experiment							X
Natural barriers							
Tracer Retention Understanding Experiments	X		X	X			X
Radionuclide Retention Project		X					
Colloid Project		X					X
Microbe Project		X					
Matrix Fluid Chemistry						X	
Task Force on Modelling of Groundwater Flow and Transport of Solutes	X		X	X	X	X	X

SKB is through Repository Technology co-ordinating three EC contracts and takes part in several EC projects of which the representation in five projects is channelled through Repository Technology. SKB takes also part in work within the IAEA framework.

6.2 ANDRA

L'Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) provides since 1992 experimental and modelling support to the Äspö HRL with emphasis on site characterisation and on engineered barrier systems to complement research activities in France.

Prime objectives of ANDRA's participation were and still are to enhance the understanding of flow and transport in fractured granitic rock and to evaluate experimental and modelling approaches in view of site characterisation of a French site.

In conjunction with SKB's development of major experiments related to the repository system, objectives appear concerning the near-field and ANDRA is enhancing the understanding of the engineered barrier systems behaviour for either spent fuel or reprocessed vitrified high level waste.

The scopes of ANDRA's contributions in different projects during 2003 are described below.

6.2.1 Prototype Repository

ANDRA's contribution to the project aims at modelling, through the EDF and the Eurogeomat team, the displacement of the interface between the bentonite buffer in the deposition hole and the backfill in the deposition tunnel during their free water saturation under thermal constraint.

6.2.2 Temperature Buffer Test

The Temperature Buffer Test (TBT) is to be set in place early 2003.

TBT aims at evaluating the benefits of extending our current understanding of the behaviour of the buffer during the initial stage of deposition to include high temperatures (above 100°C). This means the investigation of how well the bentonite buffer can endure high temperatures expected around HLW canisters of 0.6 m diameter deposited in deposition holes of 1.8 m diameter with buffer material in the annular space between the canister and the granite rock wall.

TBT provides a sister geometry to the actual Canister Retrieval Test (CRT). However for TBT, a stack of twin canisters based on vitrified HLW geometry (each 3 m long) will be placed in the deposition hole. Two possible geometries are considered and tried:

- A canister surrounded with a 0.2 m sand shield (sand/bentonite composite buffer).
- Bentonite between the canister and the rock wall (homogenous buffer).

The similar geometries of CRT and TBT, the use of artificial water saturation, and the use of MX-80 bentonite buffer will facilitate interpretation of data and comparison of results.

The high temperatures occurring in parts of the TBT bentonite buffer (150°C at canister contact) will aid to observe, understand, and model THM behaviour of the buffer under thermal constraint. THM modelling of the TBT buffer behaviour during water saturation is carried out by teams from Sweden (Clay Technology), Spain (UPC and DM Iberia), and France (EDF and Eurogeomat).

6.2.3 TRUE Block Scale Continuation

TRUE Block Scale identified diffusion/sorption in immobile pore spaces as a main retention process, but some issues are incompletely resolved. One concerns the role of rock components in the observed retention, another concerns the observed enhanced retention as compared to laboratory data. Explanations could be either the effect of underestimated flow wetted surface, or the effect of high porosity stagnant zones in fault gouge and rim zone.

TRUE Block Scale Continuation is being designed to address these issues by the mean of *in situ* tracer tests, the feasibility of which will first be assessed by modelling approaches.

ANDRA's modelling contribution during 2003, through ITASCA, will be related to "background fractures". The aim is to revisit data available on Äspö fractures at various scales in order to infer a "multi-scale" statistical distribution based on a size power law distribution (theoretical framework from Geosciences Rennes Group). A model considering all fractures will then be built to help in assessing feasibility of tracer tests with injection in "background fractures".

6.2.4 Task Force on Modelling of Groundwater Flow and Transport of Solutes

ANDRA is participating in Task 6 with the aim to gain experience on site characterisation and performance assessment modelling, which are necessary for long term safety assessment analysis. The major objective of Task 6 is to bridge the gap between site characterisation and performance assessment models.

Three modelling teams (CEA, GOLDER Associates and ITASCA) within the ANDRA group are carrying out modelling based on different approaches and numerical codes.

The work to be achieved in 2003 includes Feature A modelling (subtasks 6A and 6B) and block scale modelling (subtask 6D). Final results of Subtasks 6A and preliminary results of Subtasks 6B and 6D will be presented at the Task Force Meeting in March 2003.

6.3 BMWA

The co-operation agreement between BMWA (Bundesministerium für Wirtschaft und Arbeit) and SKB was signed in 1995 and the agreement is being extended during this year. Seven research institutes are performing the work on behalf of and funded by BMWA: BGR, DBETec, FZK, FZR, GRS, University Stuttgart, and TU Clausthal.

The purpose of the co-operation in the Äspö HRL programme is to complete the knowledge on potential host rock formations for radioactive waste repositories in Germany. The work addresses groundwater flow and radionuclide transport, two-phase flow and transport processes, and development and testing of instrumentation and methods for detailed underground rock characterisation.

The scope of work to be carried out in 2003 is described below.

6.3.1 Prototype Repository

In the frame of the Prototype Repository Project, electrical resistivity measurements are conducted in deposition holes and backfilled tunnel sections in order to investigate time-dependent changes of water content in the backfill, in the buffer, and in the rock. In these investigations advantage is taken of the dependence of the electrical resistivity on fluid content of the materials the measurements are performed in. During the preceding years 2001 and 2002, two electrode arrays were installed, one in the backfill of the inner section and one in the rock in the outer section. In 2003, two additional arrays will be installed in the buffer of deposition hole 5 and in the backfill in the outer section. Measurements are performed daily and evaluated monthly.

In order to correlate the resistivity with the fluid content, the field measurements are accompanied by laboratory calibration measurements on backfill, buffer, and rock. The laboratory calibrations will be finished in early 2003. Quarterly data reports are available since January 2002.

Combined modelling and laboratory studies in the Prototype Repository project are aimed at investigating gas and water pressure distributions in rock fractures and at further developing 3D models for calculating these processes. In order to achieve the objective, intercomparison of results from modelling calculations and laboratory tests is performed.

With the purpose of investigating the resaturation of bentonite, studies are performed in the Modelling Working Group of the Prototype Repository project. The work aims at a simplified model for simulating resaturation in view of a long term safety assessment. The conceptual models for the resaturation of bentonite by liquid water and by water vapour, respectively, have been discussed in the framework of the Modelling Working Group and translated into simulation codes. The importance of the basic resaturation mechanisms, particularly resaturation by water vapour, will be investigated more closely by confirming laboratory experiments. The main focus will lie on measurement of the time dependent saturation distribution in bentonite and of supplemental parameters for a referring numerical model.

6.3.2 Radionuclide Retention Experiments

Actinide migration experiments are conducted in the laboratory and in the CHEMLAB 2 probe. The cores used in these experiments are analysed with respect to the flow path and to the interactions between dissolved actinides and solid phases. Analyses of the flow path are performed by destructive and non-destructive investigations. In the destructive investigations a fluorescent epoxy resin is injected in the flow path, and then the core is cut perpendicular to the cylinder axis. Scanning of the resulting slices shows geometry, orientation and properties of the flow path. Additional information of the flow path is obtained by 3D visualisation.

In 2002, a migration experiment was started in the CHEMLAB 2 probe with an expected duration of 80 days applying the lowest feasible flow rate. However, the pump in CHEMLAB 2 failed and the experiment was interrupted after 2 days. The sampled solution does not provide enough information to investigate the breakthrough. Presently, actions are taken to reactivate the pump. If these actions are successful, the long term migration experiment will be continued. If problems continue, it is considered to sample groundwater directly from the drill hole (under undisturbed pressure-, O_2 -, and CO_2 -conditions) by means of a packer and tubing system. The groundwater will be piped into a glove box. Handling will be done within the glove box, and all systems containing radioactivity including reservoir, injection loop, core, pump and valves and the sampling system remain in the glove box.

Laboratory studies on the sorption behaviour of weathered granite will continue. The detailed flow path model will be used to compute the groundwater velocities by direct solution of Navier-Stokes equations.

In another project, transport and retention of typical elements in micro-fractured rock around larger fractures are studied. The objectives are to determine distribution and characteristic parameters (volume and internal surface) for altered fracture zones. The retention capacity of specific minerals in these micro-fractured systems was determined by laboratory studies. Based on these studies, the bulk retention capacity of altered rock was calculated. In 2003, the project will be concluded.

6.3.3 Colloid Project

Groundwaters present in Äspö are analysed with respect to their background colloid concentrations. The measurements are performed *in situ* by means of the mobile LIBD (Laser Induced Breakdown Detection) device containing a special detection cell which can be operated under representative hydrostatic pressures of about 3 MPa. The background colloid measurements have been evaluated and the results have been compared with results of similar measurements conducted in the Grimsel rock laboratory (Switzerland). Evaluation of the measurements shows the necessity of measurements of pH, Eh, pCO_2 (under undisturbed pressure-, O_2 -, and CO_2 -conditions). Measurements with a mobile device are planed in 2003.

6.3.4 Microbe Project

A project is performed addressing (i) the interaction of actinides with relevant bacteria found in Äspö groundwater, (ii) quantification of actinide bonding on micro-organisms in dependence of the chemical conditions in the groundwater, and (iii) characterisation of the actinide complexes/compounds formed by interaction with microbes. The project includes the continuous cultivation and quality control of the used *Desulfovibrio-äspöensis* biomass.

In 2003, the work on the culture of Desulfovibrio-äspöensis will be continued. The main aim will be to optimise the growing conditions. Furthermore, the genetic characterisation of the bacteria shall be finished. The investigations on the reduction processes of Uranium in terms of biological mass and chemical conditions will continue. In addition to this field of research, the bioaccumulation of Curium will be investigated in detail as a function of pH and conductivity. Work on the interaction between plutonium respective neptunium and *Desulfovibrio-äspöensis* will be started, accompanied by spectroscopic measurements of the bio-accumulate.

6.3.5 Two-phase flow

A project is being performed aimed at further improving the numerical tools for calculating gas-water flow in fractured and porous media. The specific objectives are to further develop the methods to describe two-phase flow processes in single fractures and to develop up-scaling methods for transferring the constitutive relations from micro-scale to macro-scale. Data from the Äspö HRL are used to generate geostatistical models. In 2003, the developed models will be finalised and the project will be concluded.

6.4 ENRESA

SKB and Empresa Nacional de Residuos Radioactivos, S.A. signed a Project Agreement in February 1997 which covers the co-operation for technical work to be performed in the Äspö HRL and related supporting work within the FEBEX project. Both parties renewed the Agreement on January 1, 2002.

One objective of the Agreement is to provide a framework for collaboration on specific tasks within the Äspö HRL Programme. ENRESA participates in:

- Prototype Repository.
- Backfill and Plug Test.
- Temperature Buffer Test.
- Tracer Retention Understanding Experiments (TRUE).

A number of critical issues related to the waste disposal, which are treated in these projects, are of interest to ENRESA:

- Disposal technology demonstration in vertical holes and THMCB performance of the engineered barrier system (Prototype Repository).
- Demonstration of technology for and function of important parts of the repository system (Backfill and Plug Test).
- TM performance of the buffer under high heat load (TBT).
- Radionuclides transport and retention processes in the rock (TRUE).
- The activities planned in the different projects during 2003 are given below.

6.4.1 Prototype Repository

The activities planned for 2003 are to continue with the canister No. 3 tracking monitoring and, based on last previsions from Clay Technology, install the displacement sensors in deposition hole No. 6 by March or April 2003.

The retention curves and the suction controlled oedometer tests will be finished and analysed during 2003. This will allow understanding of the influence of temperature and density on the water retention capacity of MX-80 and the mechanical behaviour of the clay under hydro-mechanical conditions similar to those expected in the repository. The data obtained will be provided to the modellers.

THM simulations of the full test will be performed during 2003 and compared with the measurements available. To check the validity of the assumptions (models, parameters, etc.) considered in the modelling. The work will pay attention to the 3D effects and a few models considering simplified geometries (2D and quasi-3D) will be used in the simulations.

6.4.2 Backfill and Plug Test

The activities planned for 2003, based on reaching the buffer saturation stage by the end of 2002, will consist of two campaigns of permeability measurements (pulse tests), one in February-March and a second one in September.

The interpretation of the pulse tests will provide local values of the saturated permea-bility in the backfill which will be compared with the global values derived from the flow tests.

6.4.3 Temperature Buffer Test

ENRESA will perform modelling work, concerning the operational simulation of the THM behaviour of the system, by the end of 2003.

The measurements available from field instrumentation will be used for comparison with the operational modelling. The high temperatures involved in the test constitute a particular aspect to be considered in the simulations. That will probably require some extension of some of the models used in the standard THM formulations.

6.5 JNC and CRIEPI

JNC and CRIEPI have been active participants in the Äspö HRL Project since 1992, performing significant research on hydrology, transport, and engineering aspects of radioactive waste isolation technology development. JNC's and CRIEPI's recent researches focus on development and application of experimental and numerical methods of groundwater flow, solute transport, and repository system. Furthermore, CRIEPI has been collecting voluntarily the groundwater in the Äspö tunnel for geochemical analysis every two years since 1995 and estimated a reasonable groundwater residence time at the Äspö HRL.

The objectives of JNC and CRIEPI research at Äspö during 2003 will be to:

- Develop technologies applicable for site characterisation.
- Improve understanding of flow and transport in fractured rock.
- Improve understanding of behaviour of engineered barriers and surrounding host rock.
- Improve techniques for safety assessment by integration of site characterisation information.
- Improve understanding of underground research laboratory experiments and priorities.

The scope of work planned for 2003 is summarised below.

6.5.1 Prototype Repository

JNC and CRIEPI will continue to participate in the Prototype Repository Project.

JNC will participate in Work Packages WP3h and WP3i, and collaborate on Work Package WP2. During 2003, the organisation will carry out coupled THM analysis (WP3h), perform back analysis of the two-dimensional prediction analysis using the monitored data, and perform three-dimensional prediction analysis. JNC will also continue to develop the full-way coupled THMC code (WP3i).

CRIEPI has been developing the coupling simulation code of thermo- and hydro-process to simulate the interactive phenomena expected in an engineered barrier system. During 2003, CRIEPI will simulate the mock-up tests performed in laboratory and *in situ* and validate the simulation code through these applications.

6.5.2 TRUE Block Scale Continuation

JNC's participation in the TRUE Block Scale Continuation during 2003 will address issues related to radionuclide retention processes, fracture micro-structure, fracture network connectivity/compartmentalisation, and transport pathway geometry. The organisation will be involved in all aspects of the project, including experimental design, analysis, and simulations. Potential flow and transport experiments will be simulated to determine feasibility of alternative experiments, including the ability of experiments to resolve key issues related to solute transport pathways and properties. JNC will also analyse existing site data to support experimental design, and assist in evaluation of experimental results as they become available. Long term breakthrough results from TRUE Block Scale Continuation experiments already in progress will be evaluated and simulated.

6.5.3 Task Force on Modelling Groundwater Flow and Transport of Solutes

JNC and CRIEPI will continue to participate in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes.

JNC will participate in the Task 6 Project, "Performance Assessment Modelling Using Site Characterisation Data (PASC)". The objective of JNC's participation in this task is to provide theoretical and experimental support for integration of site characterisation and performance assessment activities and techniques. During 2003, JNC participation in the PASC project will include the following activities:

- JNC FracMan discrete fracture network (DFN) model simulation of transport in a single fracture under *in situ* experiment and safety assessment boundary conditions.
- LBNL SISIM and THEMM (Transport in Heterogeneous Medium with Matrix Diffusion) model simulations of transport in a single fracture to address the effect of fracture structures in the third dimension as well as 2D heterogeneity under *in situ* experiment and safety assessment boundary conditions.
- JNC FracMan DFN model flow and transport simulation in a fracture network under *in situ* experiment and safety assessment boundary conditions.
- GoldSim safety assessment model simulation of solute transport in a single fracture and a fracture network under *in situ* experiment and safety assessment boundary conditions.

CRIEPI will perform additional calculations for the Task (6A, 6B and 6B2) and compose a report on the results. In addition, CRIEPI will start the computational work (Task 6D) by using an original numerical code, FEGM. Furthermore, CRIEPI will continue to investigate the site scale groundwater flow through inter-comparison between the ^{4}He concentration profile as a natural groundwater tracer and the simulated results of helium transport using the groundwater flow model focusing on the Äspö site.

6.5.4 Voluntary project on impact of microbes on radionuclide retention

CRIEPI will make a detailed plan of the retention experiment with microbial aspects and start to design the experimental facility. The facility should be able to evaluate the microbial impact on radionuclide migration and rock-water equilibrium by monitoring microbiological and physicochemical parameters such as cell density, pH, and redox potential.

6.6 NAGRA

NAGRA (National Cooperative for the Disposal of Radioactive Waste, Switzerland) has an agreement with SKB for participation in Äspö HRL signed in 1994; in 1998 the agreement was extended to include mutual co-operation and participation in Äspö HRL and Grimsel Test Site projects for a period of five years. It is expected to further extend the agreement this year.

Prime objectives of NAGRA's participation are to enhance and complement its own experience with the characterisation and PA-relevant conceptualisation of flow and transport phenomena in fractured rocks, as well as acquire and exchange information on disposal concepts that are complementary or alternative to the Swiss horizontal in-tunnel emplacement concept. Synergies between the two national programmes and the work in the respective underground laboratories are taken into consideration when establishing the detailed working programme.

NAGRA will participate and contribute in existing projects in 2003 and its activities will focus on the tasks described below.

6.6.1 Matrix Fluid Chemistry

The report summarising the results of the main part of the experiment will be finalised. A feasibility study proposal has been submitted and is under consideration for a similar pore water characterisation approach in the deep bore holes of the SKB Site Investigation Programme, where the Matrix Fluid Chemistry experiment will form the base for such investigations. If accepted this work will be carried out in 2003.

6.6.2 Task Force on Modelling of Groundwater Flow and Transport of Solutes

NAGRA will continue its participation in the Task Force comprising the finalisation of the Task 4 Overall Evaluation report and reviews of on-going activities. PSI will finalise the documentation of its work in Task 4. NAGRA will also host the 17th Task Force meeting in Switzerland.

Two papers, a combination of the Fracture Characterisation and Classification project and work on TRUE modelling, are expected to be published in the Journal of Contaminant Hydrology:

Mazurek M, Jakob A, Bossart P, 2003. Solute transport in crystalline rocks at Äspö I: The field basis.

Jakob A, Heer W, Mazurek M, 2003. Solute transport in crystalline rocks at Äspö II: Blind-predictions, inverse modelling and lessons learnt.

6.6.3 Support to planning activities

Although not formally a participant to the Projects, NAGRA will continue in various discussions, also with the support of SKB, for the transfer of experience from NAGRA projects to upcoming activities in Äspö. The following areas are expected to be the focus of discussions:

- Colloid Project.
- TRUE - resin technology.
- Planning of KBS-3 method with horizontal deposition.
- Gas migration issues (modelling, LASGIT etc.).

6.7 Posiva

Posiva's co-operation with SKB has deepened due the new co-operation agreement during the year 2002. The main focus of co-operation has been concentrated on encapsulation technology and repository technology. Several research projects within Natural barriers also comprise Posiva's contribution. The implementation of the construction of the underground rock characterisation facility ONKALO at Olkiluoto gives new possibilities to co-operate within the research and development of underground construction technology.

The organisation is working in the following tasks:

- Technology: Prototype Repository, KBS-3 method with horizontal deposition, Large Scale Gas Injection Test, Low-pH cementitious products, Long Term Test of Buffer Material.
- Geo-science: Äspö Pillar Stability Experiment.
- Natural barriers: TRUE-block scale continuation, Colloid Project, Task Force on Modelling of Groundwater Flow and Transport of Solutes.

Scope of the projects is divided to Äspö HRL co-operation and for generic co-operation for development of disposal concept, which can lead to demonstrations in Äspö HRL.

The work to be performed by the organisation within the different tasks during 2003 is described below.

6.7.1 Prototype Repository

During the last year of EU-supported project actions, a VTT/Posiva consortium has made final predictions of the chemical changes in the engineered barrier system (EBS) materials and evolution of the pore water compositions expected to occur in the Prototype Repository.

Considering the geochemical performance of a repository, the central issues are what kind of pore water compositions is expected to be generated in a repository and how these water compositions develop as a function of time. The first wetted volumes of buffer and backfill are created at the boundaries of the Prototype EBS. These first pore waters are sucked deeper into the under saturated volumes of buffer and backfill and represent the first wetting pore water compositions in the EBS. At the same time, new pore water compositions are repeatedly generated at the EBS boundary. These waters, as well, are likely sucked deeper into the EBS until the suction power vanishes to the EBS water saturation. Therefore, the pore water evolution at the EBS boundary and the first wetting pore water evolution in the EBS interior essentially define the limits of compositional pore water gradients that will develop in a repository EBS.

The Scope of work for 2003 comprises the geochemical modelling with the aim to predict pH and pE conditions and Na, Ca, K, Mg, Fe, Si, SO_4, and alkalinity concentrations in developed pore waters. In the case of solid phases, the modelling takes into account surface complexation and cation exchange in buffer and backfill, and makes estimates of mole-transfers at these surface sites. Furthermore, the modelling considers calcite, gypsum, pyrite, goethite and quartz as reactive phases that equilibrate with pore waters, and predict concentrations and mole-transfers of these phases as well.

6.7.2 Long Term Test of Buffer Material

Posiva's task in the Long Term Test of Buffer Material project is to study pore water chemistry in bentonite. The work with this task will be carried out by VTT Processes.

The reporting of the studies performed on the pore water chemistry of the excavated one-year parcel (A0) will be completed.

6.7.3 Low-pH cementitious products

The development of low-pH cementitious products has so far been concentrated on the elaboration of a suitable grouting mixture for sealing the bedrock. The work planned will be done in seven different work packages. Work package 6 has not been started since the penetrability of the developed new grouting mixtures was too poor. Suitable material will be searched out based on some new laboratory tests with different laboratory methods. Posiva participates in the planning of the project and in the evaluation of results.

6.7.4 KBS-3 method with horizontal deposition

Posiva and SKB have written an R&D-programme for the development of horizontal disposal concept /SKB, 2001c/. Posiva is especially concentrating on the evaluation of the long term safety performance of the barriers. A preliminary study of the boring of disposal tunnels by using horizontal raise boring will be performed.

6.7.5 Large Scale Gas Injection Test

The migration of gas in the bentonite buffer and in the near field host rock will be studied by conducting a full scale *in situ* experiment in Äspö HRL. Posiva participate in the project as a member in the project group and will support in the planning of the experiment.

6.7.6 Äspö Pillar Stability Experiment

The Äspö Pillar Stability Experiment is a large scale thermo-mechanical *in situ* test and is planned to be conducted in a pillar between two deposition holes. The main objectives are to increase the understanding of rock damages in crystalline hard rock caused by high stresses, to demonstrate the capability to predict rock damages using different analysis tools and to demonstrate the effect of backfill on the propagation of micro cracks. A new tunnel will be excavated to conduct the *in situ* test and in the tunnel underground construction methods can be tested. Sealing of the bedrock and different excavation methods are of interest during the construction work. Posiva's contribution to the project is to model the thermo-mechanical processes with FLAC3D analyses and with coupled FLAC/PFC2D analyses. Posiva also participates in the planning of the tunnel excavation.

6.7.7 TRUE Block Scale Continuation

The overall objective of TRUE Block Scale Continuation project (BS2) is summarised as: "Improve understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure, and micro-structure". From Posiva's point of view this project is beneficial for increasing the basic understanding on the retention processes in fractured rock.

Posiva will take part in the modelling support of the *in situ* tests. Especially, Posiva will concentrate on the influence of the heterogeneity to the transport.

6.7.8 Colloid Project

Since 2001 Posiva has participated in the Colloid Project, in which the stability and mobility of colloids are studied. The main activities in the Colloid project in 2003 will be to study the role of bentonite clay as a source for colloid generation and investigate the potential for colloid formation/transport in natural groundwater. This study started already in 2002 by planning, testing, and construction of the colloid reactors for the field experiment.

During 2003 field experiments are going to be done both at the Äspö HRL-tunnel and at the VLJ-repository in Olkiluoto. Posiva takes care of the experiment and participates also in the colloid and groundwater sampling and analysis at Olkiluoto.

6.7.9 Task Force on Modelling of Groundwater Flow and Transport of Solutes

Task 6 started at the end of the year 2000 and seeks to provide a bridge between site characterisation (SC) and performance assessment (PA) approaches to solute transport in fractured rock. It will focus on the 50 to 100 m scales, which is critical to PA according to many repository programmes. Posiva’s aim is to clarify the connection between site characterisation and performance assessment models.

During 2003 work in Task 6 will proceed from transport in a single feature to transport in a fracture network in block scale. The modelling tasks are Task 6D for the modelling of the transport through block scale in the tracer test scale and Task 6E for the same case but in the performance assessment scale. Preliminary results for Task 6D will be presented during 2003. It is possible that the modelling of Task 6E is started during 2003.

6.8 EC-projects

SKB is through Repository Technology co-ordinating three EC contracts: Prototype Repository, Cluster Repository Project (CROP) and the project NET.EXCEL. SKB takes part in several EC projects of which the representation is channelled through Repository Technology in five cases: FEBEX II, BENCHPAR, ECOCLAY II, SAFETI and PADAMOT.

6.8.1 Prototype Repository

SKB's reference concept for deep disposal of spent nuclear fuel, the KBS-3 method, has several features in common with other European concepts and full-scale testing is therefore of great value. Components of this system have been thoroughly investigated but the Prototype Repository is the first full-scale application. The Prototype Repository is conducted at Äspö HRL as an integrated test focusing on Engineered Barrier System (EBS) performance but comprising also canister deposition, backfilling and plug construction. It offers a number of possibilities to compare test results with models and assumptions and also to develop engineering standards and quality assurance methods. The co-operative work aims at accomplishing confidence building as to the capability of constructing safe repositories and predicting EBS performance also for somewhat different conditions than those in the Äspö HRL.

Prototype Repository – Full scale testing of the KBS-3 concept for high-level radioactive waste

Start Date: 2000-09-01	**End Date:** 2004-02-29
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries**: Finland, Germany, Japan, Spain, Sweden and United Kingdom

6.8.2 CROP

The project has the objective of assessing the experience from the various large-scale underground laboratories for testing techniques and aims specifically at comparing methods and data obtained from the laboratories for evaluating present concepts and developing improved ones. Several of these underground projects, which deal with disposal in crystalline rock, salt, and clay formations have been supported by the EC. The Cluster Repository Project (CROP) implies constitution of a forum - a cluster - for the intended evaluation and assessment, focusing on construction, instrumentation and correlation of theoretical models with field data, especially concerning engineered barrier systems.

CROP – Cluster repository project, a basis for evaluating and developing concepts of final repositories for high level radioactive waste

Start Date: 2001-02-01	**End Date:** 2004-01-31
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries:** Belgium, Canada, Finland, France, Germany, Spain, Sweden, Switzerland and USA

6.8.3 FEBEX II

The FEBEX project has the dual objective of demonstrating the feasibility of actually manufacturing and assembling an engineered barrier system and of developing methodologies and models for assessment of the thermo-hydro-mechanical (THM) and thermo-hydro-geochemical (THG) behaviour within the engineered barrier system (near-field). FEBEX II consists in the extension of the operational phase of the FEBEX I in situ test. The in situ test is performed in a TBM-drift at the Test Site at Grimsel in Switzerland, where two full-scale canisters with electrical heaters have been installed horizontally. The canisters are surrounded by bentonite, pre-compacted into blocks possible to handle by man. The FEBEX II includes dismantling of the plug, retrieval of the outer canister and casting of a new plug. The FEBEX project also includes a mock-up test in scale 1:2, and some complementary laboratory tests, as well as modelling works.

The project has been extended 10 months due to the decision to investigate the saturation process longer than originally planned before dismantling the outer section.

FEBEX II – Full-scale engineered barriers experiment in crystalline host rock phase II	
Start Date: 1999-07-01	**End Date:** 2004-10-31
Co-ordinator: Empresa Nacional de Residuos Radiactivos, Spain	**Participating countries:** Belgium, Czech Repblic, Finland, France, Germany, Spain, Sweden, and Switzerland

6.8.4 BENCHPAR

The purpose of the project is to improve the ability to incorporate thermo-hydro-mechanical (THM) coupled processes into Performance Assessment modelling. This will be achieved by three benchmark modelling tests: the near-field, up-scaling, and the far-field. Key THM processes will be included in the models. The first test will be on the resaturation of the buffer and interaction with the rock mass. The second test will determine how the up-scaling process impacts on performance assessment measures. The third test will model the long term evolution of a fractured rock mass in which a repository undergoes a glaciation deglaciation cycle. A technical auditing capability will produce a transparent and traceable audit trail for the benchmark tests. The final deliverable will be a Guidance Document giving advice to EU Member States on how to incorporate THM processes into performance assessment.

BENCHPAR – Benchmark tests and guidance on coupled processes for performance assessment of nuclear repositories	
Start Date: 2000-10-01	**End Date:** 2003-09-30
Co-ordinator: Royal Institute of Technology (Dep. of Civil and Environmental Engineering), Sweden	**Participating countries:** Finland, France, Spain, Sweden and United Kingdom

6.8.5 ECOCLAY II

Cements will be used intensively in radioactive waste repositories. During their degradation in time, in contact with geological pore water, they will release hyper-alkaline fluids rich in calcium and alkaline cations. This will induce geochemical transformations that will modify the containment properties of the different barriers (geological media and EBS, i.e. clay-based engineered barriers). ECOCLAY I identified major geochemical reactions between bentonite and cement. ECOCLAY II investigates aspects such as radionuclides sorption, kinetics of the geochemical reactions, coupled geochemistry/transport processes, conceptual and numerical modelling and performance assessment. The whole hyper-alkaline plume will be studied within the project.

ECOCLAY II – Effects of cement on clay barrier performance, phase II	
Start Date: 2000-10-01	**End Date:** 2003-09-30
Co-ordinator: National Radioactive Waste Management Agency of France	**Participating countries:** Belgium, Finland, France, Germany, Spain, Sweden, Switzerland and United Kingdom

6.8.6 SAFETI

The aim of this project is to develop an innovative numerical modelling methodology that is suitable for excavation scale simulation of geological repositories. The method, termed "Adaptive Continuum/Discontinuum Code (AC/DC)" will be developed from existing algorithms. Full validation of the codes will be carried out using laboratory and *in situ* acoustic emission and microseismic data collected in previous experiments. Further laboratory tests will be carried out during the proposed project for validation of the performance of both short- and long term rock mass behaviour. The AC/DC represents a significant advance over current numerical modelling approaches and will have a wide range of application in waste repository engineering, including feasibility studies.

SAFETI – Seismic validation of 3D thermo-mechanical models for the prediction of the rock damage around radioactive spent fuel waste	
Start Date: 2001-09-01	**End Date:** 2004-09-01
Co-ordinator: The University of Liverpool (Dep. of Earth Sciences), United Kingdom	**Participating countries:** France, Sweden and United Kingdom

6.8.7 PADAMOT

During the Quaternary global climate has alternated between glacial conditions and climate states warmer than the today. In northerly latitudes the potential for cold region processes to affect groundwater pathways, fluxes, residence times and hydrochemistry is significant, whilst for southern European localities the alternation between pluvial and arid conditions is equally important. PADAMOT will investigate the evolution of minerals and groundwater through these climate changes. The project will use advanced analytical techniques and numerical modelling tools. This palaeohydrogeological approach investigates processes that are significant for repository safety studies on length and time scales that cannot be simulated by experiment. Interpretations will be used to constrain the range of scenarios for conceptual model development and time-variant modelling in performance assessments.

PADAMOT – Palaeohydrogeological data analysis and model testing	
Start Date: 2001-11-01	**End Date:** 2004-11-01
Co-ordinator: Nirex Ltd, United Kingdom	**Participating countries:** Czech Republic, Spain, Sweden and United Kingdom

6.8.8 NET.EXCEL

The objectives are a future efficient use of European resources in research and development of safe methods for final disposal of high-level radioactive waste calls for close interaction between European end users in planning of national programmes as well as in development of international projects. The proposal concerns the forming of a network of end users for the intended analysis of present status and future requirements in RTD for the three different rock media: salt, clay sediments and crystalline rock. The expected results are common and systematic basis for priorities and co-ordination of future European RTD work for radioactive waste management, and suggested areas and priorities for joint RTD projects. The objective is develop a common and systematic basis for priorities and co-ordination of future European RTD work for Radioactive Waste Management and suggest areas and priorities for joint RTD projects. This will be accomplished by forming a Network of Excellence with the main European organisations given the national responsibilities to develop systems for safe handling and disposal of long-lived radioactive waster and by jointly working out a document that can serve as an aid for the planning and execution of future co-ordinated RTD activities between European implementers.

NET.EXCEL – Network of excellence in nuclear waste management and disposal	
Start Date: 2002-11-01	**End Date:** 2004-01-31
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries**: Belgium, Finland, France, Germany, Spain, Sweden, Switzerland, and United Kingdom

6.9 Sixth Framework Programme of the European Community

A multi-annual framework programme for Community research, technological development and demonstration activities is adopted for the period 2002-2006.

In order to contribute to the creation of the European Research Area and to innovation, this programme will be structured around the following three headings:

- Focusing and integrating Community research,
- Structuring the European Research Area,
- Strengthening the foundations of the European Research Area.

The activities under these three headings will contribute to the integration of research efforts and activities on a European scale as well as contributing to the structuring of the various dimensions of the European Research Area.

SKB plans, as co-ordinator, to submit a proposal on a European Networks of Excellence in co-operation with other European end-users, as response to the first call for proposals having a deadline of May 6^{th}.

7 Environmental research

Äspö Environmental Foundation was founded 1996 on initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its recourses available for national and international environmental research. SKB's economic engagement in the foundation will be concluded during 2003.

On the initiative of the Äspö Environmental Foundation the University of Kalmar has set up the Äspö Research School. The research school is a concrete commitment to provide conditions for today's and tomorrow's research concerning environmental issues. The research school has a special interest in the transport of pollutants and their distribution in rock, ground, water and biosphere. The research school is co-financed by the municipality of Oskarshamn, SKB, and the University of Kalmar. During 2003 detailed plans for the activities will be worked out and the goal is to let four doctorial students begin their studies. The number of students will be increased to about ten during the coming years.

The Geological Survey of Sweden (SGU) is a national authority responsible for questions relating to Sweden's geological character and handling of minerals. SGU phases out and environmentally safeguards the establishments, which hosted the national civilian stockpile of petroleum products. Field experiments have been performed at Äspö HRL to investigate the migration and degradation of petroleum products at *in situ* conditions. These experiments have been performed with participation of universities and consultant companies and will be finished during 2003. The aim with the experiments is to transfer the results to the monitoring programme at the former oil installation sites.

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