International Progress Report

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Äspö Hard Rock Laboratory

Planning Report for 2005

Svensk Kärnbränslehantering AB

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Äspö Hard Rock Laboratory

The Äspö Hard Rock Laboratory
Planning Report for 2005

This report presents the planned activities for year 2005 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 2004, 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 five 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

Repository Technology

Anders Sjöland

Director

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 460 m.

SKB's overall plans for research and development of technique during the period 2005-2010 are presented in SKB's RD&D-Programme 2004. 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 2005. Äspö HRL and the associated research as well as development and demonstration tasks, managed by the Repository Technology Department within SKB, have so far attracted considerable international interest.

Technology

At Äspö HRL, the goals are 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 carried out 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, aims at demonstrating the readiness for recovering of emplaced canisters also after the time when the surrounding bentonite buffer is fully saturated. Bentonite rings and blocks, bentonite pellets, and a canister with heater have been installed in a vertical deposition hole in full repository scale. The test has been running for a little more than four years. 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 filter mats used for artificial water supply may explain the inhomogeneous appearance. The plan is to maintain the power of the canister at 1,600 W, to continue the artificial water supply by keeping the water pressure at 800 kPa in the filter mats, and to continue the registration of sensor readings until the retrieval test starts in mid 2005.

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 has also been 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 tunnel is backfilled with a mixture of bentonite and crushed rock. In 2001 the inner section was installed and the monitoring of processes started. The installation of the outer section took place during 2003 and the surface between the outer plug and the rock was grouted in October 2004. During 2005 the instrument readings in the two sections will continue and 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 wetting of the backfill from the rock and filter mats supplying artificial water started in the end of 1999. The wetting continued until autumn 2003 when the flow testing in the backfill started. The flow testing has proceeded during 2004 and is planned to continue until 2006. Supplementary modelling will complement the flow testing and data collection and reporting will be continued. The excavation of the backfill materials is planned to start in the middle of 2006.

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 boreholes with a diameter of 300 mm and a depth of around four meters. The parcels are extracted and the water distribution in the clay is determined and subsequent well-defined chemical and mineralogical analyses as well as physical tests are performed. Two pilot tests are finalised and reported, and one parcel from the main test has been extracted, analysed, and a report is under production. The remaining four parcels are functioning well and only minor service was needed during the past year. The hourly measurement of water pressure, total pressure, temperature, and moisture will continue and the data will be carefully analysed and reported in April and October. During the spring 2005 the detailed planning for extraction of the next parcel will start. In addition, minor maintenance and improvement work on the remaining parcels are planned to be made during 2005.

In the project *Cleaning and sealing of investigation boreholes* the best available techniques for this are to be identified and demonstrated. In order to obtain data on the properties of the rock, investigation boreholes are drilled during site investigations and detailed characterisations. These boreholes must be cleaned and sealed, no later than at the closure of the deep repository. Cleaning of the boreholes means that instrumentation is removed. Sealing of the boreholes aims at receiving a conductivity in the borehole that is no higher than that of the surrounding rock. In the first phase of the project a state-of-the-art report summarising the developments of the techniques during the last 10–15 years was prepared. A final report from the second phase, which focuses on the development of a complete basic concept, has been prepared under 2004. The planning for a continuation is in progress and the aim is to continue with laboratory tests on potential sealing materials and to perform *in situ* tests in both short and long boreholes during 2005.

Late 2001 SKB published an R&D-Programme for the *KBS-3 method with horizontal emplacement* (KBS-3H). The programme, which is carried through by SKB and Posiva in co-operation, is divided into four parts: 1) Feasibility study, 2) Basic design, 3) Construction and testing at the Äspö HRL, and 4) Evaluation. The outcome from the feasibility study was that the KBS-3H method is worth further development work. The Basic design study including e.g. development of technology for excavation of horizontal deposition holes and emplacement of super containers was finalised and reported in 2004. The preparations for the full scale demonstration at Äspö HRL are in progress. The demonstration comprises two deposition holes – one short hole (15 m) which will be used for construction and testing of a low-pH shotcrete plug and one long hole (95 m) which will primarily be used for demonstration of the deposition equipment and for evaluation of the chosen excavation method. At the end of 2004 the excavation of the short hole was completed, laser scanned and approved by SKB and the pilot hole for the long hole was finished. The work with the full scale demonstration will continue during 2005 with the excavation of the long deposition hole, construction of concrete floor, and installation of the low-pH plug in the short hole. In addition, detailed design and manufacturing of deposition equipment, and analyses of buffer and long-term safety issues will be performed.

The aim of the *Large Scale Gas Injection Test* is to perform gas injection tests in a full-scale KBS-3 deposition hole. The current understanding of the gas transport process through compacted bentonite indicates that the buffer would open for gas passage before any harmful pressures are reached. However, there are still large uncertainties around the gas migration process which have to be verified in large-scale experiments. The experiments will be performed in a bored full-size deposition hole with a full-scale canister without heaters and a surrounding bentonite buffer. The installation phase is more or less finalised and the deposition of canister and buffer is planned to take place in the beginning of 2005. Water will be artificially supplied as soon as the installation is completed and the gas injection tests start when the buffer is fully saturated, which is expected to take two years.

The *Temperature Buffer Test* aims at improving the current understanding of the thermo-hydro-mechanical behaviour of buffers with a temperature around and above 100°C during the water saturation transient, in order to be able to model this behaviour. The French organisation Andra is running this test in co-operation with SKB. Two heater probes are installed in one deposition hole in the same test area as the Canister Retrieval Test. One of the probes is surrounded by an ordinary bentonite buffer and the other has a ring of sand as a thermal protection between the probe and the bentonite buffer. The operation phase, including heating, artificial pressurised saturation of the buffer and monitoring of temperature, humidity, pressure and displacement started in March 2003. Monitoring and sampling of experimental data are continuously ongoing and the information is transferred via a data link to Andra's head office in France. The initial thermal shock caused local desaturation of the bentonite in place where temperature exceeded 100°C. During 2005 the operation phase will continue and the experiment should be left without changes in boundary conditions. Two modelling tasks have been conducted during 2004 and a new modelling task will be defined in the beginning of 2005.

The *Rock shear experiment* aims at observing the forces that would act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole. Such a displacement is considered to be caused by an earth-quake, and the test set-up need to provide a shearing motion along the fracture that is equal to an expected shearing motion in real life. A feasibility study has been running since summer 2004 and will be finished in the beginning of 2005. The equipment for attaining the required force and the shear rate has been drawn up. If the decision is taken to carry out the test, the goal is to start the preparations in spring 2005 and to have the entire installation finished at the end of the year. The test will be installed at the Äspö Pillar Stability Experiment site when the rock mechanics test has been completed there.

The *Task Force on Engineered Barrier Systems* was put on a stand-by position in 2001. As the European Commission funding of the Prototype Repository project ceased in February 2004 it was judged most convenient to activate the Task Force and continue the modelling work in the Prototype Repository project within this frame, where also modelling work on all other experiments can be conducted. The Task Force was established in 2004 and a kick-off meeting was held in October. The Task Force starts with a first phase that comprises four years. This phase addresses two tasks, THM processes and gas migration in buffer material, and ends with a state-of-the-art report. The focus is on the use of codes for predictions of the conditions in the buffer during specified milestones in the repository evolution. During year 2005 benchmark calculations will be performed. The results will be analysed and the capability as well as the prerequisite for further development of the codes will be evaluated. The first milestone is expected to be reached during 2005 when comments are gathered on how well-developed the participating codes are, and the potential of the codes to meet the intended results.

Geo-science

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

A new system for *Geological mapping and modelling* to be used in the deep repository construction work will be developed within a new project. The major reasons to develop a new system for underground mapping are aspects on time requirements, precision and traceability in mapping. The work with the new system was started during autumn 2003 and has continued during 2004. A project with the name Rock Characterisation System is ready to start and the first stage is a feasibility study.

The project on *Heat transport* aims at decreasing the uncertainties in the estimates of the temperature field in the repository. Less uncertain estimates of the temperature field around a repository makes it possible to optimise the distance between canisters in the repository layout. The heat evolution in the Prototype Repository has been used to analyse thermal properties of the rock and to verify prognosis. The present work to analyse uncertainties and scale dependency in data on thermal rock properties will be evaluated and reported during the beginning of 2005.

The main objectives of the project *Inflow predictions* are to make better predictions of the water inflow into deposition holes and tunnels. The results from a number of large field tests show that when going from a borehole 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. During 2004 numerical analyses have been conducted in order to increase the understanding of the coupled hydro-mechanical aspects of inflow of water. In addition, a field experiment was performed in October 2004 at the Äspö Pillar Stability site. The aim was to monitor the changes in the conductive fractures, and the evolution of the inflow into the excavation versus time, due to the stress drop. The results from the experiment will be reported and further theoretical, experimental and numerical analyses of the inflow into excavations will be conducted during 2005.

Seismic influence on the groundwater system will be studied by analysing data on changes in the piezometric head registered by the Hydro Monitoring System (HMS). Special software is under development that may facilitate the comparison of the HMS database with other databases, e.g. SKB's site investigation database (Sicada) or the national seismological database. The plans for 2005 are to finalise the software development and to analyse the impact of earthquakes and effects of blasts in Äspö HRL.

Rock Mechanic studies are performed with the aim to increase the understanding of the mechanical properties of the rock. This is done by laboratory experiments and modelling at different scales. The aim is also to recommend methods for measurements and analyses of mechanical properties. During 2005, work will be performed within the following projects:

- Coupled processes in rock including dynamic processes at natural conditions.
- Stress measurements and stress interpretation methods.
- Understanding of variability of rock under different load conditions.
- Methods to calculate stability of underground openings and large scale failures.
- Mechanical processes in the interface between rock and backfill.

Äspö Pillar Stability Experiment was initiated 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. During 2003, a new drift was excavated to ensure that the experiment was carried out in a rock mass with a virgin stress field and two vertical holes at a distance of one metre was drilled in the floor of the tunnel. The experiment was carried out during 2004 as planned. All instruments were installed and the heaters turned on which quickly initiated spalling in the pillar wall. The spalling progressed about five metres down the hole. During 2005 the monitored data during the heating phase and the data achieved during the post characterisation of the pillar blocks removed from the drift will be analysed. An integrated analysis combining data on temperature, deformations, acoustic emissions, and the data from the post characterisation will be performed.

Natural barriers

At Äspö HRL, experiments are performed at conditions that are expected to prevail at repository depth. The aim is to increase the knowledge of the long-term function of the repository barriers. The bedrock with available fractures and fracture zones, its properties and ongoing physical and chemical processes that affect the integrity of the engineered barriers and the transport of radionuclides, are denoted the natural barriers. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The strategy for the ongoing experiments is to concentrate the efforts on those experiments that are of importance for the site investigations. Tests of numerical 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 numerical 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* are to improve the understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure, and micro-structure. During 2004 *in situ* experiments with sorbing tracers were performed. The *in situ* efforts were paralleled by model predictions employing four different modelling approaches. Evaluation and reporting of the project will be made during 2005. Individual evaluation reports will be produced by each modelling group and these will be merged to a final report that will be presented at a review seminar in mid September 2005.

One of the principal objectives of the *True-1 Continuation Project* is to map the porosity of the earlier investigated Feature A at the True-1 site. A 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. The main endeavour for 2005 is launching of what is denoted True-1 Completion. This sub-project will encompass the full application of the resin injection technology to the True-1 site and Feature A. It will also include complementary *in situ* experimentation before destroying the site completely. The time perspective for this work is to enable injection of epoxy during 2006 and have the project completed by the end of 2008. The first half of 2005 will be devoted to detailed planning of the work.

The *Long Term Diffusion Experiment* constitutes a complement to performed diffusion and sorption experiments in the laboratory, and is a natural extension of the True-experiments. The difference is that the longer duration (approximately four 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 borehole. The installation-test and pre-test programmes performed during 2004 showed that some modifications were necessary. The modifications are ongoing and the injections of radioactive tracers are planned for in the first half of 2005. In addition, laboratory experiments on core samples from the LTDE borehole will be performed at AECL.

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 probes placed in boreholes. Radiolysis experiments, intended to investigate the influence of radiolysis on the migration of oxidised technetium, were performed with the Chemlab 1 probe. The field experiment and the evaluation of collected data are finished, and the final report will be printed in 2005. Migration of actinides in a natural rock fracture in a drill core is studied in the Chemlab 2 probe. The last field experiments of the actinide project, with the tracers uranium and technetium, started in 2004 and have been prolonged due to a somewhat unexpected increase in uranium concentration in the outlet solution. Two new experiments will be started in the Chemlab probes during 2005. Both of the experiments are still in the design phase. The radionuclide transport resistance at the buffer-rock interface will be studied in Chemlab 1 and experiments on spent fuel leaching under relevant repository conditions will be started in Chemlab 2.

The *Colloid 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. The laboratory experiments, background measurements and borehole specific measurements will be compiled in a final report. The report is in progress and will be ready in spring 2005. The planning and preparations of dipole colloid experiments, to study the change in colloid content in the groundwater prior and after its transport through a natural fracture, have continued during 2004. During 2005, the main part of the work will be performed in the laboratory. However, some injections of conservative tracers and colloids will be performed to determine the experimental infrastructure at the chosen site, the True-1 site.

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 and are studied in the *Microbe Project*. Four microbial process areas have been identified: bio-mobilisation of radionuclides, bio-immobilisation of radionuclides, microbial effects on the chemical stability, and microbial corrosion of copper. The experimental work with immobilisation of radionuclides on biofilms in a system with controlled circulation of groundwater has been finalised and reporting is in progress. A summary report on design and work on the Microbe sites between 2001 and 2004 will be published in the beginning of 2005. There are two main activities planned for 2005: Investigations on *in situ* mobilisation of radionuclides by microbial complexing agents, and investigations of the response of the microbial populations to perturbation in the geochemical environment, such as oxygen intrusion.

The first phase of the *Matrix Fluid Chemistry* experiment (1998-2003) was published in 2004. The results from this phase 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 continuation phase focuses on the small-scale micro-fractures in the rock matrix which facilitate the migration of matrix waters. The understanding of the migration of groundwater, and its changing chemistry, is important for repository performance. In 2004 a study to evaluate the potential impact of the tunnel excavation at the Äspö Pillar Stability Experiment site in vicinity of the Matrix Fluid Experiment borehole was initiated. The scope of work for 2005 will very much depend on the impact of the tunnel excavation. If there is no significant impact, resampling of groundwaters and dissolved gases from borehole sections will be made during 2005. The experimental set-up from the first phase will be used.

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. The ongoing Task 6, Performance assessment modelling using site characterisation data, was initiated in 2001. The work during 2005 focuses on reporting of the modelling and continuation of the external review process of Task 6.

Padamot (Palaeohydrogeological Data Analysis and Model Testing) is an EC-project that includes developments of analytical techniques and modelling tools to interpret data, but also focusing research to investigate specific processes that might link climate and groundwater in low permeability rocks. The term palaeohydrogeology is used as a common name for information from fracture minerals that is used for interpretations of past hydrogeochemical and hydrogeological systems. The EC-project was initiated in the beginning of 2002 and was finalised at the end of 2004. A continuation is being discussed.

The basic idea behind the project *Fe-oxides in fractures* is to examine Fe-oxide fracture linings, in order to explore suitable palaeo-indicators and their formation conditions. At the same time knowledge about the behaviour of trace component uptake can be obtained from natural material as well as through studies in the laboratory under controlled conditions. The three year project on Fe-oxides started late autumn 2003 and a pilot study has been going on during 2004. Plans for 2005 are being considered.

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 Äspö HRL. This includes preventative and remedy maintenance in order to withhold high availability in all systems such 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.

The Information and public relations group is responsible for presenting information about SKB and its facilities e.g. the Äspö HRL. They arrange visits to the facilities all year around as well as special events.

International co-operation

Nine organisations from eight countries will participate in the co-operation at Äspö HRL during 2005. 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 Task Forces on Modelling of Groundwater Flow and Transport of Solutes, and on Engineered Barrier System.

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 was concluded in 2003 and the activities are now concentrated on the Äspö Research School, which was founded in 2002. The activity within the School will lead to: (a) development of new scientific knowledge, (b) increase of geo and environmental scientific competence in the region and (c) utilisation of the Äspö HRL for environmental research. Currently the scientific team consists of a professor of Environmental geology, three assistant supervisors and six Ph.D. students. The first Ph.D. dissertation will take place in 2005. The research activity focuses on biogeochemical systems, in particular in the identification and quantification of dispersion and transport mechanisms of contaminants (mainly metals) in and between soils, sediments, water, biota and upper crystalline bedrock. In the Äspö HRL, however, the activities are as yet minor. The goal during 2005 is to employ a research assistant and more Ph.D. students.

Contents

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 and the capability to model the processes taking place, while demonstration addresses the performance of the engineered barriers, and practical means of constructing a repository and emplacing the high-level nuclear waste.

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 460 m, see Figure 1-1. The total length of the tunnel is 3,600 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.

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 and rock-mechanical 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 2004 /SKB, 2004/.

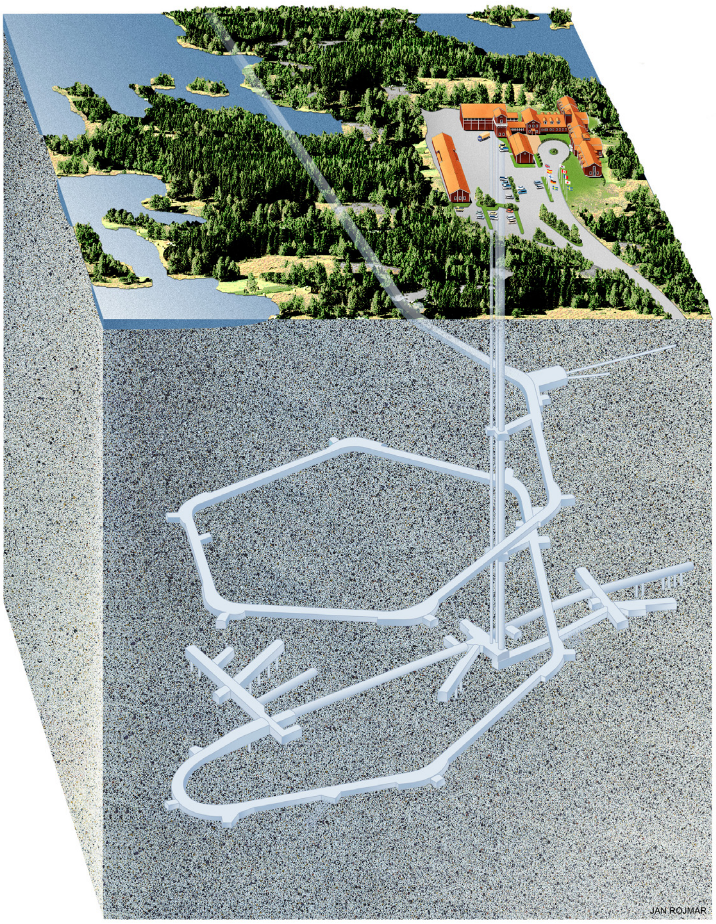

Figure 1-1 *Overview of the Äspö HRL facilities.*

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 boreholes 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 have been transferred to the Site Investigation Department of SKB which performs 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 the general public on technology and methods that are being developed for the deep repository.

1.3 Organisation

SKB's work is organised into five departments: Technology, Site Investigation, Operations, Environmental Impact Assessment (EIA) and Public Information, and Business support. The research, technical development, and safety assessment work is organised into the Technology department, in order to facilitate co-ordination between the different activities.

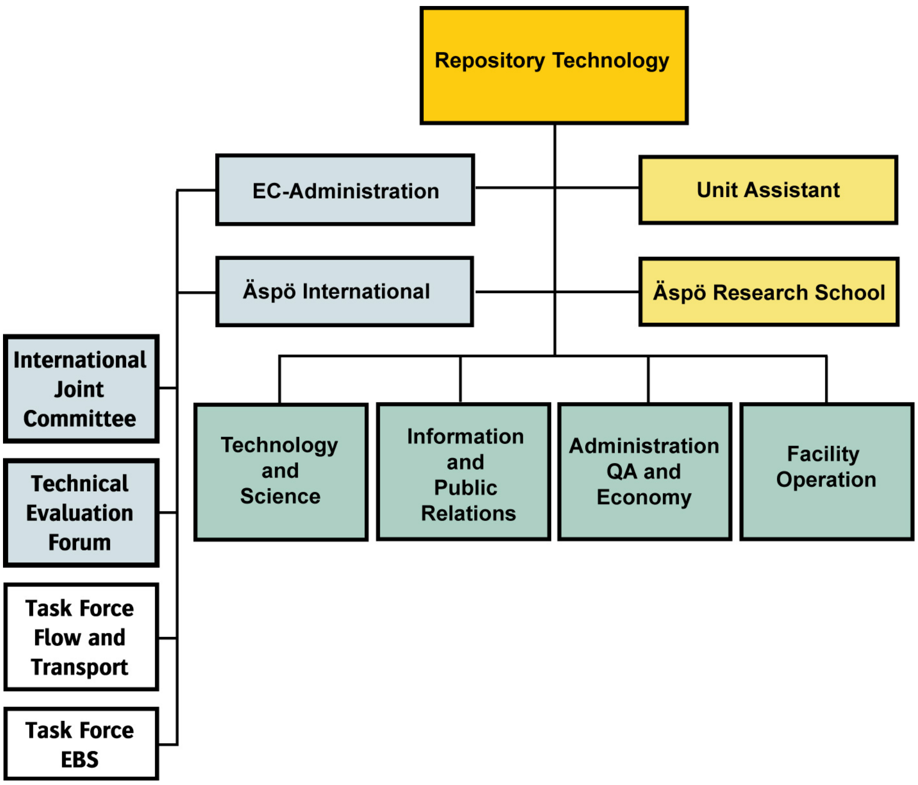

Figure 1-2 Organisation of Repository Technology and Äspö HRL.

Repository Technology (TD), one of five units 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 four 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.
- *Administration, QA and Economy* is responsible for providing administrative service and quality systems.
- *Information and public relations* is responsible for presenting information about SKB and its facilities e.g. the Äspö HRL. The facilities are open to visitors during the year.

The Äspö HRL and the associated research, development, and demonstration tasks are managed by the Director of Repository Technology. 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 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.

1.4 International participation in Äspö HRL

The Äspö HRL has so far attracted considerable international interest. Nine organisations from eight countries will in addition to SKB participate during 2005 in the Äspö HRL or in Äspö HRL-related activities. 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.
- Ontario Power Generation Inc. (OPG), Canada.
- Posiva Oy, Finland.
- Radioactive Waste Repository Authority (Rawra), Czech Republic.

For each partner the co-operation is based on a separate agreement between SKB and the organisation in question.

Andra, BMWA, CRIEPI, Enresa, JNC, OPG and Posiva form together with SKB the Äspö International Joint Committee (IJC), which is responsible for the co-ordination of the experimental 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 on stand-by but was activated during 2004.

1.5 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.

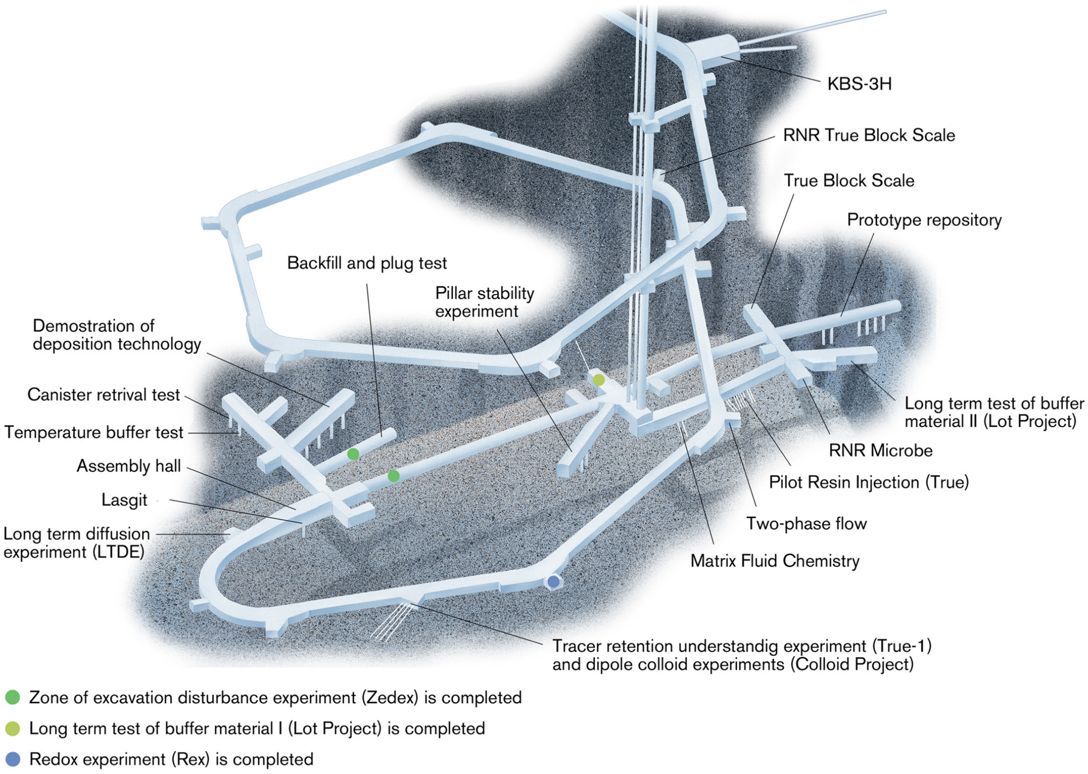

Figure 1-3 *Allocation of experimental sites from -220 m to -450 m level.*

1.6 Reporting

Äspö HRL is an important part of SKB's RD&D-Programme /SKB, 2004/. The plans for research and development of technique during the period 2005–2008 are presented in SKB's RD&D-Programme 2004. 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 2005. 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.

Joint international work at Äspö HRL as well as data and evaluations for specific experiments and tasks are reported in Äspö International Progress Report series. 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	Contributors	Director Repository Technology
Status Reports – Short summary of work covering each 3 month period	Principal Investigators or 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

1.7 Management system

SKB is since 2001 certified according to the Environmental Management System ISO 14001 and also to the Quality Management Standard ISO 9001, and since 2003 also according to the up-graded ISO standard 9001:2000.

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 for that work will be performed in accordance with SKB's management system.

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 all SKB's activities and each employer's work are expressed in three key words:

- Safety.
- Efficiency.
- Sensitivity.

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 manages 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 also makes every effort to minimise the impact of ongoing operations and activities on the environment. This environmental work is goal-oriented and the progress versus goals is assessed each 3rd months. Key assessment parameters for the selection of suppliers include security, environmental aspects and quality.

1.8 Structure of this report

The work planned at Äspö HRL during 2005 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

To meet stage goal 4, to demonstrate technology for and function of important parts of the repository system, work is performed at Äspö HRL. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a future 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 as well as 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 emplacement.
- Large Scale Gas Injection Test.
- Temperature Buffer Test.
- Rock shear experiment.

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 it to be just pulled out of the deposition hole. The canister has to be made free from the grip of the bentonite before it can be taken up.

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.

Objectives

The overall aim of the Canister Retrieval Test is to demonstrate to specialists and to the public that retrieval of canisters is technically feasible during any phase of operation. 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 including the boring disturbed zone.
- Emplacement of bentonite blocks, bentonite pellets and canisters with heaters, and artificial addition of water. However, only one of these deposition holes has been used for implementation of the Canister Retrieval Test.
- Saturation and swelling of the buffer are monitored under controlled conditions.
- 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 were made within sub-projects that concern also other tests in the Äspö HRL. In addition to the retrieval testing the results of monitoring and manual excavation with laboratory testing of parts of the buffer will be used to increase the understanding of the THM processes in a deposition hole.

Experimental concept

The Canister Retrieval Test is located in the main test area at the -420 m level. The tunnel is excavated by conventional drill and blast techniques and is 6 m wide and 6 m high. The test period is separated into three stages:

Stage I Boring of deposition holes and installation of instrumented bentonite blocks and canisters with heaters in one hole. This hole is covered in the top with a lid of concrete and steel.

Stage II Saturation of the bentonite and evolution of the thermal regime with measurement of thermal, hydraulic and mechanical processes.

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 blocks of highly compacted Na-bentonite, with a full diameter of 1.65 m and a nominal height of 0.5 m. Instruments for measuring temperature, relative humidity, total pressure and pore pressure were installed in the bentonite in many of the blocks. When the stack of blocks was 6 m high the canister equipped with electrical heaters was lowered down in the centre. Cables to heaters, thermocouples in the rock and strain gauges in the rock were connected, and additional blocks were 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 will be left open for access and inspections of the plug support. The experimental set-up is shown in Figure 2-1.

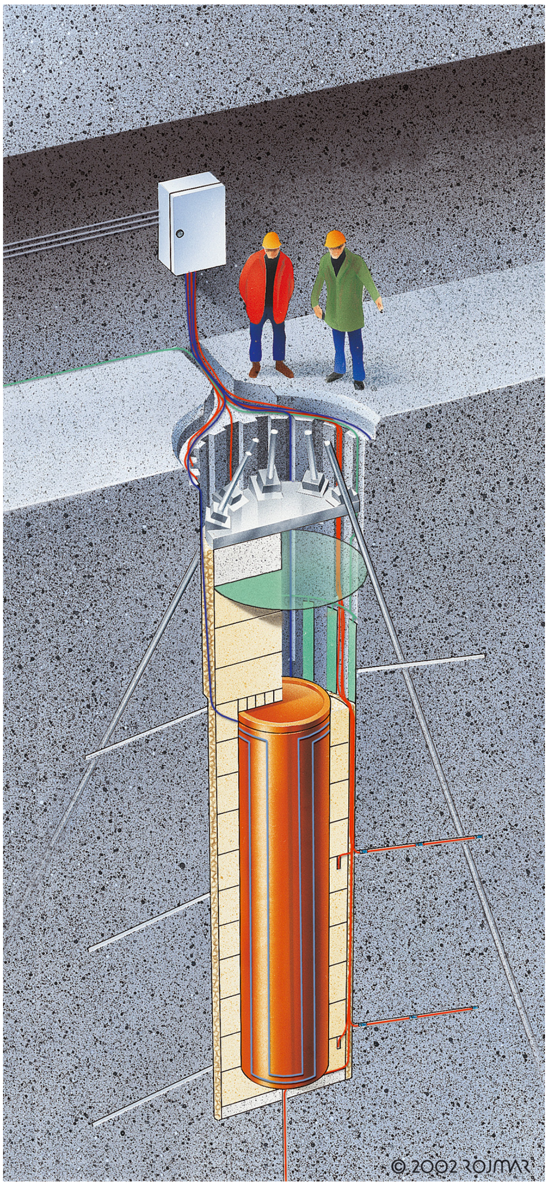

***Figure 2-1** Illustration of the experimental set-up of the Canister Retrieval Test.*

Artificial addition of water is provided evenly 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 the degree of saturation in the buffer. The instrumentation in the buffer is similar to the instrumentation in the Prototype Repository and yield comparable information during the saturation period.

Present status

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 4 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 exception of several relative humidity sensors that have failed due to water saturation and the sensors inside the canister, which all have failed. 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 increased 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 2,600 to 2,100 W in September 2002. Back flushing of the mats has been done in order to avoid clogging. In December 2003 the power was further reduced to 1,600 W. Failure of heater elements have occurred but the power 1,600 W has been kept during 2004.

Scope of work for 2005

The plan is to continue the artificial water saturation of the bentonite, to maintain the power of the canister at 1,600 W, to maintain the water pressure at 800 kPa in the mats, and to continue the registration of sensor readings during 2005. Reporting of measurements and evaluation of the results will be done as well as further modelling for increased understanding of the THM-processes in the buffer. The actual retrieval test is scheduled for 2007.

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. This technology was developed and is tested 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 provides 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. 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 installation of the Prototype Repository has been co-funded by the European Commission with SKB as co-ordinator. The EC-project started in September 2000 and ended in February 2004. The continuing operation of the Prototype Repository is funded by SKB.

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 model predictions 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 test location chosen is the innermost section of the TBM-tunnel at the -450 m level. The layout involves altogether six deposition holes, four in an inner section and two in an outer, see Figure 2-2. The tunnels are backfilled with a mixture of bentonite and crushed rock (30/70). A massive concrete plug designed to withstand full water and swelling pressures separates the test area from the open tunnel system and a second plug separates the two sections. This layout provides 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 have been positioned in the holes and surrounded by bentonite buffer. The deposition holes are placed with a centre distance of 6 m. This distance was evaluated considering the thermal diffusivity of the rock mass and the maximum acceptable surface temperature of the canister.

The decision when to stop and decommission the test will be influenced by several factors including performance of monitoring instrumentation, results successively gained, and 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. Instrumentation is used to monitor processes and evolution of properties in canister, buffer material, backfill, and near-field rock. Examples of processes that are 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.

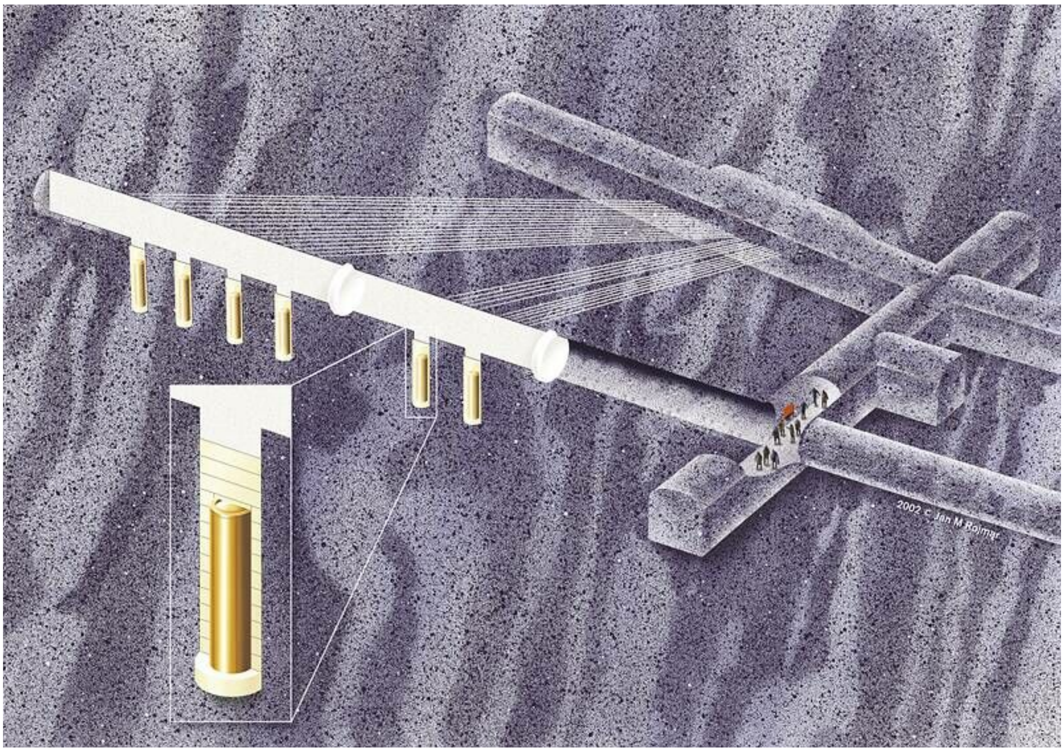

Figure 2-2 *Schematic view of the layout of the Prototype Repository (not to scale).*

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. The buffer and the canisters in the outer section were installed at the beginning of 2003. Immediately after the installation of the buffer, the tunnel section was backfilled and the heaters were turned on. This work was finished at the end of June 2003. At these stages the monitoring of processes was started. The construction and casting of the outer plug started in August and were finished in September 2003. The surface between the rock and the outer plug was grouted in October 2004.

Chemical measurements in buffer, backfill and surrounding rock are ongoing. Tests for evaluating the ground water pressure and ground water flow the rock have also been performed.

Scope of work for 2005

The instrument readings in the two sections and the chemical measurements in buffer, backfill and surrounding rock will continue. In addition, new tests for evaluation of the hydraulic conditions in the rock will be made and the modelling teams will continue the comparison of measured data with predictions. The rebuilding of the power regulation system for canisters in the inner section will be finalised.

2.4 Backfill and Plug Test

Background

The Backfill and Plug Test includes tests of backfill materials and emplacement methods and a test of a full-scale plug. It is a test of the integrated function of the backfill material and the near-field rock in a deposition tunnel excavated by blasting. It is also a test of the hydraulic and mechanical functions of a plug. The test was 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.
- Test the function of the backfill and its interaction with the surrounding rock in full-scale in a tunnel excavated by blasting.
- 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, which is about 30 m long, is 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.

The inner test part is 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 is filled with crushed rock with no bentonite additive. Since the crushed rock has no swelling potential but may instead settle with time, a slot of a few decimetres was left between the backfill and the roof and 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. The remaining irregularities between these blocks and the roof were filled with bentonite pellets.

Each one of the two test parts are divided 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 near-field rock. The mats are also used for the water saturation of the backfill. The mats were installed in both test parts with the individual distance 2.2 m. Each mat section was divided in three units in order to be able to separate the flow close to the roof from the flow close to the floor and also in order to separate the flow close to the rock surface from the flow in the central part of the backfill.

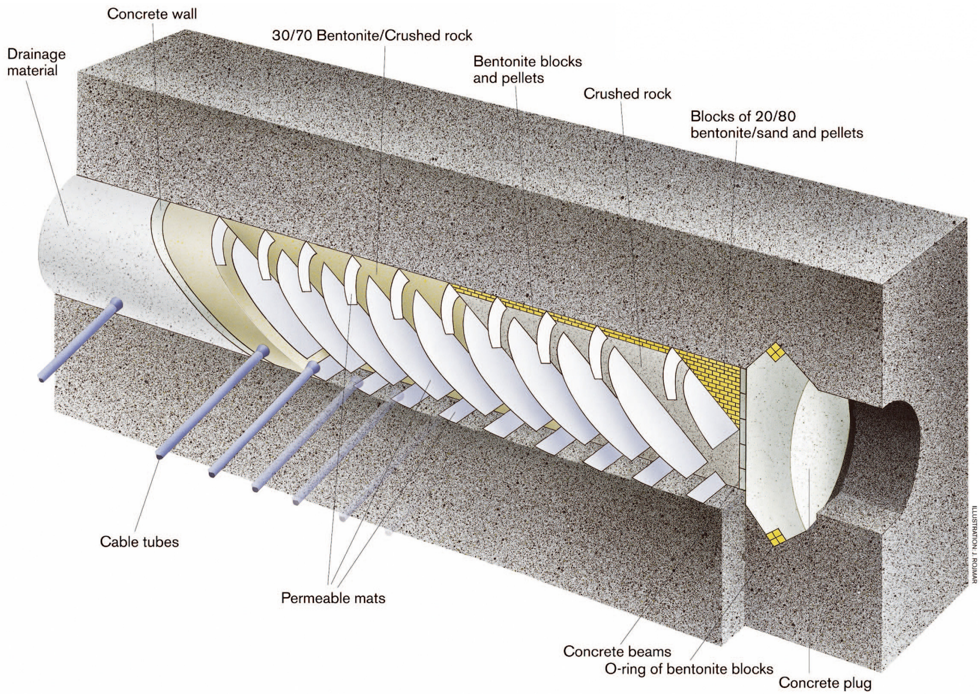

Figure 2-3 *Illustration of the experimental set-up of the Backfill and Plug Test.*

The outer test part ends with a wall made of prefabricated concrete beams for temporary support of the backfill before casting of the plug. Since *in situ* compaction of the backfill cannot be made in the upper corner, this triangle was instead filled with blocks of bentonite/sand mixture with 20% bentonite content.

The 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.

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

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 and continued until 2003. 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. The water pressure was kept at 500 kPa in all mats during a major part of 2003. During the wetting data from transducers was collected and reported.

Preparations and rebuilding of the wetting system for adapting it to the flow testing were done during 2003 and the flow testing started by decreasing the water pressure in the permeable mats sections (one by one) to 400 kPa and measuring the flow between the mat sections.

During 2004 the flow testing of the bentonite/crushed rock mixture has proceeded. Evaluation of the field results is ongoing and preliminary estimations indicate that the hydraulic conductivity of the backfill is in the same range as expected from laboratory tests.

Scope of work for 2005

The flow testing will continue during 2005 as planned. In addition to the flow testing the following activities will be accomplished:

- Continued data collection and reporting of measured water pressure, water flow and total pressure.
- Maintenance of equipment and supervision of the test.
- Supplementary modelling of the flow testing and evaluation of results.
- Supplementary laboratory testing for modelling and understanding of the hydro-mechanical properties of the backfill materials.

The flow testing is planned to continue until 2006 and the excavation of the backfill material is planned to start in the middle of 2006.

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 concept 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 in 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:

- Collect 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.
- Collect data concerning survival, activity and migration of bacteria in the buffer.
- Check of calculation results concerning copper corrosion, and information regarding type of corrosion.
- Collect data concerning gas penetration pressure and gas transport capacity.
- Collect 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 boreholes with a diameter of 300 mm and a depth of around 4 m, see Figure 2-4. The test series, given in Table 2-1, concern realistic repository conditions except for the scale and the controlled adverse conditions in three tests.

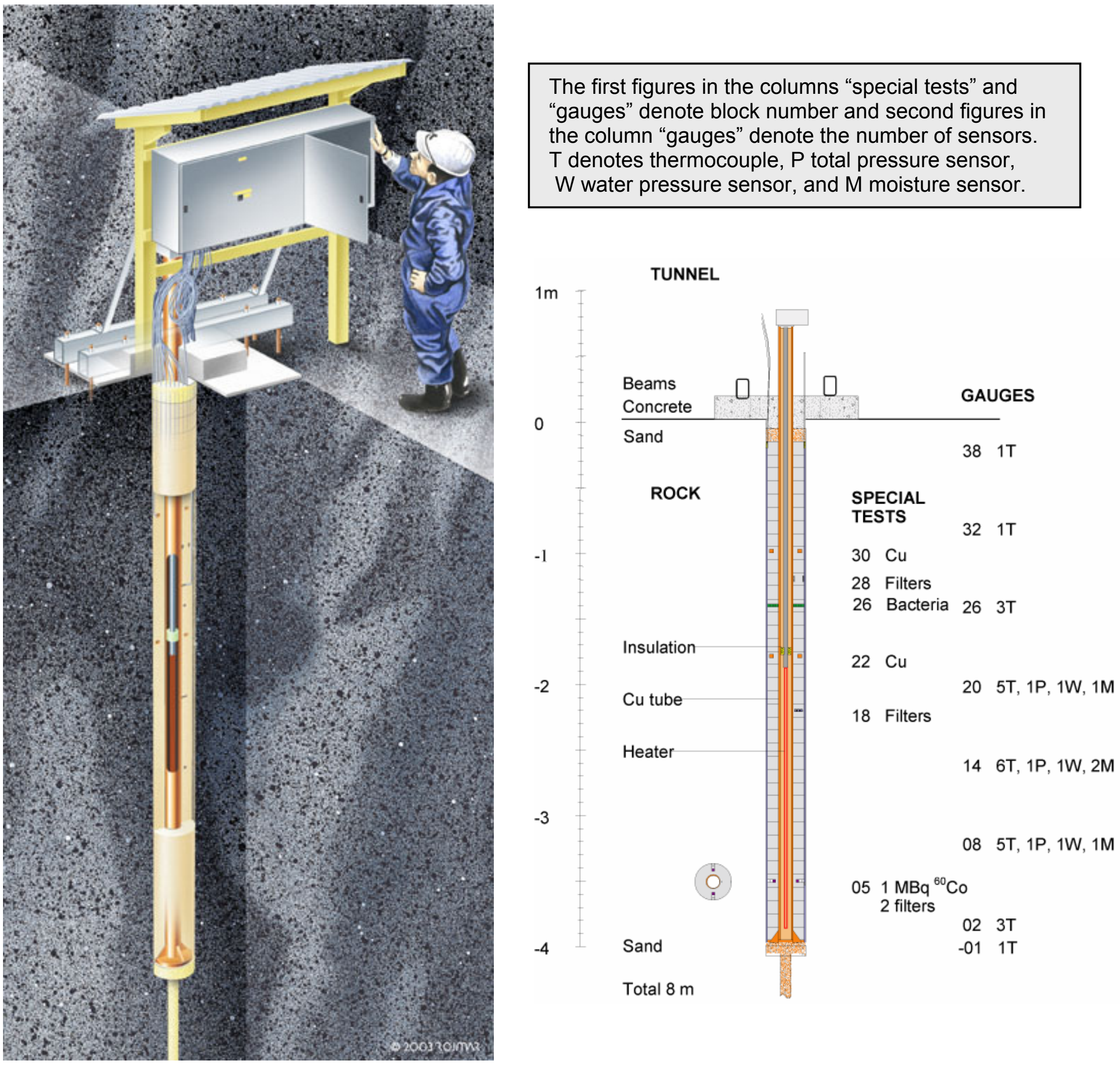

Figure 2-4 *Illustration of the experimental set-up in the Long Term Test of Buffer Material (left) and a cross-section view of one S-type parcel (right).*

Table 2-1 Buffer material test series.

Type	No.	max T, °C	Controlled parameter	Time, years	Remark 1	Remark 2
A	1	130	T, [K+], pH, am	1	pilot test	reported
A	0	120–150	T, [K+], pH, am	1	main test	under evaluation
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

Adverse conditions in this context refer to high temperatures, high temperature gradients over the buffer, and additional accessory minerals leading to 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 controlled 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 borehole. The water distribution in the clay is determined and subsequent well-defined chemical, mineralogical analyses and physical testing are performed.

Present status

The pilot tests, including parcels A1 and S1, are finalised and reported. The A0 parcel has been extracted and are being analysed, and a report is under production. The remaining four parcels are functioning well and only minor service was needed during the past year.

Scope of work for 2005

Water pressure, total pressure, temperature and moisture in the four remaining parcels will be continuously measured and stored every hour. The data are being checked monthly, and the results are analysed more carefully in April and October. Minor maintenance and improvement work will be made on the running parcels.

The next test to be terminated will likely be the A2 parcel. Development of analyse techniques in order to improve the characterisation of field exposed parcel material will continue. The work is made in co-operation with the Chemical and Geological departments at Lund University.

Detailed planning for the next parcel extraction will start in April 2005, and the overlapping core-drilling is planned to begin in September. Subsequent analyses of the bentonite material will start immediate after the extraction and is planned to continue for the rest of the year.

2.6 Cleaning and sealing of investigation boreholes

Background

Investigation boreholes are drilled during site investigations and detailed characterisation in order to obtain data on the properties of the rock. These boreholes 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 boreholes aims at receiving a conductivity in the borehole that is no higher than that of the surrounding rock. Cleaning of the boreholes means that instrumentation that has been used in the boreholes during long time-periods, in a sometimes aggressive environment, is removed.

Sealing of boreholes 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 boreholes with a length of 200 m, with very promising results. A further development of this technique is, however, required to show that boreholes with lengths of up to 1,000 m can be sealed.

Since most of the investigation boreholes are instrumented, reliable technique is also needed to clean boreholes 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 boreholes. The project comprises two phases. Phase 1, mainly an inventory of available techniques, was finalised in 2003. Phase 2 aims to develop a complete cleaning and sealing concept and to demonstrate it. In phase 2 the work is divided in the four main areas described below:

- Laboratory studies on potential materials and combinations of different materials. Laboratory tests on selected candidate materials to evaluate if the criteria set on hydraulic conductivity, shrinkage, and physical and chemical long-term stability can be fulfilled.
- Cleaning of the borehole to be used at a later stage in the project. Identification of the type of equipment left in the borehole and investigations of the distribution of equipment along the borehole. Specification of methods and equipment needed to catch and bring up the left equipment in the borehole. Finally, select methods and equipment to be applied for cleaning the hole.
- Preparations for full-scale testing in the field. Present the requirements to be set on preparations to be made before plugging the borehole. Specify the requirements to be fulfilled by equipment and material to be used for plugging of long and short boreholes from the surface and from underground.
- Compile a complete “Basic concept” for sealing of boreholes. The concept should include measures to be taken before plugging, evaluation of long-term stability of selected materials, and techniques for manufacturing and installation of plugs in boreholes. In addition, recommendations should be made on full-scale tests of the concept.

Present status

The major conclusion, from the completed phase 1, was that smectite clay is recommended as main candidate material for sealing of boreholes in the forthcoming work. The second phase, which focuses on the development of a complete basic concept for cleaning and sealing of boreholes, will be documented in a final report. The report is now being reviewed before printing. The basic concept for surface-based boreholes (see Figure 2-5) comprises the following materials at different depths:

- On the ground surface, filling of 3 m well compacted moraine from the site.
- 3–50 m, well fitting rock cylinders pressed down in the precision-drilled (reamed) uppermost part of the hole. The cylinders are from the site. Silica gel is used as mortar.
- 50–60 m, fill of well compacted moraine from the site. It constitutes a transfer from the effective underlying ductile clay seal to the overlying stiff borehole plug.
- 60–100 m, fill of smectite pellets of bentonite applied and compacted layer wise.
- Below 100 m, highly compacted smectite clay contained in perforated copper tubes (2–4 mm thick walls and degree of perforation is approximately 50%). Tubes are jointed to form a continuous clay column.

Tunnel-based boreholes are filled with highly compacted smectite clay contained in perforated copper tubes that are jointed to form a continuous clay column. These boreholes will be plugged with concrete at the tunnel.

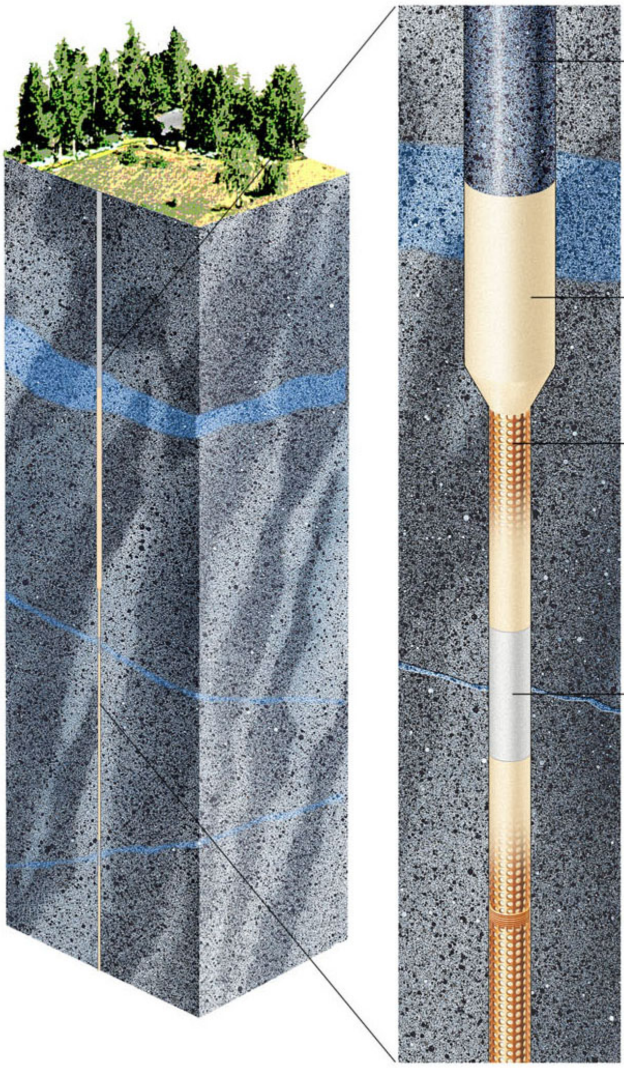

Figure 2-5 *Illustration showing the basic concept for sealing of surfaced-based investigation boreholes.*

Laboratory studies of material for plugging boreholes are in progress, test of bentonite with different water content and density are going on. Construction of machine for automatic manufacturing of copper tube has started, and will be tested in full scale during February.

A number of short boreholes for testing the concept have been drilled under ground. The testing will give information of the maturation rate, i.e. the time required for a clay plug of basic type to become at least as tight as the surrounding rock.

Boreholes with 200 mm diameter have also been drilled to a depth of 1.5 m. They will be used for testing potential sealing methods of the upper part of the boreholes.

One part of the project is a full-scale field test at Äspö where two deep candidate investigation boreholes, KAS06 and KAS07, have been investigated as a preparation for potential field test. The conclusion was that KAS06 might be used in a later stage of the project but needs to be re-bored to increase the diameter.

The planning for a continuation, phase 3, is in progress.

Scope of work for 2005

The project will continue with laboratory tests, *in situ* tests in short boreholes. The main activities are:

- Continued laboratory tests on potential sealing materials.
- Detailed planning of the plugging procedure.
- Manufacturing of plug components.
- Modelling of hydration and homogeni*s*ation process on the clay plug.
- Sealing of short boreholes with the aim to test prioritised techniques.
- Determination of sealing performance of basic plug concept in short boreholes.
- Testing of methods for sealing large-diameter holes.

2.7 KBS-3 method with horizontal emplacement

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 holes (KBS-3H) instead of vertical emplacement of single canisters in the deposition hole (KBS-3V), see Figure 2-6, has been considered since early nineties. The deposition process requires that each copper canister and its buffer material are assembled into a prefabricated so-called super container.

Most of the positive effects of a repository based on horizontal emplacement are related to the smaller volume of excavated rock. Examples of positive effects are:

- Less environmental impact during construction.
- Reduced impact on the groundwater situation in the bedrock during construction and operation.
- Reduced cost for construction and backfilling of the repository compared to KBS-3V. However, great efforts are required developing the variant.

Late 2001 SKB published an R&D programme for the KBS-3 method with horizontal emplacement. The RD&D programme /SKB, 2001/ is divided into four parts: Feasibility study, Basic design, Demonstration of the concept at Äspö HRL, and Evaluation. The RD&D programme is carried through by SKB in co-operation with Posiva.

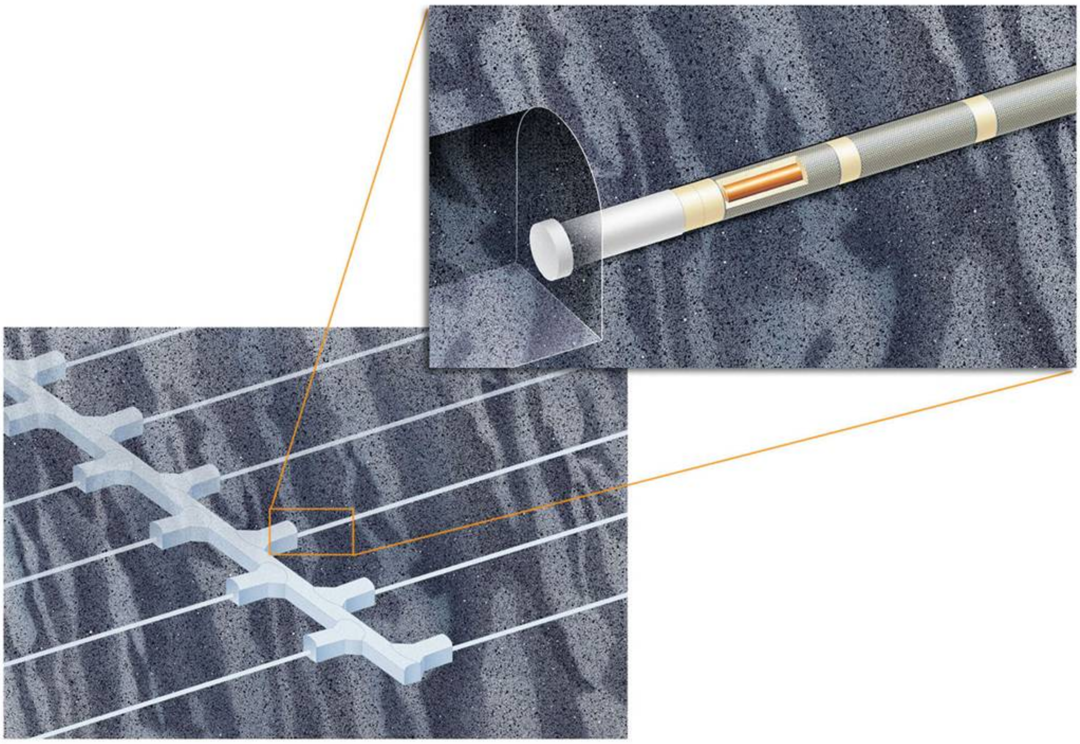

Figure 2-6 *Schematic illustrations of KBS-3H.*

Objectives

The objective of the first part of the project, the feasibility study, was to evaluate whether horizontal emplacement is a realistic alternative, and if so, to give SKB and Posiva a basis for continued evaluation of KBS-3H. The feasibility study focused on differences compared to the reference concept KBS-3V. Highlighted tasks were excavation of the deposition holes, the deposition technique, and the function of the buffer.

The second step, the Basic design study /Thorsager and Lindgren, 2004/, focuses on technology for excavation of holes, emplacement of super containers, but also the design of the bentonite buffer inside the super container. In addition, an evaluation of the long term safety of the concept is carried out.

Demonstration site

A need for a demonstration of the KBS-3H concept was foreseen in the KBS-3H feasibility study and it was decided to investigate a suitable location and prepare a site at Äspö HRL. The demonstration site is located at the –220 m level in a niche, 15 times 25 meters. The niche is designed to accommodate vehicles, machinery and auxiliary equipment for drilling of the deposition holes. Two horizontal deposition holes with a diameter of 1.85 m will be excavated, one hole is 15 m long and the other is 95 m. The short hole will be used for construction and testing of a low-pH shotcrete plug, and the long hole will primarily be used for demonstration of the deposition equipment but also for evaluation of the chosen excavation method.

Present status

During 2004 work has been focused the following parts:

- Excavation of deposition holes for the full scale demonstration by horizontal raise boring.
- Procurement of detailed design and manufacturing of deposition equipment.
- Continued research regarding buffer design and development of a new design solution.
- Resolving of critical issues related to the long term safety of the concept and modelling of THM processes.

At the end of 2004 the short deposition hole was completed, laser scanned and approved by SKB. The contractor has also finished the pilot hole for the long deposition hole. The short hole will be used for construction and testing of a low-pH shotcrete plug, and the long hole will primarily be used for demonstration of the deposition equipment but also for evaluation of the chosen excavation method.

SKB has signed an agreement with a French company CNIM for detailed construction and manufacturing of deposition equipment. In order to come to an agreement SKB has evaluated and improved the basic design and expressed functional requirements in the tender documents. These were after advertisement in the official journal sent to a number of companies in June. The tendering period, which was completed in September, was followed by an extensive evaluation and negotiation period. This part of the KBS-3H project is partly financed by the EC-project Esdred "Engineering studies & demonstration of repository designs".

During the year SKB has continued the research regarding the buffer design, work has been focused on two design alternatives which were both described in internal PM's by the end of August. In December SKB decided to continue with the design alternative called "tight distance block" as the reference design.

During 2004 Posiva, who is responsible for the KBS-3H Safety Case, has continued investigations regarding the KBS-3H critical issues with respect to long term safety and also started the preparations for a safety case. The iron bentonite interaction has been studied and will be reported during 2005. Nagra has carried out THMC analyses in order to investigate the influence of the super container. Posiva has also initiated the work with the KBS-3H Safety Case planning report.

Scope of work for 2005

The KBS-3H project will continue with the following: demonstration of the concept, technical development and safety case.

Next year will start with the completion of excavation at Äspö HRL. After that further preparations for the next step in the demonstration (construction of a concrete floor) will take place. The low-pH shotcrete plug will be installed in the short hole during the second part of the year.

SKB will follow the detailed design and manufacturing of the deposition equipment throughout the year and some small pieces of equipment will also be delivered. The deposition machine itself will however be delivered next year.

Research regarding the buffer design will continue during next year with a number of experiments in different scale. The objective is to further verify the limitations of the system with respect to water inflow, pressure increase rate but also to give input to the design of the so called fixing ring which is a necessary part of the tight distance block design.

Preparations for the KBS-3H Safety Case will continue with completion of a Planning report. In addition, work to resolve the critical issues highlighted in the review of the preliminary safety assessment will continue.

2.8 Large Scale Gas Injection Test

Background

The aim of the large scale gas injection test (Lasgit) is to perform a large scale gas injection test in a full-scale KBS-3 deposition hole.

The bentonite buffer is an important barrier in the KBS-3 system. The key purpose of the buffer is to serve as a diffusion barrier between the canister and the groundwater in the rock. An important performance requirement on the buffer material is to not cause any harm to the other barriers. Gas build up from corrosion of the iron insert could potentially affect the buffer performance in three ways:

- Permanent pathways in the buffer could form at gas breakthrough. This could potentially lead to a loss of the diffusion barrier.
- If the buffer does not let the gas through, the pressure could lead to mechanical damage of the other barriers.
- The gas could de-hydrate the buffer.

The small scale experiments that have been performed over the last ten years indicate that effects described above do not occur. The current understanding of the gas transport process through compacted bentonite, indicates that the buffer would open for gas passage before any harmful pressures are reached. However, there are still large uncertainties around the gas migration process and all these findings have to be verified in a large scale experiment. The project will be conducted as a SKB and Posiva joint project.

Objectives

The objective of this experimental programme is to undertake a large-scale gas injection test to provide data to improve process understanding and test/validate modelling approaches which might be used in performance assessment. Specific objectives are:

- Perform and interpret a large scale gas injection test based on the KBS-3 repository design concept.
- Examine issues relating to up-scaling and its effect on gas movement and buffer performance.
- Provide additional information on the process of gas migration.
- Provide high-quality test data to test/validate modelling approaches.

The Lasgit project will end after two years of gas testing. At that stage a decision will be taken whether to dismantle the experiment or to continue with testing in a new project.

Experimental concept

The experiment will be performed in a bored full-size deposition hole at Äspö HRL. A full scale canister, without heaters, and a surrounding bentonite buffer is installed, see Figure 2-7. Water will be artificially supplied to the buffer and the gas injection tests will start when the buffer is fully saturated. The test is divided into three phases: installation phase, hydration phase, and gas injection phase.

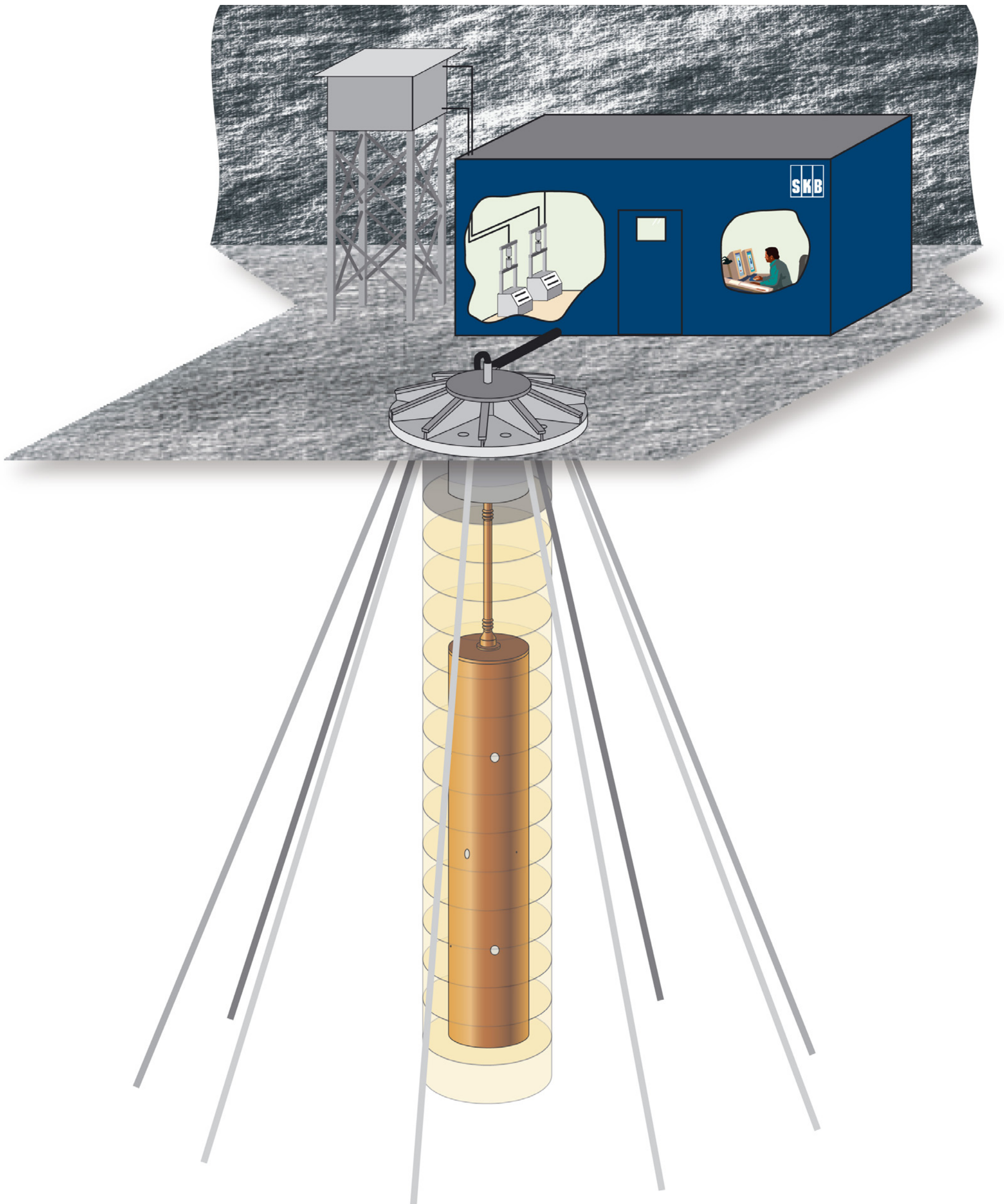

Figure 2-7 *Illustration of experimental set-up of the Large Scale Injection Test.*

The *installation phase* consists of the design, construction and emplacement of the experiment and it includes mainly:

- Characterisation of the deposition hole, hydraulic measurements and instrumentation of the wall.
- Development of a technique for the manufacturing of buffer blocks with exceptional high water content. Manufacturing of a set of blocks. Preliminary modelling of the hydration of the buffer.
- Preparation of a full-scale canister with gas injection equipment. Design and construction of a lid, which will seal the deposition hole and simulate the tunnel backfill.
- Design and construction of a gas injection and measurement field laboratory. Installation and testing of the equipment before deposition of the canister.
- Installation of canister, buffer, lid, and sealing of the deposition hole.

The aim with the *hydration phase* is to fully saturate and equilibrate the buffer. This will be done by:

- Water uptake from natural groundwater in the deposition hole.
- Artificial saturation by water injection through the gas injection ports mounted on the surface of the canister.
- Artificial saturation by water injection through mats located at a number of positions within the buffer and around the walls of the emplacement borehole.

The saturation will be monitored by measuring pore pressure, total pressure and suction at both the buffer/rock interface and key locations within individual clay blocks.

The hydration phase will provide an additional set of data for (T)HM modelling of water uptake in a bentonite buffer. However, no such modelling is planned within the project at this stage.

The *gas injection phase* starts when the buffer is considered to be fully saturated. Gas injection might be accomplished using a combination of controlled flow rate and constant pressure test stages.

Present status

The canister is manufactured and has been delivered and placed on the -420 level in Äspö HRL. The leak-testing of the canister has been going very well with all 12 injection filters performing as expected and appearing leak-tight. The replacement pressure transducers are also all giving very good, stable readings and we no longer seem to be having stability problems with the Geokon software. The leak-testing are more or less finalised and preparations are ongoing for the installation in the deposition hole e.g. a new water supply has been installed, load cells for lid has been installed and tested, and the reinforcement for the concrete plug is prepared.

In the project problems with instrumentation and pumps are now solved but they have caused delays in the project.

Scope of work for 2005

The deposition of buffer and canister is planned to take place in January and thereby is the installation phase finalised. The goal is that the hydration phase with artificial saturation of the buffer by water injection will start in February. A programme for de-airing of voids has been worked out and during the hydration phase the saturation of the buffer will be monitored. The water injection will continue until the buffer is fully saturated, which is foreseen to take about two years and hereafter the gas injection phase will be initiated.

2.9 Temperature Buffer Test

Background

The aim of the Temperature Buffer Test (TBT) is to evaluate the benefits of extending the current understanding of the behaviour of bentonite buffer to include high temperatures (above 100°C). The French organisation Andra is running the test in Äspö HRL in co-operation with SKB.

The scientific background to the project relies on results from large-scale field tests on engineered barrier systems carried out in underground laboratories: the Buffer Mass Test (Stripa), the Buffer/Container Experiment (URL in Canada), Febex (Grimsel Test Site), Canister Retrieval Test and Prototype Repository (Äspö HRL).

Objectives

The Temperature Buffer Test aims at improving the current understanding of the thermo-hydro-mechanical behaviour of clay buffers at temperatures around and above 100°C during the water saturation transient, in order to be able to model this behaviour.

Experimental concept

TBT is located in the same test area as the Canister Retrieval Test (CRT) at the -420 m level. Two identical heater probes, each 3 m long and 0.6 m in diameter, are stacked in a vertical 1.8 m diameter deposition hole. The principle design of the test and the experimental set-up are shown in Figure 2-8.

Two buffer arrangements are being investigated:

- One probe is surrounded by bentonite in the usual way, allowing the temperature of the bentonite to exceed 100°C locally,
- The other probe has a ring of sand between the probe and the bentonite, as thermal protection for the bentonite, the temperature of which is kept below 100°C.

The principle of the TBT test is to observe, understand and model the behaviour of the deposition hole components, starting from an initial unsaturated state under thermal transient and ending with a final saturated state with a stable heat gradient.

Heat transfer comes into play from the start of the test, possibly redistributing water being present in the buffers, with partial desaturation of very hot zones (>100°C). Inflow of water then causes saturation and consequent swelling of the bentonite.

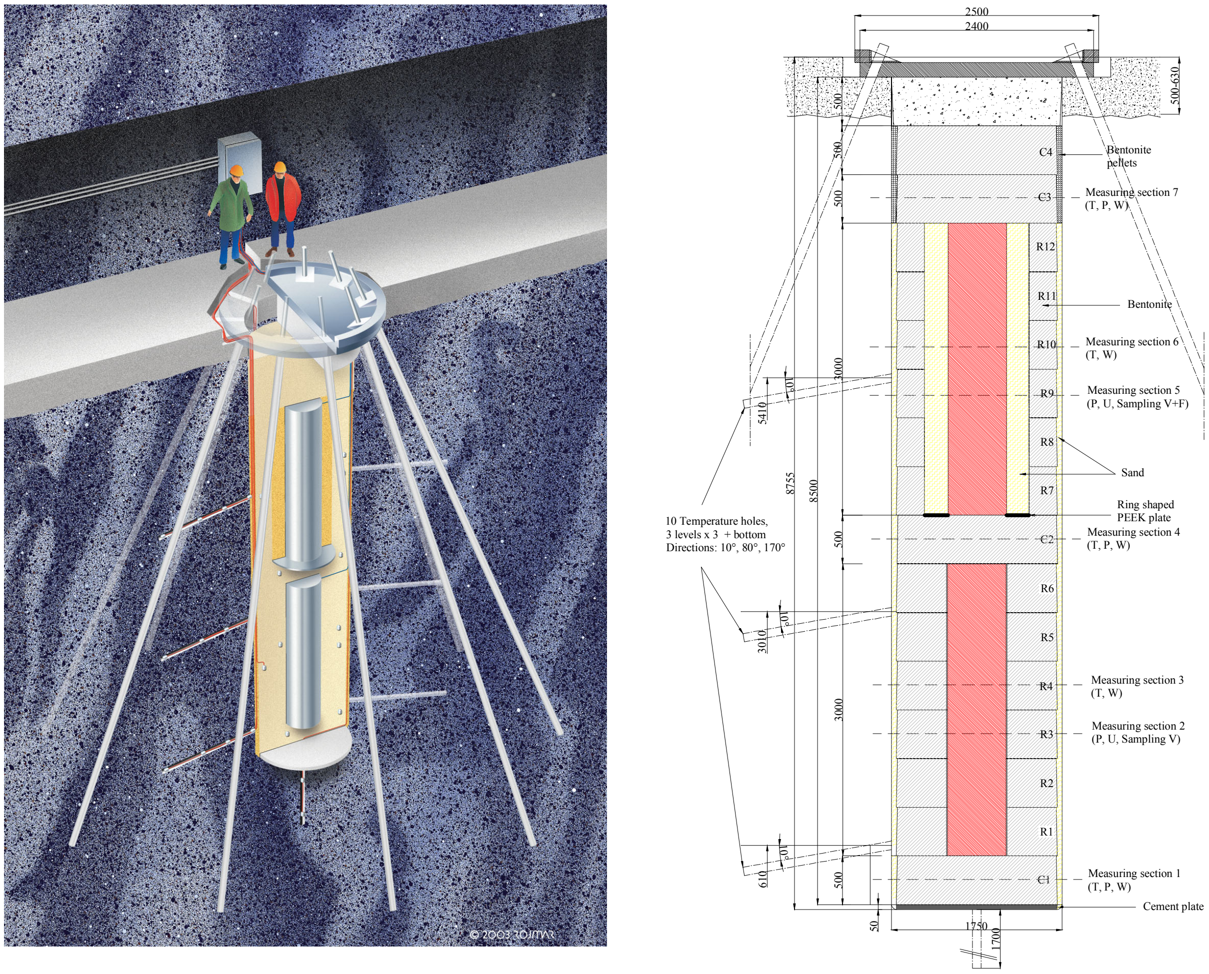

***Figure 2-8** Principle design and experimental set-up of the Temperature Buffer Test.*

The effects of a bentonite desaturation/resaturation cycle on the confinement properties are not well known. An open question which TBT is designed to answer is whether the mechanical effects of desaturation (cracking of the material) are reversible.

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

Present status

During 2002, TBT design modelling, procurement of instruments, fabrication of bentonite blocks were carried out by Clay Technology and heater probes built by Aitemin.

Early 2003, the experiment was installed in Äspö HRL. The operation phase started late March 2003. Artificial water pressure and heater power have been set according to plan. Monitoring and sampling of experimental data are continuously ongoing during the operation phase. A data link to Andra's head office in France has been established.

The initial thermal shock has produced its effect showing local desaturation of the bentonite in place where temperature exceeded 100°C. No fluid pressure was measured in the sand of the composite buffer.

A modelling group, formed with Swedish, Spanish and French teams, issued a preliminary predictive modelling report mid 2003. The predictions were compared with the first experimental results and presented in November 2003 at Sitges /Hökmark, 2003/.

Two modelling tasks have been conducted during 2004. The first one was predictive, and addressed the effect of increasing the output from the upper heater. From the results it was decided not to change the heat load. The second one emphasised on the evaluation of the development of stresses in Ring 9 around the upper heater, see Figure 2-8.

The function of the sand filter has been investigated and modified in April and October 2004.

Scope of work for 2005

The operation phase continues and the experiment should be left without changes in boundary conditions in order to be reasonably confident about the conditions in the barriers at the time of dismantling and final interpretation.

A new modelling task will be defined in the beginning of 2005. This will concentrate on a new mock-up test, conducted by CEA, designed to mimic the conditions at the interior of the buffer around the lower heater. Comparison and evaluation of model and test results is scheduled for September 2005.

2.10 Rock Shear Experiment

Background

Rock displacement is one out of a few processes, which can seriously damage a canister, and constitutes thereby a threat against the integrity of a deep repository. The effect of the process is thus of importance to analyse and describe in an accurate way.

Fractures and fracture systems are natural components in granitic rock, and can not be avoided totally in the repository areas. Deposition holes will be bored through such features and the issue for the final decision on accepting or rejecting a bored deposition hole will among other things be based on the properties of the fractures the deposition hole is crossing. One of these properties is the possible displacement along the fracture caused by seismic events. The buffer in KBS-3 is assumed to protect the canister from loosing its integrity for instant displacements up to 100 mm. The forces on the canister at such a major displacement have been modelled as well as analysed based on experiments in laboratory scale (small up to 1:10 scale). The results are, however, proposed to be verified in larger scale than 1:10, if a significantly more accurate criterion shall be feasible to apply in the accepting/rejecting process.

Objectives

The project aims at observing the forces that act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole at canister height. Such a displacement is considered to be caused by an earthquake, and the test set-up needs to provide a shearing motion along the fracture that is equal to an expected shearing motion.

Experimental concept

The test set-up is planned to use the site of the Äspö Pillar Stability Experiment when the rock mechanics test there has been completed. Two full scale deposition holes then exist with a rock pillar of one metre in between. Figure 2-9 illustrates the present, schematic idea for a test set-up. The left deposition hole is used for the buffer and canister, while the right deposition hole is used for the shearing equipment. Half of the rock between the holes is removed (is partly fractured after the Apse test) and replaced by concrete that has a plane for movements. Half of the upper part of the left hand hole is enlarged by sawing away about 200 mm in order to make room for the shear displacement. This upper part, which shall be sheared, is surrounded by a steel pipe, which is attached to the steel structure and is mobile in the direction of the shearing. The hole is plugged by a combined steel and concrete structure, which is anchored to the rock by a steel beam or by cable bolts as in Canister Retrieval Test and Temperature Buffer Test.

The shearing may not be done before the buffer has saturated, but this time can be reached after about two years by using highly saturated bentonite blocks, 95–98% saturation, and lining the hole with permeable mats for artificial water supply. Planned shearing speed is 0.1 m/s. For this shearing speed pistons may be used as shown in Figure 2-9.

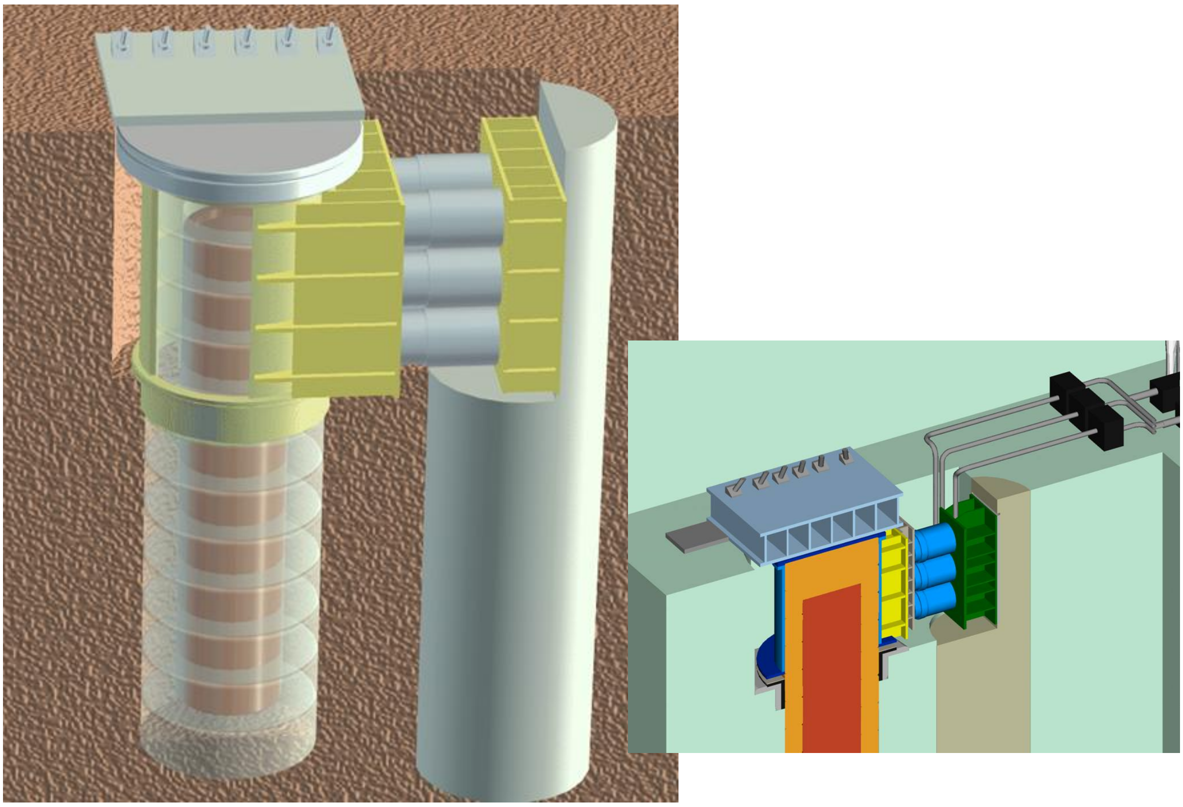

Figure 2-9 *Schematic view of a possible test set-up for verification of the stress and strain a canister may exhibit during an instant shearing of 100-200 mm.*

Present status

The feasibility study has been running since summer 2004 and is finished. The results are compiled in a report, which also includes evaluation of the work, recommendations and cost estimates. A preliminary design based on the predicted test evolution has been made. The equipment for attaining the required force and shear rate has been drawn up.

The main conclusion of the feasibility study is that the test could be performed with the required demands.

Scope of work for 2005

The feasibility study will be reviewed in the beginning of 2005. If the decision, after review of the study, is to carry out the test the plan is to start the preparations in spring 2005 and have the entire installation finished at the end of the year.

2.11 Learning from experiences

Background

Several large-scale experiments have during the years been installed in Äspö HRL and methods and machines used have provided experiences 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.

In this project these experiences are documented and analysed with respect to possible improvements as well as acceptable water inflows.

Objectives

The prime objective is to answer questions and provide information to the work on the SKB´s applications for an Encapsulation Plant in 2006 and a Deep Repository in 2008.

The aims are to:

- Compile results from more than ten years of performed engineering experiments in Äspö HRL.
- Compile and evaluate experiences from methods for emplacement of buffer and canisters, backfilling of tunnels, and estimate acceptable water inflows for the applied methods.

Present status

A draft list of questions to be answered, as a basis for the applications, has been compiled. A report on experiences from operation of the Äspö HRL is in progress.

Scope of work for 2005

The questions that will be addressed during 2005 in the first place are the importance of the ground water regime, like water inflow to tunnels and water supply to buffer and backfill. The strategy is to formulate the question in view of how the results are going to be utilised and then provide facts and experience on the matter from the work in Stripa, Äspö HRL, as well as from SKB’s co-operation in other URL’s when applicable. A report on groundwater inflow into deposition holes (KBS-3V) and seepage impact on backfill properties is planned to be completed in 2005.

2.12 In situ corrosion testing of miniature canisters

Background

The development inside a copper canister with a cast iron insert after failure is of great importance for the release of radionuclides from the canister. After failure of the outer copper shell, the course of the subsequent corrosion in the gap between the copper shell and the cast iron insert will determine the possible scenarios for radionuclide release from the canister. This has been studied experimentally and been modelled. The corrosion will take place under reducing, oxygen free conditions and such conditions are very difficult to create and maintain for longer periods of time in the laboratory. *In situ* experiments at Äspö HRL would be invaluable for understanding the development inside the canister after initial penetration of the outer copper shell.

Objectives

The objective of the project is to obtain a better understanding of the corrosion processes inside a failed canister. The results of the experiment will be used to support process descriptions and safety analyses.

Experimental concept

Miniature copper canisters, with a diameter of 15 cm, will be emplaced in boreholes, with a diameter of 30 cm. The canisters will be exposed to natural reducing groundwater during several years and the experiment will be monitored.

Present status

The planning of the project was finalised during 2004 and the miniature canisters have been designed and manufactured.

Scope of work for 2005

The experiment will be installed and initiated during this year. The activities comprise e.g. boring of small deposition holes (at tunnel length 3354) and emplacement of canister and installation of instrumentation. The first phase of the experiment is planned to run during five years.

2.13 Task Force on Engineered Barrier Systems

Background

The Task Force on Engineered Barrier Systems (EBS) was in 2000 decided to focus on the water saturation process in buffer, backfill and rock. Since the water saturation process also was a part of the modelling work in the Prototype Repository project, the work was transferred to the Prototype Repository project, and the Task Force was put on a stand-by position. As the European Commission funding of the Prototype Repository project ceased in February 2004 it was judged most convenient to activate the Task Force on EBS and continue the modelling work in the Prototype Repository project within this frame, where also modelling work on all other experiments can be conducted. One possibility is also to incorporate the modelling work on EBS experiments carried out in the Grimsel Test Site (GTS) in Switzerland.

Present status

The Task Force was established in 2004 and a kick-off meeting was held on October 28th. Two tasks were chosen for the Task Force work, namely:

Task 1 THM processes in buffer materials.

Task 2 Gas migration in buffer material.

The objectives of the Tasks are to:

- Verify the capability to model THM and gas migration processes in unsaturated as well as saturated bentonite buffer.
- Refine codes that provide more accurate predictions in relation to the experimental data.
- Develop the codes to 3D standard (long-term objective).

Focus in the work is to use the models for predicting the state-of-conditions during specified milestones in the evolution of a repository, in the first place:

- At saturation.
- After thermal pulse.
- At penetration of canister.
- At the time when gas is anticipated to migrate through the buffer.

Participating organisations from the start are besides SKB: Andra (France), BMWA (Germany), Criepi (Japan), Enresa (Spain), Nagra (Switzerland), Posiva (Finland), OPG (Canada) and Rawra (Czech Republic).

Scope of work for 2005

The Task Force on EBS starts with a first phase that comprises four years. This phase addresses two tasks, THM processes and gas migration in buffer material, and ends with a State-of-the-art report. The work will take into account the interaction between the buffer and backfill barriers and the host rock. Experimental data are in both tasks taken from small scale laboratory experiments as well as large scale field experiments, which will be selected by the Task Force in the course of the work, when needed.

During year 2005 will the parameters needed be defined and a common database compiled with these data. Means of quality assuring the data in the database have to be developed. Tests/experiments to be used for benchmarking in the initial calculations are selected, and the calculations are run in such a way that the results from the different codes can be compared. The results of this benchmarking are analysed and the capability as well as the prerequisite for further development of the codes are evaluated. Milestone 1 is expected to be reached during 2005 comprising comments on how well developed each participating code is, are fundamentals missing, and what potential does each code have to meet the intended result.

3 Geo-science

3.1 General

Geo-scientific research is a part of the activities at Äspö HRL as a complement and an extension of the stage goals 3 and 4. Studies are performed in laboratory and field experiments as well as by modelling work. The major aims are to:

- Establish and maintain geo-scientific models of the Äspö HRL rock mass.
- Establish and develop the understanding of the Äspö HRL rock mass material properties as well as the knowledge of measurements that can be used in site investigations.
- Determine the rock mechanics characteristics at potential repository depths at candidate sites.
- Develop methods for numerical modelling of stress and strain evolution, and methods for *in situ* stress measurements.

3.2 Geological mapping and modelling

Background and objectives

A new project concerning geological mapping techniques is going to be performed beside the regular mapping and modelling tasks, *i.e.* mapping of the deposition holes drilled at the KBS-3H site and modelling of the rock volume. This coming project aims at performing a feasibility study for the future plan to identify or develop a new method for underground geological mapping to be used in the construction of a future deep repository. The major reasons for this project are aspects on objectivity of the data collected, traceability of the mappings performed, saving of time required for mapping and data treatment and precision in mapping. At this initial feasibility study-stage, the major objective is to establish a knowledge base concerning existing and possible future methods and techniques to be used for a mapping system suitable for SKB requirements.

Present status

The project name Rock Characterisation System (Rocs) has been accepted and the project organisation has been established. Contact has been established with Posiva as project co-operator and with European experts as participators in a scientific committee.

Scope of work for 2005

A feasibility study in the Rocs-project will be performed. At the end of the year, the evaluation stage of the project may possibly be started, depending on the results from the feasibility study.

3.3 Heat transport

Background

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

Objectives

The aim is to analyse the thermal properties of the rock in different scales to decrease the uncertainties in the estimates of the temperature field in a repository. Less uncertain estimates of the temperature field make it possible to optimise the distance between canisters in the repository layout. The work includes inverse modelling of thermal properties, measurements of thermal properties of the rock at different scales and examination of the distribution of thermal conductivities from density loggings.

Present status

The heat evolution in the Prototype Repository has been used to analyse thermal properties of the rock and to verify prognosis of the temperature evolution. Data has been monitored since September 2001 and are used in a finite difference model to calculate thermal properties of the rock by inverse modelling. The inverse modelling is made in different distances and different directions from the canisters. The scale dependence is further analysed by measurements of thermal properties and thermal conductivity calculations from density loggings. Uncertainties in existing data and the utility of continued data collection will be analysed.

Scope of work for 2005

Uncertainties and scale dependencies in data on thermal rock properties are going to be evaluated and reported during the summer of 2005.

3.4 Inflow predictions

Background

SKB has conducted a number of large field tests where predictions of inflow into tunnels or depositions holes have been a component: the Site Characterisation and Validation Test in Stripa /Olsson, 1992/, the Prototype Repository /Rhén and Forsmark, 2001/, and the Groundwater Degassing and Two-Phase Flow experiments in Äspö HRL /Jarsjö *et al.*, 2001/. The results from these tests show that when going from a borehole 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:

- Evaluation of experimental results from 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 boreholes.
- 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 boreholes.
- To identify the different mechanisms determining the inflow, and quantify their importance.

Present status

So far, extensive numerical analyses using the three-dimensional distinct element code 3DEC /Itasca, 2003/ have been conducted. The aim has been to improve the knowledge about the effect of the effective stress redistribution, caused by excavation, on the fracture inflow into deposition holes considering single-phase flow /Mas Ivars, 2004/. The objectives of this numerical study are:

- To conduct a number of numerical simulations in order to increase the understanding of the coupled hydro-mechanical aspects of inflow into deposition holes, and thereby improve the possibilities to predict the inflow.
- To demonstrate that results of numerical analyses can be used in the planning of full-scale field tests of inflow at Äspö HRL.

The results from the numerical study showed that:

- It is of critical importance to consider the hydro-mechanical coupling in simulations of the total inflow into excavations.
- The most relevant parameters for the inflow, within the uncertainty ranges considered in this study, were: the fracture shear and normal stiffness, friction angle, dilation angle and magnitude of minimum horizontal stress, σ_{zz}. Of prime importance is also the initial and residual hydraulic aperture of the fractures since the flow along the fractures is assumed to follow the “cubic law”.

- The inflow into excavations can be largely underestimated when a linear fracture deformation model is used.
- Stress-permeability coupling can be considered as one of the causes for the less than expected inflow into large diameter holes (Figure 3-1).

Besides the numerical study, a field experiment was performed in October 2004 at the Apse site. The field experiment, the hydro-mechanical (HM) acquisition project, was done due to the fact that when carrying out the Äspö Pillar Stability Experiment two highly conductive sub-vertical fractures intersected one of the deposition holes and the inflow into the excavation reached values of around 30 l/min. In order to extract the pillar for the next phase of the Pillar Stability Experiment project, it had to be de-stressed previously. The de-stressing of the pillar was carried out by drilling a semicircular array of boreholes. This caused a number of coupled hydro-mechanical effects. The effective normal stress acting on the conductive fractures was expected to drop and the aperture to increase with the consequent increase in inflow. Besides, the decrease in normal stress would cause a decrease in the fracture shear strength, which could lead to slip and dilation of the fracture.

The aim of the HM data acquisition project at the Apse site was to monitor the changes (normal and shear displacement) in the conductive fractures, and the evolution of the inflow into the excavation versus time, due to the stress drop. The data gathered is expected to enhance the understanding about the hydro-mechanical behaviour of fractured rocks, with special emphasis on processes influencing on groundwater flow through single conductive fractures and inflow into excavations. Data regarding pore pressure changes was also gathered in other locations expected to be influenced by the de-stressing of the pillar, making use of the existing HMS monitoring system.

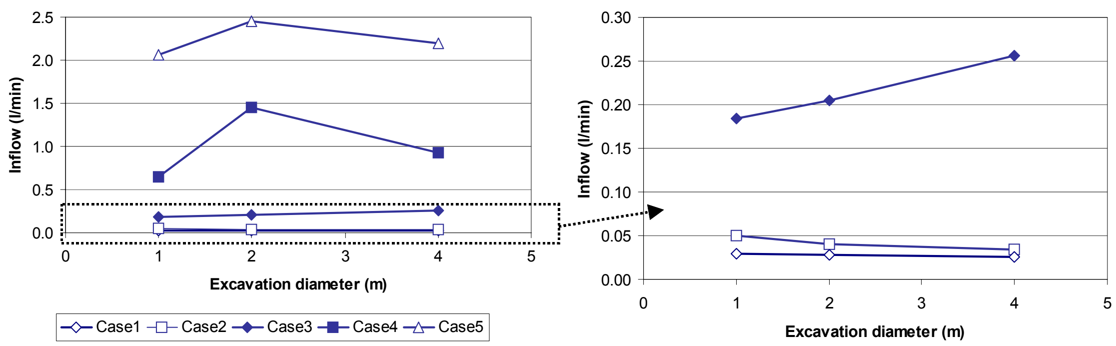

Figure 3-1 *Measured inflow versus excavation diameter for different fracture cases according to Table 3-1.*

Table 3-1 Fracture parameters for the different excavation diameter model cases presented in Figure 3-1.

Case	Normal stiffness (GPa/m)	Shear stiffness (GPa/m)	Friction angle (degrees)	Dilation angle (degrees)	Initial hydraulic aperture (µm)	Residual hydraulic aperture (µm)	Maximum hydraulic aperture (µm)
Case 1	20	12	30	5	30	5	60
Case 2	61.5	35.5	30	5	30	5	60
Case 3	180	105	30	5	30	5	60
Case 4	360	210	30	5	30	5	60
Case 5	700	410	30	5	30	5	60

Scope of work for 2005

A report will be written about the HM data acquisition project at the Apse site and further theoretical, experimental and numerical analyses of the inflow into excavations will be conducted.

3.5 Seismic influence on the groundwater system

Background and objectives

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 in a database.

The data in the database are assumed to bear witness of different seismic activities in Sweden but also abroad, dependent on the magnitude of the event, as well as the position of the epicentre. 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 analyses. A special computer code is under development that may run and compare the HMS database with other databases, like the SKB site investigation database (Sicada) or the national seismological database. For example, the earthquake in the Indian Ocean on the 26th of December was registered by the HMS system after 23 minutes.

Scope of work for 2005

The software development for cross comparison of different databases will be finalised. The impact of earthquakes in Sweden and abroad and the effects of blasts in Äspö HRL will be analysed and documented.

3.6 Rock Mechanics

Rock Mechanic studies are performed with the aims to increase the understanding of the mechanical properties of the rock but also to recommend methods for measurements and analyses. This is done by laboratory experiments and modelling at different scales and comprises:

- Natural conditions and dynamic processes in natural rock.
- Influences of mechanical, thermal, and hydraulic processes in the near-field rock including effects of the backfill.

During 2005 work will be performed within the following projects:

- Coupled processes in rock including dynamic processes at natural conditions.
- Stress measurements and stress interpretation methods (see Section 3.6.1).
- Understanding of variability of rock under different load conditions (see Section 3.6.2).
- Methods to calculate stability of underground openings and large scale failures (dynamic effects of earth quakes).
- Mechanical processes in the interface between rock and backfill.
- Äspö Pillar Stability Experiment (see Section 3.7).

All SKB's work on rock mechanics is directed from the staff of Repository Technology having its base at Äspö.

3.6.1 Stress measurements and stress interpretation methods

Background

State of stress has a significant impact on the possibility for tunnelling at large depth, such as the planned deep repository. Both improvements of exciting measurement methods, as well as alternative methods for evaluation of the state of stress have strategic importance in tunnelling design and tunnelling works at large depth. Activities are planned within both these fields. The project is a joint SKB and Posiva project.

Objectives

The main objectives of the study are to:

- Develop further possibilities for so called transient strain analysis of stress measurements by over coring for anisotropic conditions.
- Develop the overall strategies for back analyse of state of stress based on convergence measurements during tunnelling, and estimate the uncertainty bounds.

Present status

Method for transient strain analyse of stress measurements by an over-coring method for isotropic conditions has been developed and published. The method is used as a standard procedure in the ongoing site investigations in Sweden. A project plan for the possibility to also do transient strain analyse on anisotropic rock was agreed upon between Posiva and SKB late 2004.

Positive experiences from back analyse of stresses based on convergence measurements was gained during tunnelling for the Apse project in 2003 /Staub *et al*., 2004/. The applied method covers a much larger volume than any borehole method, and seems to be reliable. However, it is also known that a significant deformation has occurred already when the installation for the convergence measurements can be done.

Scope of work for 2005

The development of methods for transient strain analyse is planned to be completed in 2005. The results will be published in Posiva reports and an International Journal. In addition, a literature review and scoping calculations comprising simple 3D elastic modelling will be carried out and reported.

3.6.2 Understanding of variability of rock under different load conditions

Background

The strength of both intact rock and a fractured rock mass depends on the material properties, as well as the stress path a volume of rock is exposed to. The stage of knowledge in rock stability, to large extent based on the Zedex experiments in Äspö, were published in 2001 /Martin *et al.,* 2001/.

Objectives

The main objectives of this project are to:

- Follow the development of knowledge within rock mechanics.
- Increase the understanding of the bearing capacity in the rock mass surrounding a tunnel exposed to different heavy load conditions e.g. thermal load during a long time period.

Present status and scope of work for 2005

The present knowledge and results from the Zedex experiment in Äspö HRL is reported in Martin *et al.* /2001/.

The main activities planned for 2005 are:

- Periodic literature reviews of possible new knowledge.
- Review of parameters used for calculation in fracture mechanics.
- Experimental studies in laboratory on the long term strength, primarily as support for a PhD student in rock mechanics at the University of Luleå.

3.7 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 spacing of the canister holes gives an impact on the optimisation of the repository design.

A Pillar Stability Experiment was 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 in the transitional zone.

Objectives

The Äspö 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.

Experimental concept

To achieve the objectives a new drift was excavated in Äspö HRL to ensure that the experiment is carried out in a rock mass with a virgin stress field. In the new drift a vertical pillar is constructed in the floor between two large boreholes, each with a diameter of 1.8 m. The pillar is designed in such a way that spalling will occur in the walls of the boreholes when the pillar is heated.

The two large vertical holes were drilled in the floor of the tunnel so that the distance between the holes is one metre. To simulate confining pressure in the backfill (0.7 MPa), one of the holes was subjected to an internal water pressure via a liner. Convergence measurements, linear variable displacement transducers (LVDT), thermistors and an acoustic emission system were used to monitor the experiment. The experiment drift has a rounded floor to concentrate the stresses in the centre of the drift. The finished drift is shown in Figure 3-2.

Figure 3-2 *The Apse experimental drift shortly after the excavation.*

Present status

The experiment was carried out as planned during 2004. All instruments where installed and the heaters turned on which quickly initiated spalling in the pillar wall. The spalling progressed about 5 m down the hole. Excellent monitoring results where collected and we could for example clearly correlate displacements with acoustic emission events. When a steady state in the pillar was reached in the end of the heating period the confinement was lowered in intervals. The effect of the confinement was obvious. It can preliminary be concluded that very little confinement is needed to suppress the spalling process.

The pillar wall was laser scanned after removal of all equipment in the hole. The slabs formed during the spalling was removed and stored for further documentation. After removal of the slabs the pillar wall was laser scanned again to get the best possible survey of the final geometry. Figure 3-3 shows two photographs from the pillar wall taken during the heating phase and during the removal of the slabs.

Figure 3-3   *Left: the spalling notch propagating downwards and just passing one of the instrument levels where displacement measurements are done by LVDT transducers. Right: Photograph taken from the bottom of the hole and upwards during the removal of the slabs. The different layers of slabs formed are clearly visible as well as the quite smooth surface of the notch that remains after removal of all the slabs.*

In late 2004 and early 2005 the pillar was sawn into five large blocks and taken up to the surface for further analysis. The sawing was done with a wire saw to avoid jamming of the wire due to the high stresses in the pillar it has to be de-stressed. The de-stressing was preformed by drilling an arched vertical slot outside the pillar area perpendicular to the direction of the major principal stress. Extensive numerical modelling was made to optimise the design of the slot. It was thought unavoidable to induce some additional spalling in the pillar wall during the de-stressing. This has though given an excellent opportunity to further calibrate the numerical tools used. Figure 3-4 is a photograph taken after removal of the five blocks.

The reporting of the field part of the experiment including all monitored results is progressing and is scheduled to be printed in early 2005 /Andersson and Eng, 2005; Haycox *et al.*, 2005/. Some preliminary results are presented in /Andersson, 2005/. The major references for the project works this far are /Andersson, 2003; Andersson *et al.*, 2003a; 2003b; Andersson e*t al.*, 2004a; Fredriksson e*t al.*, 2004; Rinne e*t al.*, 2004; Staub e*t al.*, 2004; Wanne e*t al.*, 2004/.

Figure 3-4 *Photograph of the experiment site after removal of the five one metre high pillar blocks between the two large holes.*

Scope of work for 2005

During 2005 analyses of the monitored data during the heating phase and the data achieved during the post characterisation of the pillar blocks removed from the drift will be done. An integrated analysis combining data on temperature, deformations, acoustic emissions, and the data from the post characterisation will be performed.

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, see Figure 4-1.

The experiments are related to the rock, its properties, and *in situ* environmental conditions, and the programme includes projects with the aim to evaluate the usefulness and reliability of different conceptual and numerical models and to develop and test methods for determination of parameters required as input to the models.

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.

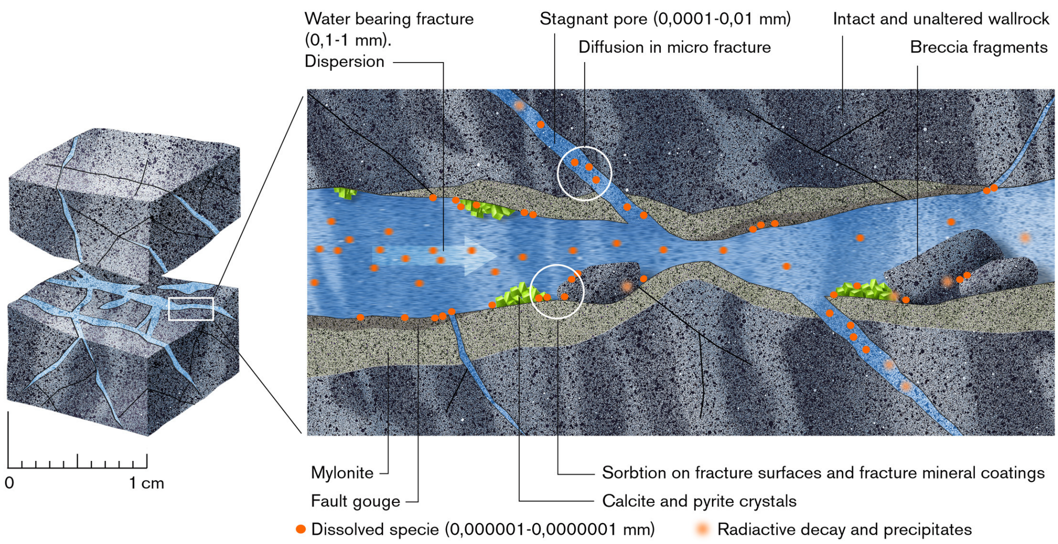

Figure 4-1 *Illustration of processes that influence migration of species along a natural rock fracture.*

The ongoing experiments and projects within the Natural Barriers at Äspö HRL 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.
- Padamot (Palaeohydrogeological Data Analysis and Model Testing).
- Fe-oxides in fractures.

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 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. 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.

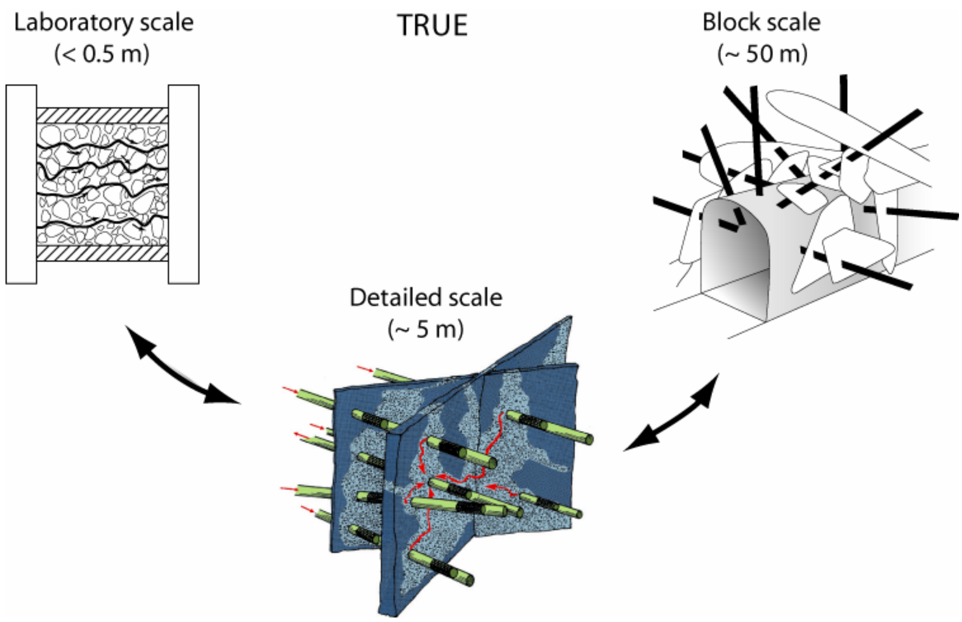

***Figure 4-2** Schematic representation of transport scales addressed in the True programme.*

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. An 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 4-2. A test of the integration and modelling of data from different length scales and assessment of effects of longer time perspectives, partly based on True experimental results, is made as part of Task 6 in the Task Force on Modelling of Groundwater Flow and Transport of Solutes, see Section 4.8.

4.2.1 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 Complementary modelling work in support of BS2 *in situ* tests. Continuation of the True Block Scale (phase C) pumping and sampling including employment of developed enrichment techniques to lower detection limits.

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 without developed wall rock alteration and fault gouge signatures.

Present status

The year 2004 started with a technical committee meeting in Oskarshamn where results of the performed pre-tests (CPT-1 through CPT-4) were reviewed /Andersson *et al*., 2004b/. The results showed that opportunities exited for successful high mass recovery tracer experiments using tracer injection in KI0023B:P2 and KI0025F02:R3 (Structure #19) and KI0025F02:R2 (Background fracture #1, BG#1, formerly Structure #25), BG#1 is in hydraulic contact with Structure #19. Pumping was conducted in KI0025F03:R3 (Structure #19) at Q=2-8 l/min. Injections during CPT-4a and CPT-4b were made using a passive injection. However, it was identified that radioactive sorbing tracer should be administered using a forced injection. This partly due to consideration of possible exposure of the technical staff to radiation during the experiment. Although the general experience is that the mass recovery improves when using forced injection it was decided to rerun the three selected tests using forced injection. The results of the ensuing CPT-4c singled out sections KI0025F02:R3 (#19) and KI0025F02:R2 (BG#1) for the planned tests with radioactive sorbing tracers. The BS2b sorbing tests were commenced March 31 with injection as decaying pulses with simultaneous injection of water (unlabelled formation water) creating a slight excess pressure and thus, a weak dipole flow field resulting in injection flow rates of 5 and 2 ml/min, respectively. Pumping in KI0025F03:R3 was conducted at Q=2.5 l/min. The tracers used are indicted in Table 4-1. The official termination of the test, to enable timely evaluation and comparison with model predictions, was set to October 8, 2004, resulting in more than 6 months of pumping.

At a technical committee meeting in Paris early June, the premises for numerical model predictions were reviewed. This included detailed descriptions of the structures involved and results from verifying laboratory sorption experiments on fault gouge and altered wall rock materials. The latter experiments verified the earlier calculated K_d-values for the latter material as reported by Andersson *et al*. /2002/ and Derschowitz *et al.* /2003/. Similarly, early qualitative results in terms of imagery from epoxy resin injections in fault rock zones provide indirect support for conceptual models developed e.g. Andersson *et al*. /2002/.

Model predictions were conducted by four modelling teams, representing different modelling methodologies and model codes, all previously employed in the True Block Scale project in various capacities. The modelling teams included Posiva VTT, JNC-Golder, Andra-Itasca and SKB-KTH/WRE. The results of the model predictions were reviewed at a technical committee meeting in Stockholm early November 2004, including comparisons with experimental results. Breakthrough has been noted for all injected tracers including Cs-137 (injection in Structure #19) and Mn-54 (injection in BG#1). It was noted that predictions for injection in Structure #19 overall were good, with good mapping of the shape of the breakthrough curves, although the magnitude was not captured in full. An example comparison for Cs-137 is given in Figure 4-3. The predictions for BG#1 were not equally good, although predictions even for Mn-54 were surprisingly accurate.

Scope of work for 2005

In conjunction with the technical committee meeting in November 2004, detailed plans were drawn up for the ensuing evaluation and reporting of True Block Scale Continuation. Individual evaluation reports will be produced by each modelling group. These will be merged to a common final report. This report will be presented in conjunction with a review seminar in mid September and a final report is due by the end of September 2005.

Table 4-1 Tracers used during the True Block Scale Continuation BS2 tests with sorbing tracers.

Tracer Class	Fast flow path (F02:R3 – F03:R3)	Slow flow path (F02:R2 – F03:R3)
Non-sorbing	$^{131}I^{-}$	HTO
Non-sorbing metal complex	^{160}Tb-DTPA	^{155}Eu-DTPA
Weakly sorbing	$^{85}Sr^{2+}$	$^{22}Na^{+}$
Moderately sorbing	$^{86}Rb^{+}$	$^{133}Ba^{2+}$
Strongly sorbing	$^{137}Cs^{+}$	$^{54}Mn^{2+}$

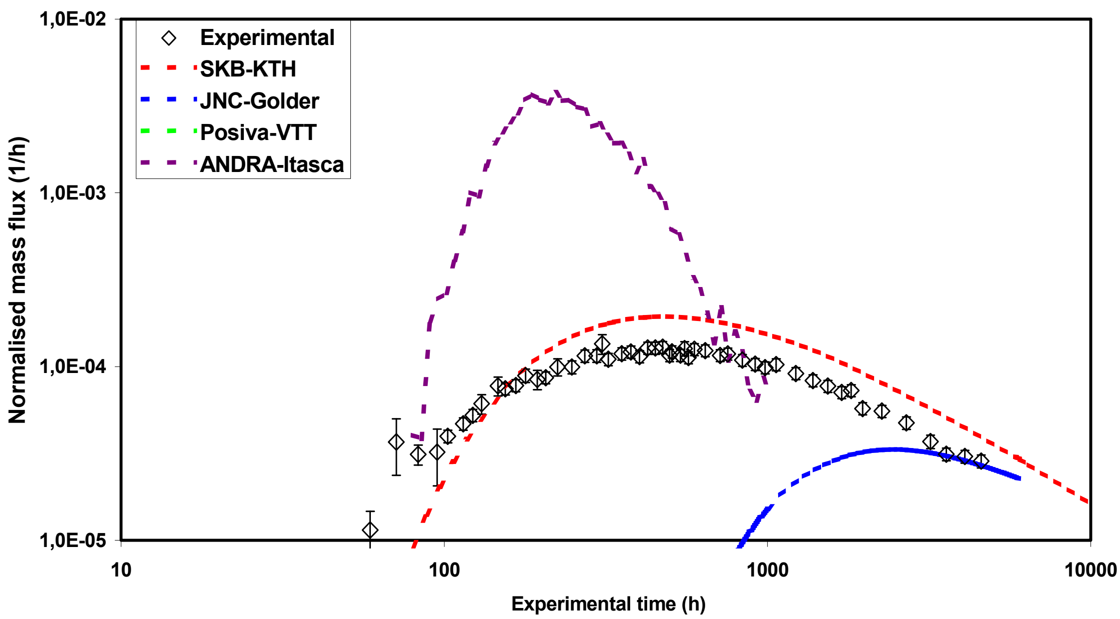

Figure 4-3 *Injection of Cs-137 in KI0025F02:R3 (Structure #19). Comparison between calculated breakthrough (hatched colours) and measured breakthrough (non-filled diamond symbols). Posiva-VTT predictions are outside plot window.*

4.2.2 True-1 Continuation

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 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.

Complementary activities include: (a) test of the developed epoxy resin technology to fault rock zones distributed in the access tunnel of the Äspö HRL, (b) laboratory sorption experiments for the purpose of verifying K_d values calculated for altered wall rock and fault gouge, (c) writing of scientific papers relating to the True-1 Project. A previously included component with the purpose of assessing fracture aperture from radon data has been omitted due to resources prioritisation.

A complication for the scheduling of planned future work at the True-1 site 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 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.
- 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.

Writing of three scientific papers accounting for the SKB True Project team analysis of the True-1 experiments.

- 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 experimental laboratory work on altered wall rock and fault gouge material is essentially finished. It is shown that the theoretical K_d values estimated earlier /Andersson *et al*., 2002; Dershowitz *et al*., 2003/ based on cation exchange capacities, mineralogy, water chemistry and selectivity coefficients compare well with the new experimental results. Reporting is under way.

In the Fault rock zone characterisation project /Stigsson *et al*., 2003; Maersk Hansen and Staub, 2004/ over coring has been performed on in total seven sections where injection of uranine-labelled epoxy has been performed. The 76 mm pilot boreholes were over cored to a diameter of 300 mm, resulting in 277 mm cores. Of the seven cores, three fell apart due to insufficient resin impregnation /Maersk Hansen and Staub, 2004/. The remaining four cores show good results. In particular the core from borehole KA2423A03 exhibits a remarkable suite of pore spaces ranging from microscopical webs of thin micro-fissures, see Figure 4-4, to intersection of macroscopic fractures larger than the core diameter. The cores from the other boreholes of interest, KA2169A01 and KA2169A03, do not show the same degree of complexity. Tentative analysis of already exposed surfaces and a selection of new cuts have been analysed. Various qualitative and quantitative descriptive measures from image analysis have been tentatively analysed and quantified.

Draft versions of the three aforementioned scientific papers on the True team analysis of the True-1 experiments have been produced and have been subject to internal review.

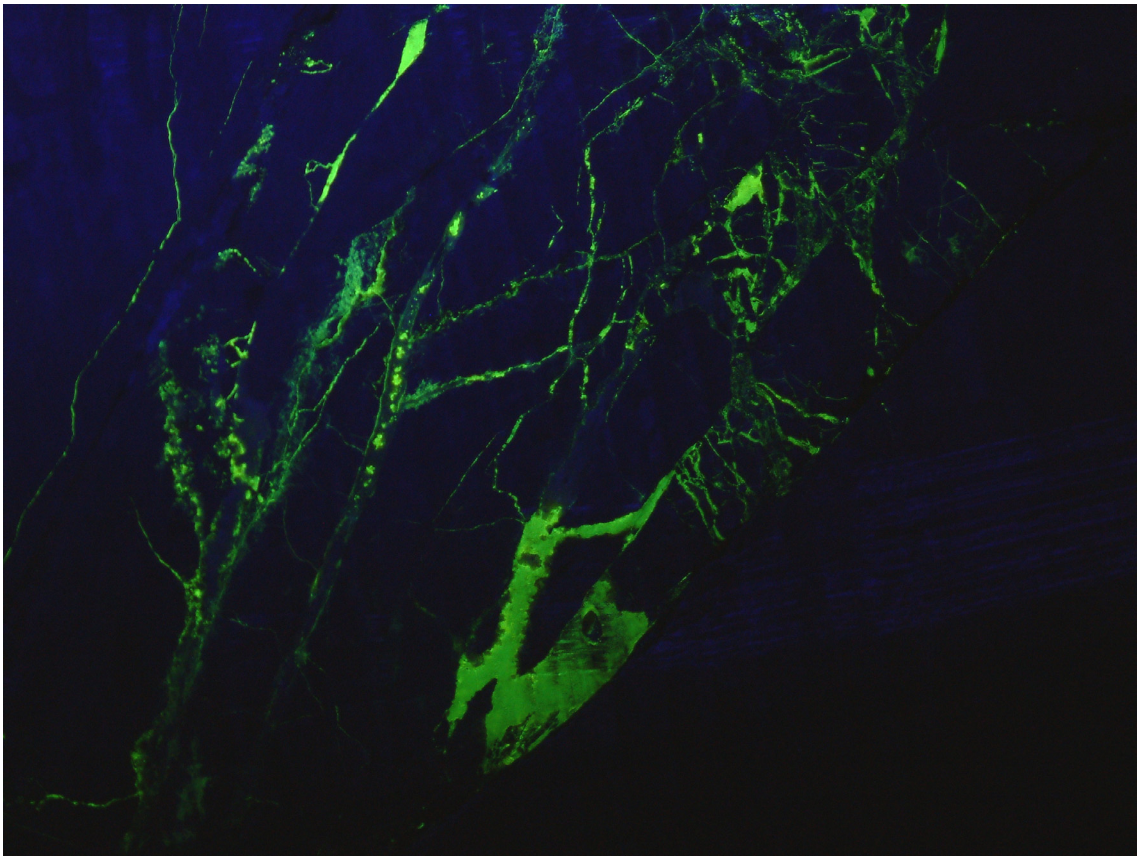

Figure 4-4 *Example photograph under fluorescent light of resin-impregnated pore spaces in KA2423A03. The width of the right leg of the large object in lower central part of the image is about 10 mm.*

Scope of work for 2005

During the next coming year the Fault Rock zones characterisation project will be terminated and reported. The extent of possible complementary analyses will be decided at a technical meeting late January. A second minor component of the Laboratory Sorption work is reporting of the leaching component of the experiments. Similarly, the final drafts of the True-1 papers will be submitted before the end of the first quarter.

The main endeavour for 2005 is launching of what is denoted True-1 Completion. This subproject will encompass the full application of the resin injection technology to the True-1 site and Feature A. It will also include any type of complementary *in situ* experimentation before destroying the site completely. The time perspective for this work is to enable injection of epoxy during 2006 and have the project completed by the end of 2008. The first half of 2005 will be devoted to detailed planning of the work.

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 is a natural extension of the performed *in situ* experiments, e.g. the True-1 and the True Block Scale experiments. The difference is that the longer duration (approximately 4 years) of the experiment is expected to enable an improved understanding of diffusion and sorption both in the vicinity of a natural fracture surface and in the matrix rock.

Matrix diffusion studies using radionuclides have been performed in several laboratory- and *in situ* experiments. Some experimental conditions such as pressure and natural groundwater composition are however difficult to simulate with good stability in long-term 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/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 original form /Byegård *et al*., 1999/, which will be subject to a separate report.

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, natural 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 borehole. In addition a small diameter borehole is drilled through the core stub into the intact undisturbed rock beyond the end of the large diameter borehole. A cocktail of non-sorbing and sorbing tracers are circulated in the test section for a period of approximately 4 years after which the core stub is over-cored, and analysed for tracer content and tracer fixation, see Figure 4-5.

The experiment is focussed on a typical conductive fracture identified in a pilot borehole (KA3065A02). A telescoped large diameter borehole (300/197 mm) (KA3065A03) is drilled sub-parallel to the pilot borehole 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 boreholes.

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 borehole 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 300 mm long section that will be exposed for the radionuclides. The system of packers and an intricate pressure regulating system will be used to eliminate the hydraulic gradient along the borehole, see Figure 4-6.

During the circulation of tracer, samples of water will be collected at various times over the duration of the experiment. The red-ox situation in the circulation loop will be monitored continuously with a flow through electrochemical cell, which will measure pH, Eh and temperature. Strategically positioned filter will ensure limited build-up of microbes in the water circulation loop. After completion of tracer circulation, the core stub is over-cored, sectioned and analysed for different radionuclide tracers.

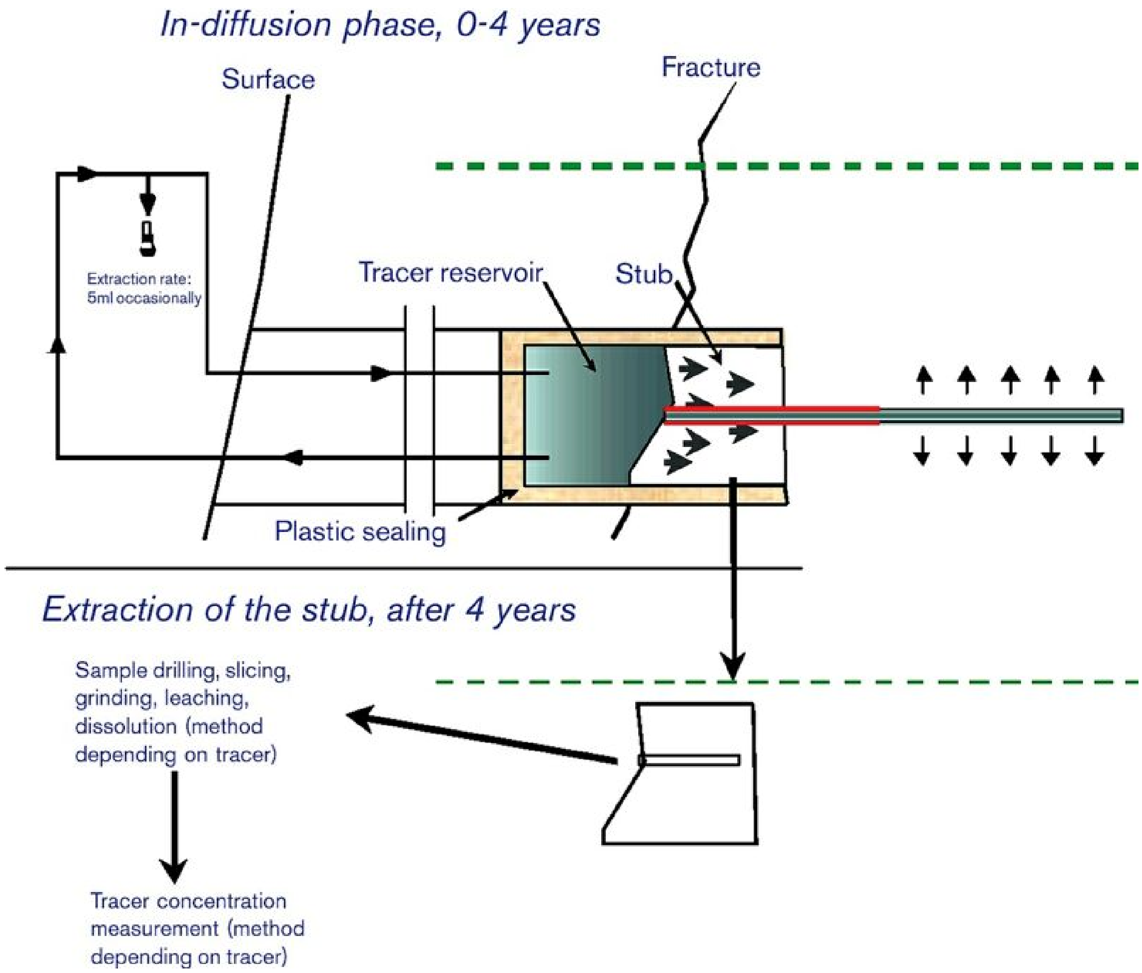

Figure 4-5 *LTDE experimental concept including injection borehole in contact with a fracture surface.*

The project also involves a variety of mineralogical, geochemical and petrophysical analyses. In addition, laboratory experiments with the core material from KA3065A03 (Ø 277, 177 and 22 mm) and the fracture "replica" material will be performed. Both "batch" sorption and through diffusion experiments are planned.

The drilling of the telescoped large diameter experimental borehole was performed with a high degree of interactivity between: careful iterative drilling in short uptakes (particularly in the inner part of the borehole), 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.

A 36 mm borehole was drilled in 2001 as an extension of KA3065A03 into the intact matrix rock. Characterisation of the experimental borehole KA3065A03 and a structural model of the LTDE site based on boreholes KA3065A02 and KA3065A03 is presented in a separate report /Winberg *et al*., 2003/.

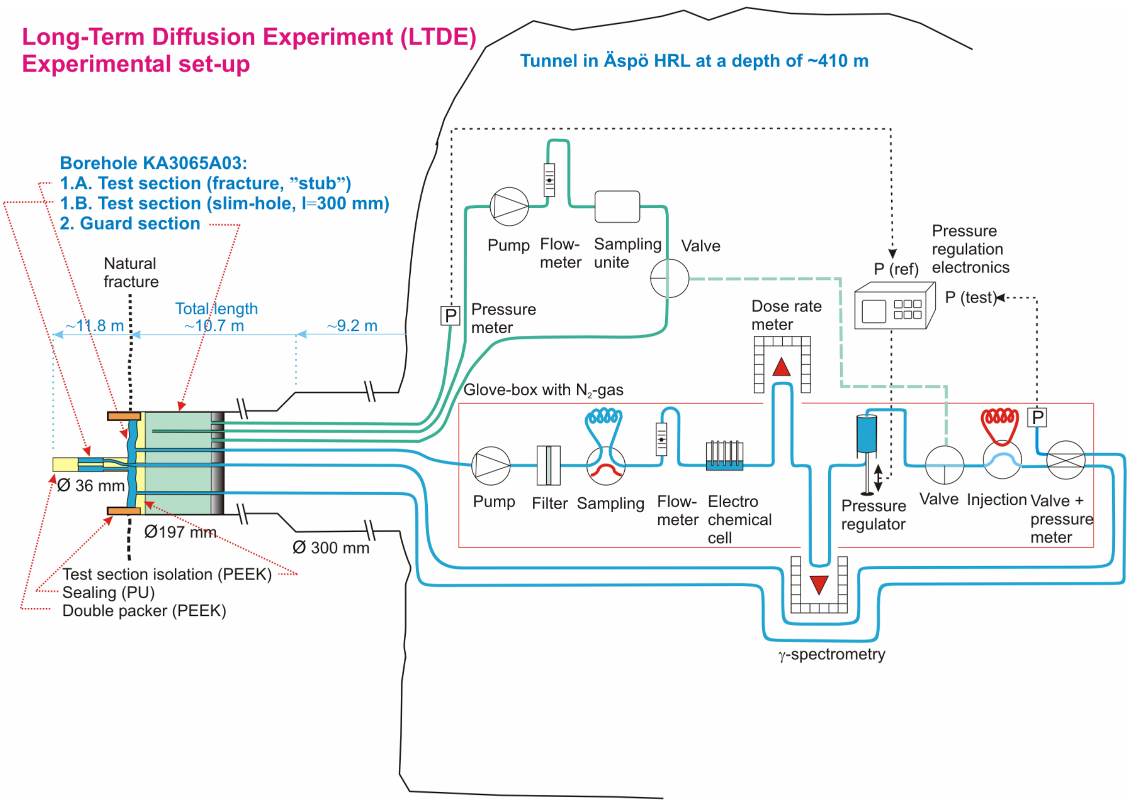

__Figure 4-6__ LTDE experimental set-up in the experimental borehole including the water circulation system to the test-section and the hydraulic pressure control system.

Present status

The following topics have been carried out during 2004:

- Completion of the pre-test programme for evaluation of the hydrological conditions in the vicinity of the experimental borehole, KA3065A03, and possible hydrological interferences from other activities in Äspö HRL.
- Collaboration has been initialised with OPG, who are providing a technical expert on *in situ* diffusion from AECL, Canada. Core samples from borehole KA3065A03 have been prepared and delivered to AECL for supporting laboratory experiments.
- Installation-test programme focused on system function control and simulation of extreme experimental conditions. Test showed some modifications necessary in the electronics of the pressure regulation device and also in the electronics for the electrochemical cell. The modifications are ongoing.
- Documentation of the experimental set-up in Äspö HRL.

Scope of work for 2005

The following topics are planned for 2005:

- Laboratory experiments on core samples from LTDE borehole KA3065A03, to be performed by AECL.
- Start of LTDE by injection of radioactive tracers.

4.4 Radionuclide Retention Experiments

Background

The retention of radionuclides in the rock is the most effective protection mechanism when the engineered barriers fail and radionuclides are released from the waste form. The retention is mainly due to the chemical properties of the radionuclides, the chemical composition of the groundwater, and to some extent also by the conditions of the water conducting fractures and the groundwater flow.

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 used in the experiments. 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 studied.

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 1 and 2 are borehole laboratories built into probes, 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, see Figure 4-7. 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. In Figure 4-8 the principles of the Chemlab 1 and Chemlab 2 borehole laboratories are given.

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 (completed).
- The influence of primary and secondary formed water radiolysis products on the migration of the redox-sensitive element technetium (final report in print).
- Migration of actinides (americium, neptunium, and plutonium) in a rock fracture.

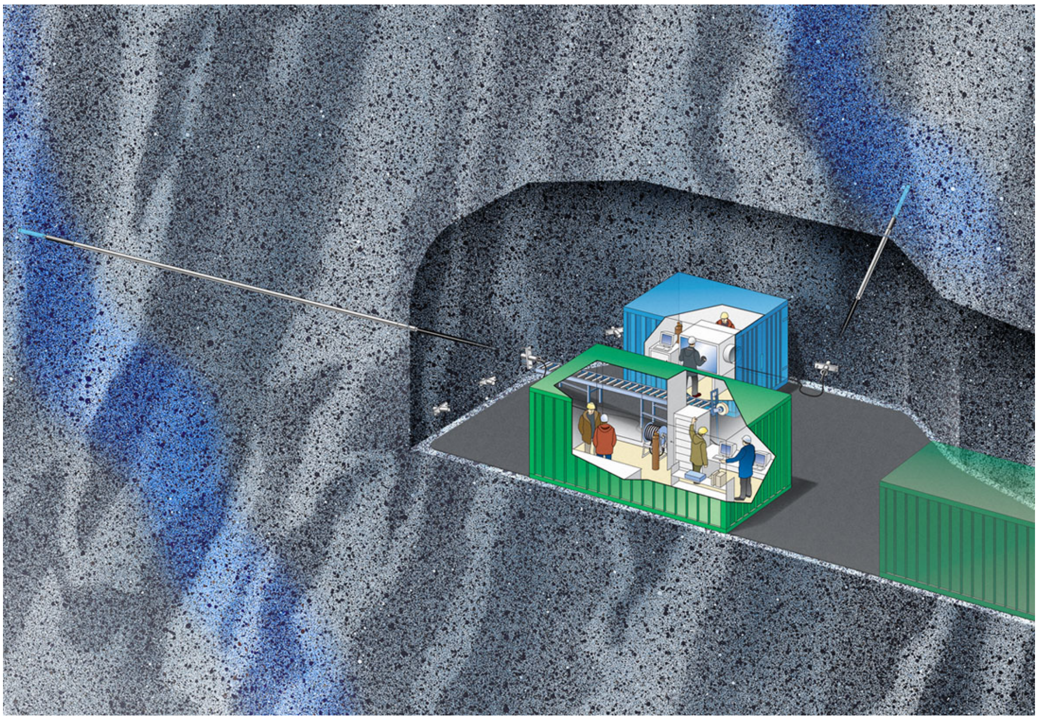

Figure 4-7 *Illustration of the experimental set-up of the Radionuclide Retention Experiments.*

Radiolysis experiments

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

Migration of actinides

Experiments on the migration of actinides, americium, neptunium and plutonium, as well as uranium and technetium in a natural rock fracture in a drill core are carried out in 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.

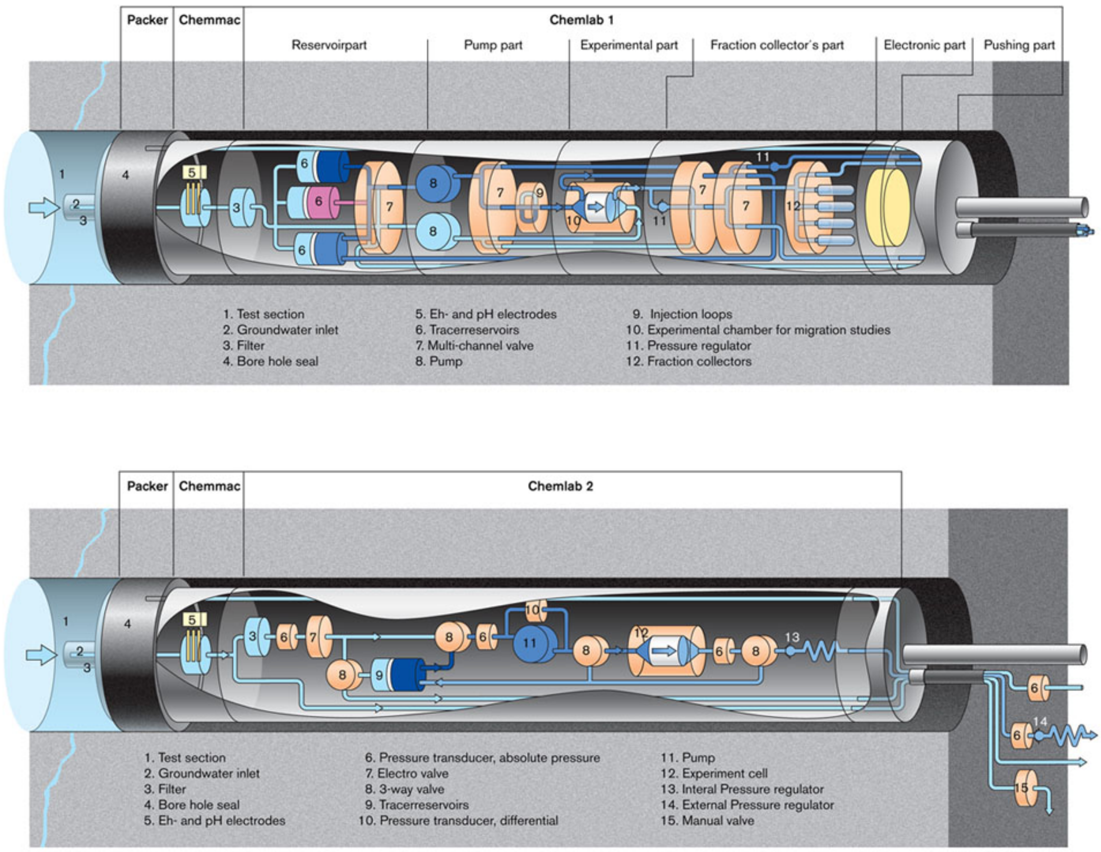

Figure 4-8 *Schematic illustration of Chemlab 1 and 2 borehole laboratories.*

Present status

The radiolysis experiments are finished and evaluated. The final report /Jansson and Eriksen, 2005/ is in print.

The last field experiment of the actinide project, where the tracers are uranium and technetium, have been prolonged due to a somewhat unexpected increase in uranium concentration in the outlet solution.

Scope of work for 2005

Two new experiments will be started in the Chemlab probes during 2005. Both of the experiments are still in the design phase.

In Chemlab 1 a project called Transport Resistance at Buffer-Rock Interface will be started. It has been reported that there is a transport resistance when radionuclides change media from diffusing in bentonite clay to transport with groundwater in a fracture. The project aims at examining whether this resistance exists and if so, the magnitude of the resistance shall be determined.

In Chemlab 2 a project called Spent Fuel Leaching will be started. The project will examine which radionuclides are released and in what extent when spent nuclear fuel is leached with groundwater under relevant repository conditions.

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.

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 as well as field experiments. The latter include background measurements, borehole specific measurements and dipole colloid experiments.

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 boreholes during 2002, representing groundwater with different ionic strength, along the Äspö HRL-tunnel, see Figure 4-9.

The colloid content is measured on-line from the boreholes by using modified laser based equipment LIBD (Laser-Induced Breakdown-Detection) which has been developed by INE in Germany.

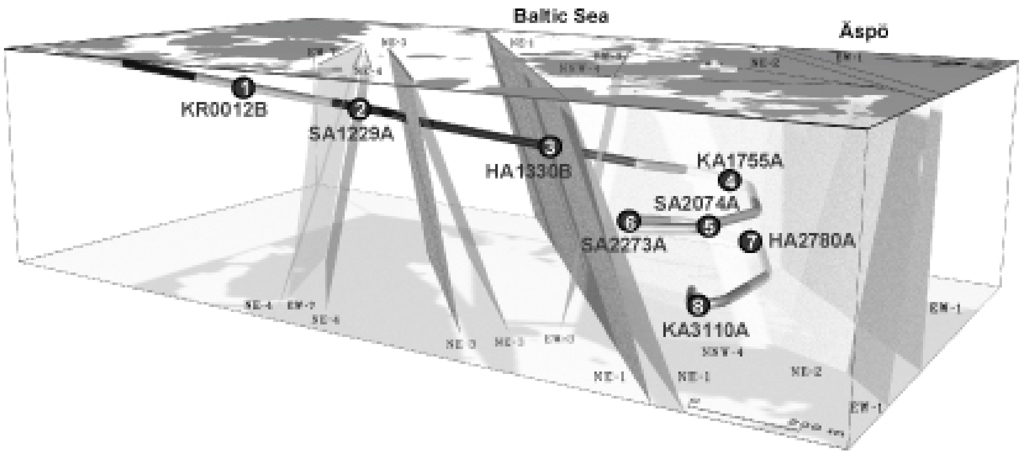

Figure 4-9 *The eight boreholes sampled for colloids along the Äspö tunnel.*

The results from the background measurements indicate that the natural colloid content is decreasing with groundwater salinity and depth. 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 bentonite clay in contact with groundwater prevailing at repository depth. 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 4 boreholes along the Äspö tunnel and 2 boreholes at Olkiluoto in Finland were investigated. The boreholes were selected so the natural variation in the groundwater composition at Fennoscandia was covered. The groundwater is in contact with the bentonite clay adapted in a container/packer equipment in the borehole and the colloid content is measured prior and after contact with the bentonite clay. The bentonite reactor is 50 cm long and installed in boreholes with a diameter of 36 mm. The colloid content was measured by using conventional filtering and ultra filtration at different flow conditions. The results indicate that the colloid release from the bentonite clay at prevailing groundwater conditions is small and the increased flow did not increase the colloid release from the bentonite reactor.

Dipole colloid experiment

The dipole colloid experiment is a fracture specific experiment planned to be performed within the Colloid Project during the time period 2004–2007. According to present plans two nearby boreholes intersecting the same fracture having the same basic geological properties will be selected for the dipole colloid experiment at Äspö HRL. One of the boreholes will be used as an injection borehole and the downstream borehole 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 e.g. a lanthanide and the fluid is labelled with a water conservative tracer. The mixture will be injected into the injection borehole, see Figure 4-10. 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.

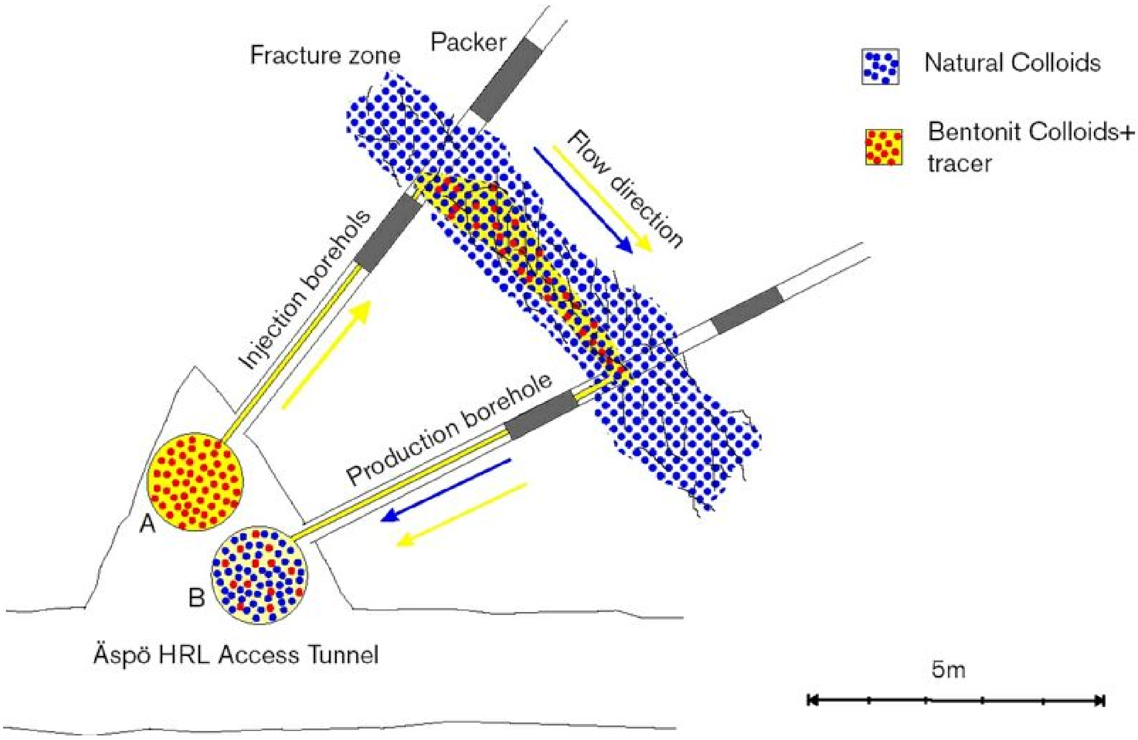

***Figure 4-10** Dipole colloid experiments – injection of bentonite colloids and monitoring of the injected and natural colloids in the production borehole.*

Present status

A final report (covering the laboratory experiments, background measurements, and the borehole specific measurements) for the Colloid Project is in process and will be ready in spring 2005. The experimental data from the bentonite reactors at Äspö and Olkiluoto are under evaluation. A complementary campaign for determining the background colloid concentration in different Äspö waters was performed in October-November 2004. Planning of the Colloid Dipole Project started in September 2004. The Colloid Dipole Project will end with a final report in December 2007.

Scope of work for 2005

During 2005, the main part of the work will be performed in the laboratory. Background data are needed before the actual Colloid Dipole experiment can be performed at Äspö. At KTH stability experiments with bentonite as well as other colloids that are going to be used in the Colloid Dipole experiment will be performed. The experiments are heading for finding the stability criteria for colloids of Äspö type. Parallel sorption experiments with actinides and colloids and other competing mineral surfaces, will be performed by the INE-team in Karlsruhe (see also Section 6.3). To determine the experimental infrastructure at Äspö some injections of conservative tracers and colloids will be performed at the True-1 site, which is chosen for the Colloid Dipole Project.

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 university 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, two along the A-side of the tunnel at 907 and 2,200-m tunnel length and one at the B-side of the tunnel at 1,127-m, were established during 2002. However, a devastating flood event occurred summer 2003 at the 907 site, and filled it with sand. This site has, therefore, been abandoned. At the 1,127-m site, the important inflow of groundwater with high concentration of sulphide diminished during 2002 and the sulphide feature is now completely lost. The 1,127-m site is now also abandoned.

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 of deep groundwater environments 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

A large group of microbes catalyse the formation of iron oxides from dissolved ferrous iron in groundwater that reaches an oxidising environment /Ferris *et al*., 1999, 2000/. Such biological iron oxide systems (Bios) will have a retardation effect on many radionuclides. Typically, 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 with the groundwater and the organic biological material adds a strong retention capacity in addition to iron oxides. The retention effect from Bios was studied at the site at 2,200 m tunnel length. A strong retention of rare earth metals, U and Th was found /Anderson and Pedersen, 2003/. During 2004, a quantitative approach to immobilisation by Bios has been applied. This work was executed in co-operation with scientists from dept of Geology, University of Toronto, Canada. The work will be published during 2005.

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 contributes to the redox stability of deep groundwater via microbial turnover of this gas. Hydrogen, and possibly also carbon monoxide and methane energy metabolisms will generate secondary metabolites such as ferrous iron, sulphide and organic carbon. 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 have been addressed at the Microbe-450 m site during 2003 and 2004.

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 deep repository for spent fuel.

Experimental concept

Four sites along the tunnel have been in operation. However, at present, only two sites are active. 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, an additional site is configured along the tunnel at 2,200 m tunnel length.

The Microbe 450-m site

The main Microbe site is at 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, see Figure 4-11. A gas chromatograph and a gas extraction system are installed. This system can analyse the following gases (detection limit): hydrogen (1 ppb), carbon mono-oxide (1 ppb), carbon dioxide (1 ppm), methane (1 ppm), ethane (1 ppm) and ethylene (1 ppm).

Three core drilled boreholes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures at 12.7, 43.5 and 9.3 m, respectively, are connected to the Microbe laboratory via 1/8" PEEK tubing. The boreholes are equipped with metal free packer systems that allow controlled circulation of groundwater via respective fracture /Pedersen, 2000/. Each borehole has been equipped with a circulation system offering a total of 2,000 cm^2 of test surface in each circulation flow cell set up (four flow cells) for biofilm formation at *in situ* pressure, temperature and chemistry conditions. The cells can be installed with any type of surface with the dimensions 120 x 22 x 1 mm (length x width x height), see Figure 4-12. The systems operate at the pressures 26, 32 and 26 bars in KJ0050F01, KJ0052F01 and KJ0052F03, respectively. The flow through the flow cells is adjusted to about 25 ml per minute, which corresponds to a flow rate over the surfaces of 1 mm per second. Temperature is controlled and kept close to the *in situ* temperature at around 15-16°C. Remote alarms have been installed for high/low pressure, flow rate and temperature. In Figure 4-13 one of the three installed flow cell cabinets is shown.

***Figure 4-11**. A view of the laboratory environment at the 450-m Microbe site is shown. The laboratory is equipped with three circulation systems (right), an anaerobic box (forward), an in situ gas extractor and a Kappa 5 gas chromatograph (right of the anaerobic box).*

***Figure 4-12** One of the twelve flow cells that are installed at the Microbe 450-m site is shown. Ten pieces of surfaces can be installed. They can be made of granite, glass metal or combinations, depending on the aim of the experiment. Three flow diffusers before and after the surface pile distributes the flow evenly over the test surfaces.*

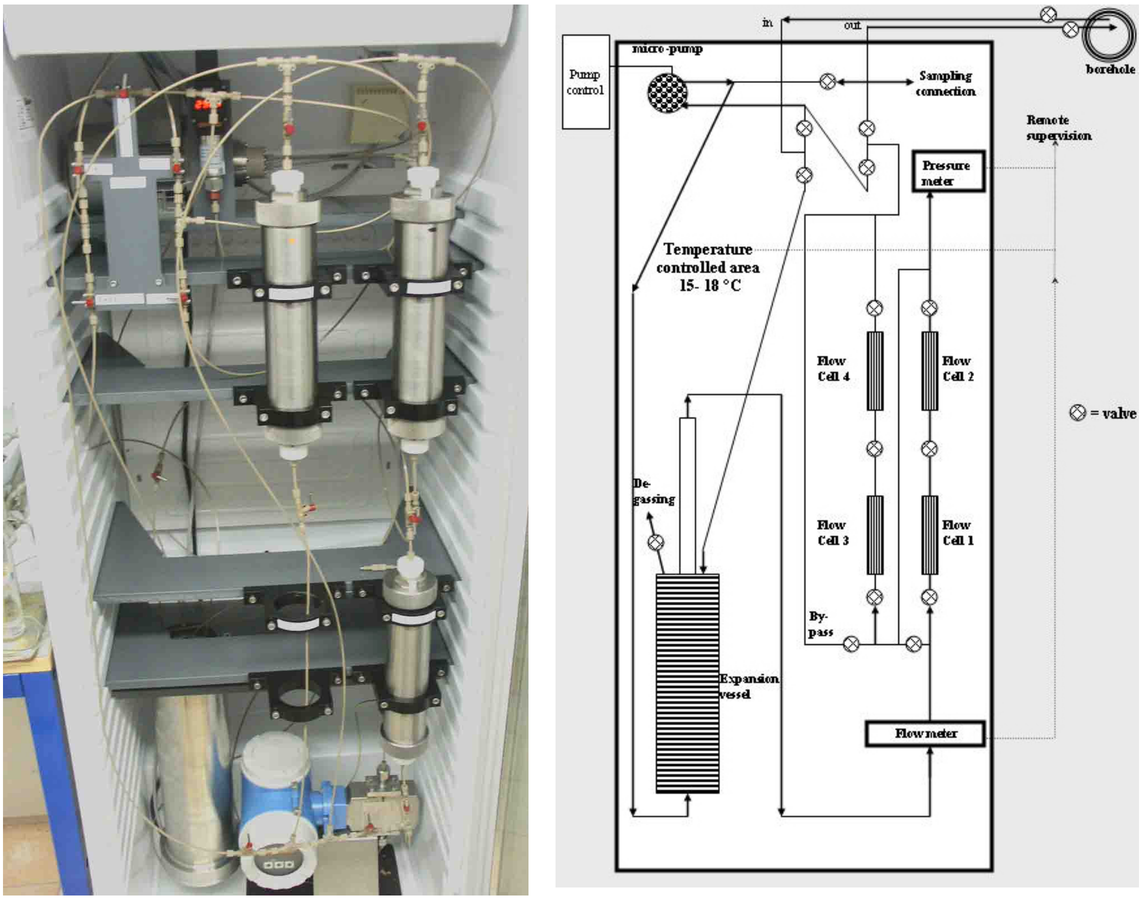

Figure 4-13 *Left: Image of one of the three installed flow cell cabinets. (Lower left flow cell has been removed and sampled). Right: Schematic view of the cabinet.*

The Bios-site at 2,200A m tunnel length

Organic surfaces and iron oxides have been identified as important factors in radionuclide transport modelling. Several microorganisms oxidise ferrous iron to ferric iron resulting in a mix of organic material (microbes) and iron oxides, here denoted Bios. Bios can be found everywhere along the Äspö HRL tunnel system. This Bios is mainly produced by the stalk-forming bacterium *Gallionella ferruginea* /Hallbeck and Pedersen 1990, 1991, 1995; Hallbeck *et al*., 1993/. One particularly good site for investigations has been identified at tunnel length 2,200-m, on the A side. A vault is reaching about 10 m into the host rock perpendicular to the tunnel and it has a borehole in the front that delivers groundwater rich in ferrous iron and iron oxidising bacteria. The borehole has been connected to two 200 x 30 x 20 cm artificial channels that mimic ditches in the tunnel (see Figure 4-14). The channels have rock and artificial plastic support that stimulate Bios formation. Retention of naturally occurring trace elements in the groundwater by the Bios was investigated during 2003 /Anderson and Pedersen, 2003/. Qualitative experiments were set up and preformed during 2004.

Figure 4-14 *The artificial channels at 2,200-m Microbe site are feed by water from a common borehole, but they are inhabited by either iron oxidising microbes (left) or sulphur oxidising microbes (right). The balance between iron and sulphur microbes is very delicate. A small difference in the inlet profile of ground water results in a huge difference in the structure of the respective population.*

Present status

The gas chromatography system has successfully been used for analysis of gases in the Prototype Repository during 2004.

The experimental work with immobilisation of radionuclides on biofilms from the KJ0052F03 circulation has been finalised. Manuscripts are in preparation and will be published during 2005.

A methodology for the quantification of biomass at low concentrations has been established. ATP is an energy transport molecule that exists in all living organisms in fairly constant concentrations. It is possible to extract and analyse this compound by using biochemical protocols and a luminometer. The methodology has been incorporated in the standard protocols for analysis of biomass at Microbe, and elsewhere. A manuscript is in preparation for publication during 2005.

Principal component analysis has shown that there is an up-coning of deeper groundwater to the Microbe boreholes.

The design and work on the Microbe sites between the years 2001 and 2004 will be summarised in a SKB report ready for publication in January 2005.

Scope of work for 2005

There are two main tasks for 2005:

- *In situ* mobilisation of radionuclides by microbial complexing agents will be investigated. Laboratory work indicates that the extent of this process under *in situ* conditions must be explored.
- The response of the microbial populations to perturbation in the geochemical environment, such as oxygen intrusion, will be studied. This includes in a first step molecular characterisation of the populations present at the Microbe 450-m site and thereafter, their respective response to perturbations introduced under controlled conditions.

4.7 Matrix Fluid Chemistry

Background

The first phase of the Matrix Fluid Chemistry experiment (1998–2003) increased the 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. The results of this first phase were published in early 2004 /Smellie *et al.*, 2003/.

The continuation phase (2004–2006) will focus on areas of uncertainty which remain to be addressed. These are:

- The nature and extent of the connected pore waters in the Äspö bedrock (chemical, hydraulic and transport properties).
- The nature and extent of the microfracture groundwaters which penetrate the rock matrix (chemical, hydraulic and transport properties) and the influence of these groundwaters (by in- and out-diffusion) on the chemistry of the pore waters.
- The confirmation or otherwise of laboratory-derived matrix fluid compositions (i.e. crush/leach and diffusion extractions) by conducting a long-term *in situ* out-diffusion porewater experiment in the matrix borehole.
- The confirmation of rock porosity values previously measured in the earlier studies.

This continuation phases, however, requires an initial feasibility study to assess the potential for further characterising the matrix borehole. This is necessary because of the untimely excavation of a new tunnel close to the matrix borehole for the Äspö Pillar Stability Experiment carried out in April/May, 2003. Repercussions from this excavation may have influenced the hydraulic (and therefore the hydrochemical) character of the matrix borehole and the host rock vicinity. Prior to any further studies, therefore, these repercussions require to the quantified.

Objectives

Because of the possibility that the hydraulic and hydrochemical character of the matrix borehole and the host rock vicinity has been disturbed, the following objectives have been identified:

- To establish the impact of tunnel construction on the matrix borehole by evaluating the monitored pressure profiles (Äspö HMS) registered on the isolated borehole sections during the period of construction (small-scale).
- To establish the impact of tunnel construction on boreholes located in the near-vicinity of the matrix borehole in "Tunnel F" by similar means (large-scale).
- If the evaluation indicates that the rock hosting the matrix borehole has been unaffected by tunnel construction, the experiment will proceed first to hydrochemically and hydraulically characterise the presently isolated borehole sections containing microfractures and, secondly, to hydrochemically and hydraulically characterise the original fracture-free borehole sections.
- Furthermore, on the same basis, *in situ* out-diffusion experiments will be conducted in the same isolated fracture-free borehole sections.
- To carry out additional porosity measurements on drillcore samples to confirm or otherwise those values already measured.

Experimental concept

The first phase of the Matrix Fluid Chemistry Experiment was designed to sample matrix pore water from predetermined, isolated borehole sections. The borehole 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 ongoing experiments at Äspö HRL.

Special downhole equipment, see Figure 4-15, was constructed 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 pore waters (and gases) under pressure, and (g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

This experimental equipment, with some modifications, will be used in the continuation phase to sample groundwaters from the microfractures, to measure the hydraulic parameters of the microfractures and the rock matrix, and finally to conduct the long term *in situ* diffusion experiment.

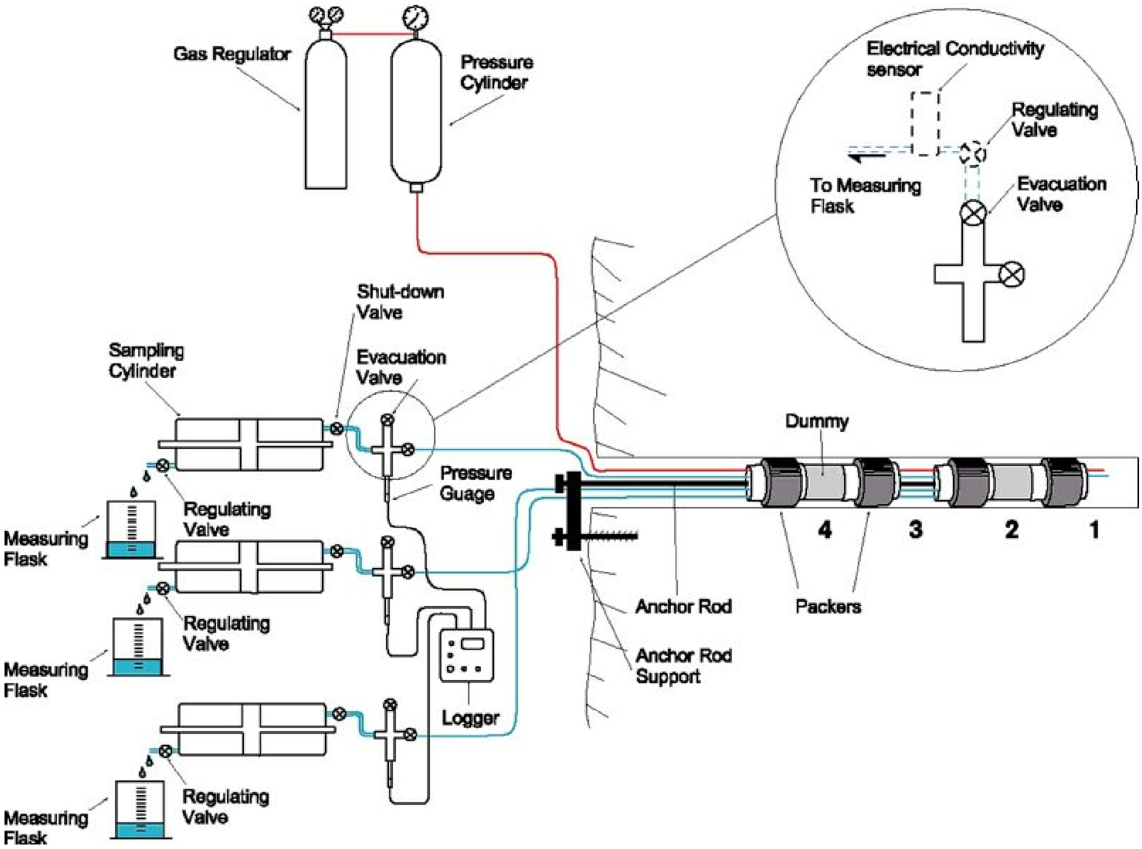

Figure 4-15 Matrix Fluid Chemistry experimental set-up. Borehole sections 2 and 4 were selected to collect matrix fluid, sections 1-4 were continuously monitored for pressure.

Present status

The Matrix Fluid Experiment Continuation commenced in January 2004 with a feasibility study to evaluate the potential impact of the Äspö Pillar Stability Experiment (i.e. the tunnel excavation) in vicinity of the Matrix Fluid Experiment borehole (KF0051A01). This was scheduled to be completed by the end of March, 2004. Unfortunately, hydraulic pressure monitoring data from the Äspö HMS system became available in November, 2004. Because of site characterisation priorities influencing key personnel, the feasibility study has not been completed.

Additional porosity measurements on drillcore samples close to the matrix borehole have been successfully carried out and these have been reported, awaiting publication.

Scope of work for 2005

The scope of the work for 2005 will depend on the impact evaluation of the tunnel excavation. This will be determined initially by a feasibility study which will evaluate the pressure variations recorded (i.e. using data from the Äspö HMS system) in the matrix borehole and other monitored boreholes in the near-vicinity during tunnel excavation. If there is no significant deviation from those measured prior to tunnel excavation, then it will be assumed that no major impact has occurred.

Assuming no significant impact the following tasks will be carried out during 2005:

- Resampling of groundwaters and dissolved gases from the borehole sections containing two identified microfractures.
- Repositioning the borehole equipment to resample groundwaters and dissolved gases from the fracture-free borehole sections earlier characterised hydrochemically.
- Hydraulic characterisation of the fracture-free borehole sections.
- Repositioning the borehole equipment to hydraulically characterise the borehole sections containing the microfractures.

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

Background

The work within Äspö Task Force constitutes an important part of the international co-operation within the Äspö HRL. The group was initiated by SKB in 1992 and is a forum for the organisations to interact in the area of conceptual and numerical modelling of groundwater flow and transport. 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 (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, 1st stage (completed).

Task 5: Coupling between hydrochemistry and hydrogeology (completed).

Task 6: Performance assessment modelling using site characterisation data (ongoing).

Task 7: Long-term pumping experiment (to be initiated).

Objectives

The Äspö Task Force is a forum for the organisations supporting the Äspö HRL 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 assessments.

The ongoing Task 6 was initiated in 2001. Task 6 does not contain experimental work but it uses experimental results of the former Task 4 and True Block Scale project. Task 4 included a series of tracer tests performed in a single feature over transport distances of about 5 m using simple flow geometry and both conservative and sorbing tracers. In True Block Scale, a series tracer tests were performed in a fracture network over tens of metre distances. The main objectives of Task 6 are to:

- Assess simplifications used in performance assessment (PA) models.
- Assess the constraining power of tracer experiments for PA models.
- Provide input for site characterisations programme from PA perspective.
- Understand the site-specific flow and transport at different scales using site characterisation models.

These sub-tasks have been defined within Task 6:

6A Model and reproduce selected True-1 tests with a PA model and/or a site characterisation (SC) model to provide a common reference.

6B Model selected PA cases at the True-1 site with new PA relevant (long term/base case) boundary conditions and temporal scales.

6C Develop semi-synthetic, fractured granite hydrostructural models. Two scales are supported (200 m block scale and 2,000 m site-scale).

6D This modelling task is similar to sub-task 6A, and is using the semi-synthetic structural model in addition to a 50 to 100 m scale True Block Scale tracer experiment.

6E This modelling task extends the sub-task 6D transport calculations to a reference set of PA time scales and boundary conditions.

6F Task 6F is a sensitivity study, which is proposed to address simple test cases, individual tasks to explore processes, and to test model functionality.

Present status

Two Task Force meetings and one workshop have been held during year 2004. The 18^{th} International Task Force meeting, hosted by SKB was held in January at Äspö HRL, and the 19^{th} International Task Force meeting was hosted by Posiva and held in September and took place in Nantaali, Finland. At these meetings, the modelling groups presented final results of sub-task 6D, and preliminary results for sub-task 6E and 6F. The venue for the workshop was Arlanda in August. At this workshop for delegates only, issues on how to steer and improve the work within the Task Force were discussed.

The work within the Task Force has been in progress after the meetings. Minutes and Proceedings from the International Task Force meetings are published on the Task Force Website (www.skb.se/taskforce). In the planning group, telephone meetings are held on a regular basis. Modelling reports regarding sub-task 6A, 6B and 6B2 have been printed. The external review process for Task 6 is ongoing. Specifications of sub-task 6F have been sent out to the Task Force members.

Scope of work for 2005

The main activities targeted to be accomplished during 2005 are summarised below:

- Organise the 20th International Task Force meeting in May, hosted by SKB at Äspö HRL.
- Produce modelling reports of sub-task 6D, 6E and 6F.
- Continue the external review process of Task 6.
- Initiate the new modelling of Task 7.
- Efforts to publish the work of the Task Force in scientific journals will be encouraged.

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 EC founded 3 year project with the name EQUIP (Evidences from Quaternary Infills for Palaeohydrogeology) was started in 1997. 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 EC-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 include:

- Further developments of analytical techniques that exploit the rapid advances in instrumental capabilities especially for quantitative microanalyses of trace elements and isotopes for dating.
- Development of modelling tools to interpret data quantitatively and to relate it to both water-rock reactions at the scale of mineral crystals and also to evolution of the groundwater systems at larger scales.
- Focus of further research to investigate specific processes that might link climate and groundwater in low permeability rocks.

The Swedish part of the Padamot study concentrates on the two work packages: WP2 (Palaeohydrogeological characterisation of sites) involving applications of several analytical techniques on fracture filling calcites dominantly from KLX01, and WP5 that deals with performance assessment applications of palaeohydrogeological data and modelling.

Present status

The EC part of the project will be reported in the beginning of 2005. Major achievements are especially the methodology for selecting calcite samples that represent the possible youngest calcite and also the use of calcite morphology of these calcites in order to sort out different palaeohydrogeological imprints. In addition to morphology detailed scale laser technique and traditional bulk analyses (on very small samples) have been used for trace elements and stable isotopes. The small sample volumes together with the very fine zoning of the samples cause serious limitations in the analyses possible to be applied. The overall pattern obtained from the different analytical techniques shows, however, a past scenario with large variations in salinities in the upper 900 meters in borehole KLX01. For example are fresh water carbonates found as deep as 900 meters. On the other hand calcites typical for brackish water are found from 20 meters depth and saline water precipitates from 100 m. The calcites with stable isotope composition typical for precipitates from Baltic Sea water seems to be less significant at Laxemar compared with Äspö. Decreasing influence of interaction with the surface is recorded although the contribution of e.g. trace elements and organic material seems to reach larger depth at Laxemar compared with Äspö. This is also in agreement with the hydrogeological situation.

Scope of work for 2005

Uranium series measurements were originally planned within the Padamot EC-project but were later removed from the common part of WP2. Natural uranium decay series analyses have been used previously on smaller sets of samples from Äspö /Tullborg *et al*., 2003; Landström *et al.*, 2001/. Different methods can be used including bulk samples analyses and sequential leaching. The plan for 2005 is to apply this type of analyses to a set of samples from Äspö and Laxemar, in order to test the different techniques. In addition the promising results with biomarker analyses of fracture calcites reported in WP2 will be followed up.

4.10 Fe-oxides in fractures

Background

Uptake of radioactive elements in solid phases can lead to immobilisation, thus minimising the release to the environment. Uptake extent depends on solution conditions such as concentration, pH, Eh, temperature, pressure, and the presence of other species. Transition metals, lanthanides and actinides are often incorporated by identical processes, consequently better understanding of the behaviour of the two first groups mentioned strengthens understanding also of the actinides, which are difficult to study. Moreover, presence of trace components in minerals can provide information about a mineral’s genesis conditions and history. Fe-oxides line fractures are found in the Äspö bedrock and they are present as minor components nearly everywhere at the Earth’s surface. Their affinity for multivalent species is high but Fe-oxide uptake of lanthanides and actinides has not been studied to any great extent. Fe(II)-oxihydroxides, known as “green rust”, form in Fe-bearing solutions under reducing conditions and are associated with the early stages of corrosion. Their uptake capacity during formation and transition to Fe(III)-oxides is essentially unknown at present. These minerals could be an important sink for radioactive species where Fe is abundant in the natural fractures or in materials brought into the repository. Fe itself can be an indicator of redox state. Fe-isotope fractionation, a very new topic of research, might give clues about redox conditions during Fe-mineral formation or as a result of its inclusion in other secondary fracture minerals.

There are three questions relevant for radioactive waste disposal in fractured granite:

- How extensive is the capacity for Fe(III)-oxides, in fracture linings, to take up radionuclides or other toxicants from solutions, and what happens during transformation of the oxides to more stable phases?
- What capacity do the reduced Fe(II)-oxides have for uptake and retention?
- Does the suite of trace components and isotopes measured in minerals from fracture linings provide information about conditions of the water that passed through them in the past?

These questions can be rephrased more specifically, for direct application to problems for Swedish waste disposal, as:

- Can more detailed information about the uptake of higher valent elements such as Eu^{3+} provide a model for actinide behaviour and Cr^{3+} as a palaeo-redox-indicator?
- Can stable Fe-isotopes from Fe-oxides or from other minerals tell us anything about solution conditions during genesis?
- What is the uptake and retention capacity of green rust under solution conditions relevant for Äspö?
- Is it possible to find evidence to support or refuse the hypothesis that, at the time of glacier retreat, oxidising water might have penetrated to or below the depth of the planned deep repository?
- How might secondary Fe-minerals affect the migration of radionuclides accidentally released from a repository?

Objectives and experimental concept

The basic idea of the project is to examine Fe-oxide fracture linings, in order to explore suitable palaeo-indicators and their formation conditions. At the same time knowledge about the behaviour of trace component uptake can be obtained from natural material as well as through studies in the laboratory under controlled conditions.

A glove-box set-up, where Atomic Force Microscopy is possible *in situ*, will be used to investigate green rust under a stable atmosphere at reducing conditions. More possibilities for extracting chemical information from the secondary Fe-oxides will be tested and the merits of stable Fe- and O-isotope fractionation as well as Mössbauer (MS) and energy dispersive X-ray (EDS) spectroscopy will be examined.

Present status

One possible suggestion to separate low temperature Fe(III) oxyhydroxides, hydrothermal hematite, and drilling induced Fe(III) precipitates is the use of combined Fe-isotope studies and Mössbauer analyses. This looks very promising and the first study will be reported soon.

Green rust (GR) has been studied in laboratory and the structural of $GRSO_4$ have been determined. It has been shown that the structure changes depending on cation introduced.

Scope of work for 2005

The project will continue with Fe-isotope studies and Mössbauer analyses of more samples from host rock and fracture zones.

The green rust part will continue along the line described above. During this year a collaboration with Enviros will take off comprising reactive transport modelling involving Fe(II)/Fe(III) species.

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.

The Information and public relations group is responsible for presenting information about SKB and its facilities e.g. the Äspö HRL. They arrange visits to the facilities all year around as well as special events.

5.1 Facility operation

Background

The main goal for the operation is to provide a facility which is safe for everybody working in, or visiting it, and for the environment. This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power, ventilation, alarm and communications are available in the underground laboratory at all times.

Present status

The plant supervision system has considerably increased the possibility of running the facility in a safe and economic way. The reliability of the underground-related systems has been more than 99%, which means that the goal for 2004 has been fulfilled.

An automatic registration and object-monitoring system with the aims of increasing personnel safety underground has been tested and found not to fulfil the requirements. The contract with the supplier is cancelled and alternative systems from other suppliers on the market will be considered.

A PC-based maintenance system has been implemented and the aim is that the system will facilitate the planning of maintenance of the facilities, vehicles and machinery.

The long term rock control and reinforcement programme has been continued to ensure safe and reliable rock conditions. Work on increased fire safety was also of concern during 2004 and safety-related education and fire fighting training was held in co-operation with the local fire brigade. The installation of a pipe, from -440 to -340 m level, which will supply water to the ramp for fire protection and water to the experiments has been finalised during this year.

Scope of work for 2005

Work planned and goals for 2005 are summarised below:

- Safety of the personnel is of main concern and safety-related education and fire fighting training will be held. Improvements to be made in the fire protection system were identified in a fire hazard analysis for the underground facility. An extensive inspection of the rock in the underground facility will be performed during the autumn and the long term rock control and reinforcement programme will be continued.
- One of the main targets for a number of years has been to increase the reliability in the underground-related systems. The goal for 2005 is to provide an availability of 99%.
- The maintenance and service of equipment, installations, and vehicles shall be of high quality. A computerised system for the purchase of machines and vehicles is available in order to improve the documentation, follow-up, and effectivity of maintenance.
- Plan and complete the extension of the facility.
- A goal for the environmental work is to decrease the energy consumption with 5%. This is to be done by mechanical trimming of the underground ventilation system and also by informing the staff about energy saving activities.

5.2 Hydro Monitoring System

Background

The monitoring of groundwater changes (hydraulic and chemical) during the construction and operation of the laboratory is an essential part of the documentation work aiming at verifying pre-investigation methods. The great amount of data calls for an efficient data collection system and data management procedures. Hence, the Hydro Monitoring System (HMS) for on-line recording of these data have been developed and installed in the tunnel and at the surface.

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

As an effect of the excavated tunnel, the groundwater levels in the core drilled boreholes in the vicinity of the tunnel have been lowered up to 100 meters. Because of this the installations in the boreholes, e.g. the stand pipes (plastic tubes) in the open boreholes 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 boreholes 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.

Present status

The measuring system is at present working satisfactorily.

Scope of work for 2005

The activities during 2005 comprise operation, maintenance and documentation of the HMS 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. The monitoring of water level in surface boreholes started in 1987 while the computerised HMS was introduced in 1992. The number of boreholes included in the network has gradually increased. The tunnel construction started in October 1990 and the first pressure measurements from tunnel drilled boreholes were included in the HMS in March 1992. The tunnel excavation began to affect the groundwater level in many surface boreholes during the spring 1991.

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.

Present status

To date the monitoring programme comprises a total of 127 boreholes (52 surface boreholes and 75 tunnel boreholes). Many boreholes are equipped with inflatable packers, dividing the borehole into different sections, and the pressure is measured by means of pressure transducers. The measured data is relayed to a central computer situated at Äspö village through cables and radio-wave transmitters. Once a year, the data is transferred to SKB's site characterisation database, Sicada. Manual levelling is also obtained from the surface boreholes on a regular basis (once a month). Water seeping through the tunnel walls is diverted to trenches and further to 22 weirs where the flow is measured.

Scope of work for 2005

The measuring points from the previous years will be maintained.

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 boreholes drilled from the ground surface and from the tunnel.

Objectives

At the beginning of the Äspö HRL 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.

Present status

The last monitoring campaign was performed as planned and initial data gave a broad general geochemical overview of the tunnel, see example in Figure 5-1. Chloride concentration varied in general from 590 mg/l to around 9,700 mg/l from the most shallow boreholes to the deepest ones. A few samples showed increased concentrations of chlorides, up to about 14,500 mg/l, as well as other main components.

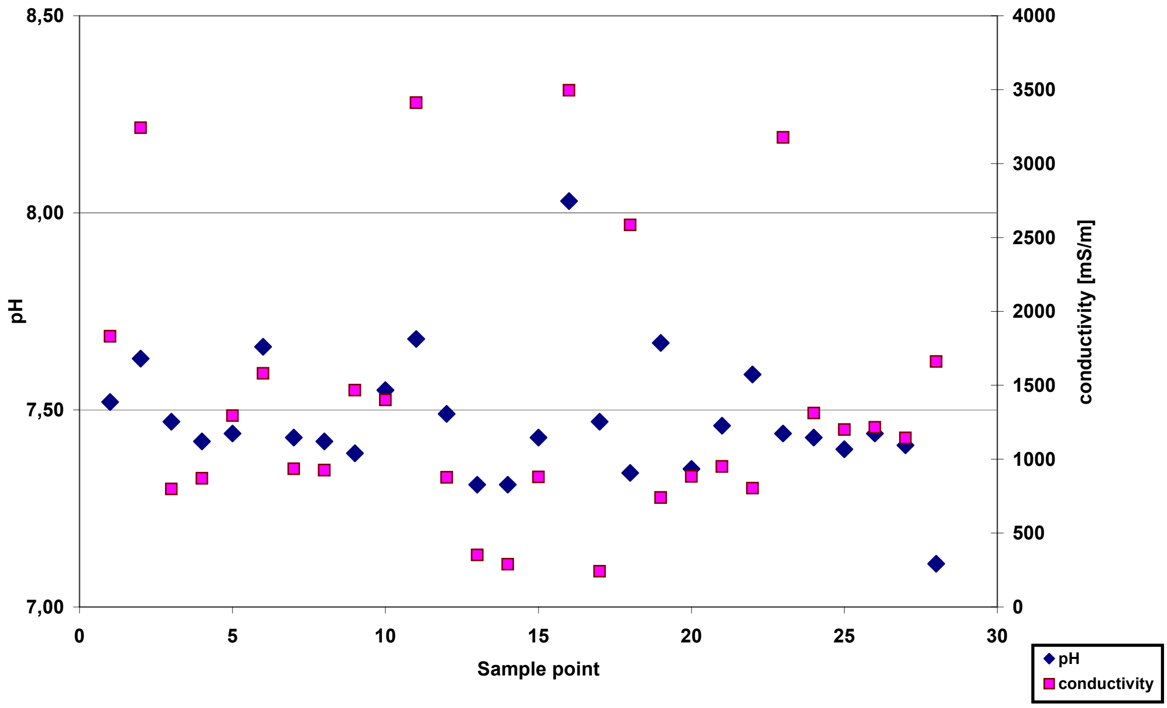

Figure 5-1 Measured pH and electric conductivity in the groundwater in the different sample points. Data is from the last monitoring campaign.

Scope of work for 2005

One hypothesis of these few "hot-spots" of increased salinity in the Äspö-tunnel may be a possible effect of up-coning from deeper, much more saline, old waters of so called brine composition. This effect will be furthered studied also in combination with interactions from the sub-surface and surface hydrogeochemical groundwater composition.

5.5 Information and public relations

Background

SKB operates three facilities in the Oskarshamn municipality: Äspö HRL, Central interim storage facility for spent nuclear fuel (Clab) and Canister Laboratory. In 2002 SKB began site investigations including drilling of deep investigation boreholes at two sites, whereof one site is at Simpevarp.

The main goal for the Information and public relations group is to create public acceptance for SKB, which is done in co-operation with other departments at SKB. The goal will be achieved by presenting information about SKB, the Äspö HRL, and the SKB siting programme on surface and underground.

During the year 2004, the Äspö HRL and the site investigation activities were visited by about 10,000 visitors. The visitors represented the general public, municipalities where SKB perform site investigations, teachers, students, politicians, journalists, and visitors from foreign countries.

The total number of visitors to all SKB facilities, Äspö HRL, Clab, Canister Laboratory and SFR was almost 25,000. The information group has a special booking team at Äspö HRL which books and administrates all visitors.

Planned special events for 2005

During the year 2005 the summer tours for the general public, called U500, starts in June and finishes up in August. The goal is to reach 2,750 visitors this year.

An annual event "The Äspö Day" takes place on May 29. It is an open house where the visitors can visit the underground laboratory and also participate in tours on the ground. These tours provide information on e.g. geology, history and nature. The plan is to have 300 visitors.

On September 29 "The Geology Day" will be celebrated for the fifth time in Sweden. SKB invites the public to take part in a special train tour through the nearby landscape. At "geological stops" geologists and SKB guides will inform about the work to find a suitable site for a deep repository.

6 International co-operation

6.1 General

Nine organisations from eight countries will participate in the co-operation at Äspö HRL during 2005. Most of the participating organisations are interested in groundwater flow, radionuclide transport, rock characterisation, and THMC modelling. Several organisations are participating in the two Äspö Task Forces on: (a) 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, and (b) THMC modelling of Engineered Barrier Systems, which is a forum for code development on THMC processes taking place in a bentonite buffer and gas migration through a buffer.

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. Descriptions of the main activities to be performed by the different organisations during 2005 are given in the following sections.

Table 6-1 International participation in the Äspö HRL projects during 2005.

Projects in the Äspö HRL during 2005	Andra	BMWA	Enresa	CRIEPI	JNC	Nagra	OPG	Posiva	Rawra
Technology									
Prototype Repository	X	X			X			X	
Backfill and Plug Test									
Long Term Test of Buffer Material								X	
Cleaning and sealing of investigation boreholes								X	
Injection grout for deep repositories								X	
KBS-3 method with horizontal emplacement								X	
Large Scale Gas Injection Test	X	X					X		
Temperature Buffer Test	X	X	X						
Task Force on Engineered Barrier Systems	X	X		X		X	X	X	X
Geo-science									
Äspö Pillar Stability Experiment							X	X	
Natural barriers									
Tracer Retention Understanding Experiments	X				X			X	
Long Term Diffusion Experiment							X		
Radionuclide Retention Project		X							
Colloid Project		X						X	
Microbe Project		X							
Matrix Fluid Chemistry									
Task Force on Modelling of Groundwater Flow and Transport of Solutes	X			X	X			X	

6.2 Andra

L'Agence Nationale pour la Gestion des Déchets Radioactifs (Andra) provides experimental and modelling support to the Äspö HRL with emphasis on site characterisation and on engineered barrier systems, EBS, to complement research activities in France. Andra's participation aims at enhancing the understanding of flow and transport in fractured rock and to evaluate experimental and modelling approaches in view of site characterisation.

In conjunction with SKB's development of experiments related to the repository system, Andra is carrying out research on EBS for either spent fuel or reprocessed waste. An objective is to extend current THM understanding of bentonite buffer behaviour during saturation to include high temperatures. The knowledge gained in the EBS field is valuable for granite host rock, but also for clay host rock.

The scopes of Andra's contributions in different projects during 2005 are described below.

6.2.1 Prototype Repository

THM evolution in buffer and backfill in the Prototype Repository will be evaluated through sensors data reports analyses. Further evaluation modelling is not foreseen during 2005.

6.2.2 Large Scale Gas Injection Test

Being a new partner in the Large Scale Gas Injection Test (Lasgit), Andra intends to support a modelling team to predict the HM behaviour of the bentonite buffer, first during the hydration phase, and later when subjected to gas injection tests.

6.2.3 Temperature Buffer Test

The Temperature Buffer Test (TBT) should be left without changes in boundary conditions, notably the hydraulic one, until the bentonite buffer is fully saturated.

Tests on a mock-up designed to mimic the conditions of field TBT will be conducted in France by Commissariat à l'Energie Atomique, CEA. Predictive and evaluation modelling of these mock-up tests will be carried out during 2005.

6.2.4 Task Force on Engineered Barrier Systems

In the Task Force Andra intends to participate in the THM modelling dedicated to 1D mock-up tests carried out on bentonite both by Ciemat in Spain and by CEA in France.

6.2.5 True Block Scale Continuation

The reporting of BS2b modelling predictions performed by Andra-Itasca and for an evaluation of these results will be done during 2005. It will also be time for thinking and decision about what a BS3 phase should be and how partners would participate in it.

Many True experiments have produced a lot of data, and interpretation has already brought significant improvement in transport and retention understanding. Nevertheless, more lessons are still to learn through either a global reinterpretation of existing geological and tracer test data, or rock investigations pursuing better understanding of fractures.

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

Modelling tasks based on different approaches and numerical codes are carried out by CEA and Golder Associates for Andra.

Simulations of True Block Scale tracer test C2 using a semi synthetic hydro structural model within Task 6D is completed. The ongoing Task 6E, dedicated to transport in the fractured block within performance assessment time scales, will end during 2005.

A new sub-task came out from Task 6 Workshop held at Krägga in 2003. In order to be able to compare results of various modelling groups, a series of benchmark runs on simple system will be made. The simple systems to be modelled consists of "building block" from sub-task 6C model, i.e. single feature of geological structure Type 1 and Type 2, respectively. Simulations of flow and transport in single Type 1 and Type 2 features will be achieved during 2005.

6.3 BMWA

The first co-operation agreement between Bundesministerium für Wirtschaft und Arbeit (BMWA) and SKB was signed in 1995. The agreement was extended in 2003 for a period of six years. Five research institutes are performing the work on behalf of and funded by BMWA: BGR, DBE Tec, FZK, FZR, and GRS.

The purpose of the co-operation with the HRL Äspö programme is to improve the knowledge on the engineered barrier system and on potential host rocks for radioactive waste repositories in Germany. The topics of special interest are:

- Behaviour of the bentonite buffer.
- Characterisation of fracture zones in the rock mass and disturbed zones surrounding underground openings.
- Geochemical investigations of the migration behaviour especially of actinides under near-field and far-field conditions.
- Geochemical modelling of individual processes controlling migration.
- Thermodynamic databases for radionuclides relevant for long-term safety.
- Behaviour of colloids and microbes and their respective interaction with radionuclides.
- Groundwater flow and transport of solutes.

The work to be carried out in 2005 is described below.

6.3.1 Prototype Repository

Measurements of the electric resistivity distribution are performed in the backfill, the buffer, and the rock between two of the deposition boreholes. Since there is a direct correlation between solution content and electric resistivity, these measurements can be used to monitor the water uptake in backfill and buffer, and the potential desaturation of the rock.

The following automatic measurements are performed on daily bases:

- Tomographic dipole-dipole measurements using electrode arrays installed in the backfill in Sections I and II, and in the buffer at the top of deposition hole #5.
- Wenner measurements along three electrode chains placed in boreholes located between the deposition holes #5 and #6.

The recording unit for these arrays is controlled remotely from Braunschweig in Germany via a telephone connection. The data are evaluated monthly. The evaluation comprises determination of the resistivity distribution around the electrode arrays by inverse modelling using the code SensInv2D. From laboratory measurement results obtained during an earlier phase of the project, the resistivity distributions can be interpreted in terms of solution content of the backfill, the buffer, and the rock, respectively.

Fibre optics temperature and pressure sensors are installed in deposition holes #5 and #6. Measurement values are being recorded and documented. The values are compared, checked and tested for plausibility and reliability with results of other project partners.

Scope of work for 2005

The daily measurements of the electric resistivity distribution will be continued. Data evaluation will be performed in Braunschweig and contributions to SKB's sensor data reports will be provided on a quarterly basis. To increase the confidence in the results of the inversions of the apparent resistivities measured *in situ*, a laboratory experiment is prepared in which controlled water uptake in drift backfill will be simulated and monitored by geoelectric measurements. The comparison between the known state of water uptake and the results of the measurements will allow better assessment of the inversion accuracy.

Based upon the results of the temperature fibre optic sensors, it is planned to build a 3D-model to analyse the thermal behaviour of the bentonite buffer of a single canister. Afterwards, the thermal evolution of the whole experiment will be simulated.

6.3.2 Large Scale Gas Injection Test

The work being conducted as part of the Lasgit project focuses both on the investigation of processes and interactions occurring in the experiment and the behaviour and nature of the engineered barriers system and the excavation disturbed zone (EDZ). Surface packers are to be used to determine the hydraulic properties of the tunnel wall EDZ in the millimetre range, and mini packers to determine the dependence of permeability on depths within the EDZ. Threshold pressures are measured by gas tests. Tracer tests with gas to determine transport relevant features of the EDZ will be performed.

Test evaluation and modelling exercises are executed by using the finite-element code Rockflow/Rockmech (THM-code).

Scope of work for 2005

The surface packer tests that have already been performed are to be complemented by additional tests with modified conditions. Furthermore, gas tracer tests will start when the buffer is saturated. The Rockflow finite-element code will be upgraded to include THMC coupled processes, both for the analysis of the permeability and gas tracer tests and for modelling of processes in the engineered barriers system and the EDZ.

6.3.3 Temperature Buffer Test

The aim of the test is to improve the understanding of the thermo-hydro-mechanical behaviour of clay buffers at temperatures around and above 100°C. The effects of the temperature on the bentonite behaviour will be recorded and evaluated.

Fibre optic sensors monitoring temperature, total pressure, and porewater pressure are installed. Besides data recording, it is also important to test and evaluate the sensors with regard to their long-term reliability, plausibility, and corrosion stability to proof their suitability for monitoring technical barriers. Measurements are accompanied by TH-modelling. Decommissioning and final evaluation of the devices are part of the activities.

Scope of work for 2005

Measurement values from the fibre optic sensors will be continuously recorded, documented and analysed by using numerical simulation methods. In the area of data recording a technical modification (optical switch) is intended.

After developing and testing of a detailed 3D numerical model to simulate the temperature evolution, it is planned to simulate the thermal evolution of the whole TBT-experiment. Afterwards, modelling of the porewater pressure evolution is intended, firstly by applying coupled TH-calculations and, secondly by coupled THM-calculations using the total pressure values.

6.3.4 Task Force on Engineered Barrier Systems

The Task Force on Engineered Barrier Systems has the objectives to verify the ability to model THM and gas migration processes in the buffer and, to refine and improve codes (coupling and 3D-capabilit). The work will be performed on the basis of appropriate benchmarks.

Proposals for the codes to be used, the benchmarks and, the databases for the benchmarks were discussed at a kick-off meeting in October. BMWA will use the codes Rockflow/Rockmech and Vapmode (Vapour diffusion).

In 2005 the activities to be performed are determined by the Task Force EBS schedule. It is required to submit first modelling results in the middle of 2005.

6.3.5 Radionuclide Retention Experiments

The objectives of FZK/INE's *in situ* actinide migration experiment in the Äspö HRL are to examine the applicability of laboratory data to natural conditions and to verify the laboratory sorption studies, and to reduce uncertainties connected with the actinide behaviour in a granitic environment. The migration experiments were performed in individual fractures in drill cores in the laboratory and in the Äspö HRL. To guarantee most realistic conditions - as close to nature as possible - the experiments are performed in the Chemlab 2 probe. Important aspects in these experiments cover the breakthrough of the tracers and the quantification of sorbed actinides along the flow path after termination of the migration experiments.

In 2004, a migration experiment was performed providing a residence time of U and Tc for about 8 month (core #7, open fracture). A report and publications about this experiment are under preparation.

Migration experiments are complemented by batch experiments providing detailed information on the relevant retention processes for actinides onto granite and altered fracture material. α-autoradiography and XPS were used to quantify local sorption properties of the rock samples. It was shown that sorption of U is strongly correlated with the occurrence of iron oxide phases, however, the surface related sorption coefficient of U(VI) onto weathered granite is by a factor of about 100 less than the sorption coefficient of Pu(IV) and by a factor of 10 less than of Np(V).

Scope of work for 2005

In 2004, it was intended to terminate the *in situ* migration experiments. Presently, the U/Tc migration experiment is still running, showing a certain increase of the uranium concentration in the eluted water after several month. In 2005, the core #7 will be recovered and analysed with respect to the radionuclides under investigation. At the beginning of 2005, the present experiment will be terminated in Chemlab 2. The core will be transferred to FZK/INE´s laboratory, prepared, cut and analysed.

Further, migration experiments are planned in connection with the Colloid Project. With regard to an extension of the actinide migration experiments in Chemlab 2, it was agreed by SKB to use the True-1 site for a colloid migration experiment. In a first phase of the experiment, colloid migration will be investigated based on the experience gained in the actinide migration technique. For this reason, Chemlab 2 together with the glove box will be transferred to borehole KXTT 3/3 and 4/4. Core #6 was prepared and is available for Chemlab 2. On the basis of experimental data on colloid stability in the groundwater of this borehole, the actinide-colloids will be prepared and applied in Chemlab 2. The sampling procedure and the analysis of the solid materials will be performed as in the previous experiments.

6.3.6 Colloid Project

To obtain insight into the behaviour of colloids under conditions relevant to the situation in the vicinity of a repository in deep underground, a Colloid Dipole experiment is planned on the transport of colloids and colloid facilitated transport of radionuclides. For preparation of such experiments, the existence and properties of natural aquatic colloids present in the selected groundwater are of particular importance.

In 2004, additional background colloid measurements were performed at different sites at Äspö HRL, including the KXTT 3/3 and KXTT 4/4 boreholes. In 2005, measurements and sampled groundwaters will be investigated further. The stability of a colloid bearing cocktail will be investigated and prepared to be used in Chemlab 2.

A prerequisite of these investigations is a support by a post-doc scientist send to FZK-INE by SKB. Within his/her stay at INE, a study on stability and preparation of colloids will be performed as well as the characterisation of size and properties of the colloids to be injected.

Scope of work for 2005

A colloid migration experiment is planned at the Äspö HRL in a Colloid Dipole experiment carried out in a hydrologically well-defined fracture (True-1 site).

Within 2005 it is planned to conduct a number of preparatory laboratory experiments:

- Experimental determination of colloid stability in groundwater from the site. (Stability of groundwater colloids and colloidal material from a selected bentonite are studied by light scattering methods).
- Investigation of metal ion interaction with colloids and fracture infill material. It is planned to study the behaviour of Eu(III), Hf(IV), Th(IV) and U(VI) as chemical representatives for the actinides occurring in nuclear waste.
- Study of colloid interaction (attachment) to fracture infill material.
- Extension of the mobile LIBD with a PC-based fast image processing system for direct on-line colloid size detection.

As an outcome of these laboratory investigations, the design of the colloid migration study will be defined.

After transfer, installation and test of Chemlab 2 and the actinide glove box to drillhole KXTT 3/3 and 4/4, core #6 will be inserted and an actinide-colloid experiment will be performed in Chemlab 2 using the sampling and analysis procedure as in the previous experiments.

6.3.7 Microbe Project

In the last three years, a project was performed investigating: (a) the interaction of actinides (U, Cm, Np and Pu) with relevant bacteria found in Äspö groundwater, (b) quantification of actinide bonding on bacteria in dependence of the chemical conditions in the groundwater, and (c) spectroscopic characterisation of the actinide complexes/compounds formed by interaction with microbes. This project was focused on the sulphate reducing bacterial (SRB) strain *Desulfovibrio äspöensis* which frequently occurs in the deep granitic rock aquifers at the Äspö HRL. The main outcome was the determination of the bonding of the actinides U, Cm, Np, and Pu to cells of *D. äspöensis.* The results obtained with the several actinides will be summarised in a final report.

Scope of work for 2005

A new project investigating the mobilisation of actinides by microbial ligands released by relevant Äspö bacteria is planned to start in the middle of 2005. The aim is to clarify the complexation of the actinides U, Cm, and Np with microbial ligands and relevant model compounds. The formation constants determined in this project will be used directly in the speciation and transport models.

6.4 Enresa

SKB and Empresa Nacional de Residuos Radioactivos, S.A. (Enresa) signed a project agreement in February 1997 covering the co-operation for technical work to be performed in the Äspö HRL. Both parties renewed the Agreement in January, 2002.

6.4.1 Temperature Buffer Test

Enresa participates in the modelling aspects of the project. Predictive modelling performed during 2004 has been compared with the field measurements. Also, some changes in the code Code_Brigth, required to cope with the effect of the high temperatures in the HM performance of the barrier were performed.

Scope of work for 2005

Enresa will participate in the operational THM modelling of the data generated during 2005. A comparison between simulations and field measurements will be carried out and it will contribute to improve the models and the assumptions considered in the modelling work. In particular, the effect of high temperatures on the bentonite HM behaviour is considered to be a fundamental issue in this test. Some laboratory experiments will be performed as well in order to clarify that effect.

6.4.2 Integrated Project Esdred within 6th EU Framework Programme

Within the frame of the 6th EU Framework Programme Enresa participates in the Integrated Project Esdred which overall objective is to demonstrate the technical feasibility, at an industrial scale, for activities to be carried out to construct, operate, and close a deep geological repository in compliance with requirements on operational safety, retrievability and monitoring. Some of the demonstration work of the IP Esdred is scheduled to be done at the Äspö HRL. Enresa participates in – Low-pH shotcrete technology (IP Esdred M#4). The research work will be developed by Enresa, SKB, Posiva, Nagra, Aitemin and CSIC. Enresa acts as co-ordinator.

Scope of work for 2005

The basic objective of the research activities is to develop solutions for the use of low-pH shotcrete for the construction of plugs, for the sealing of disposal galleries, and of rock support.

In this sense, the specific objectives of the proposed activities are:

- Development of low-pH shotcrete formulations for industrial application in repository construction.
- Development or adjustment of the required low-pH shotcrete techniques for construction of repository plugs and rock support.
- Full scale demonstration of a low-pH shotcrete plug and rock support (in Äspö HRL).

The installation of the shotcrete plug in the Äspö HRL in the KBS-3H gallery excavated at the -220 m level, is schedule to start during the fall of 2005.

6.5 CRIEPI

Central Research Institute of Electric Power Industry (CRIEPI) made a contract with SKB for the Äspö HRL Project in 1991 and renewed it 1995, 1999 and 2003. Since 1991, CRIEPI has participated in the exchange of information concerning research and technology for geological disposal of high-level radioactive wastes with other organisations within the Äspö HRL co-operation. In addition, CRIEPI has performed a few voluntary works, groundwater dating, fault dating, and measurement of velocity and direction of groundwater flow etc., as well as participated in the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

The main objectives of CRIEPI's participation are to demonstrate the usefulness of its numerical codes, develop its site investigation methods, and improve the understanding of the mechanisms of radionuclide retention in fractured rock and the interaction between engineered barriers and surrounding rock.

In 2005, CRIEPI will participate in the following projects:

- Task Force on Engineered Barrier Systems.
- Task Force on Modelling of Groundwater Flow and Transport of Solutes.
- Voluntary project on impact of microbes on radionuclide retention.

In addition, CRIEPI will take part in information exchange on research, disposal technologies and methodologies for site investigations. CRIEPI's activities in the individual projects during 2005 are summarised below.

6.5.1 Task Force on Engineered Barrier Systems

It is important to evaluate the phenomena around engineered barrier system, since the conditions of engineered barriers will influence the radionuclide transport. CRIEPI has been developing the coupling simulation code of thermo-, hydro- and mechanical (THM) processes expected in engineered barriers and surrounding rock mass. In order to validate and improve the code, CRIEPI will participate in the Task Force on Engineered Barrier Systems.

In 2004, CRIEPI started to apply its numerical code for the thermo-hydraulic infiltration tests selected as the first benchmark of THM processes. In 2005, CRIEPI will continue to perform benchmarking calculations and submit the results.

6.5.2 Task Force on Modelling Groundwater Flow and Transport of Solutes

CRIEPI has been developing numerical codes for the analyses of groundwater flow and solute transport in rock formation to assess the safety of disposal facilities of radioactive wastes. CRIEPI does not have its own underground rock laboratory. Therefore CRIEPI will continue to participate in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes to apply its numerical codes to the *in situ* experiments and demonstrate their usefulness.

During 2005 CRIEPI will apply its numerical code for groundwater flow and solute transport in rock mass, FEGM, to Task 6E and 6F and write international progress reports that summarise the results for modelling of these tasks. In addition, CRIEPI will start the computational work for Task 7, modelling of an interference test at the Onkalo site in Finland.

6.5.3 Voluntary project on impact of microbes on radionuclide retention

Microbes can affect the redox potential and pH of the environment by their metabolic activities such as aerobic respiration, iron and sulphate reduction, and acid production, which in turn affects radionuclide solubility and hence migration. The purpose of the study is to understand microbial influences on geochemistry of the environment and radionuclide retention under an *in situ* physical and chemical condition.

CRIEPI will investigate the microbial impacts on geochemistry using the groundwater circulating system with crushed-rock-packed columns at the CRIEPI's laboratory in Japan. In 2005, the groundwater under the pressure of *in situ* condition in granite rock will be sampled at Äspö. The effects of groundwater pressures (i.e., *in situ* and atmospheric pressure) and an inhibitor of microbial activity on geochemistry of groundwater will be investigated. During the experiments, variations of microbial community in the system will be analysed by a molecular technique.

6.6 JNC

Japan Nuclear Cycle Development Institute (JNC) is currently constructing underground research laboratories in fractured granite at Mizunami and in sedimentary formation at Horonobe. The aims are to establish comprehensive techniques for investigating the geological environment and to develop a range of engineering techniques for deep underground applications. The results obtained from these laboratories will contribute to ensure the reliability of repository technology and establish a safety assessment methodology. JNC also continues to be active in the research at Äspö HRL, which is directly applicable to the Japanese programme.

The objectives of JNC's participation in Äspö HRL during 2005 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

These objectives are designed to support high level waste repository siting, regulations, and safety assessment in Japan.

6.6.1 Prototype Repository

JNC will continue to participate in the Prototype Repository project. JNC will carry out simulation analysis for thermo-hydro-mechanical (THM) and thermo-hydro-mechanical-chemical (THMC) coupled process modelling using software developed by JNC.

During 2005, JNC will carry out long-term prediction calculation on coupled THM phenomena using the input data modified on the basis of the results from the back analysis of the three-dimensional prediction using the monitored data. JNC will also continue to develop the full-way coupled THMC code.

6.6.2 True Block Scale Continuation

JNC has participated the True Block Scale Project since 1997. During 2005, JNC participation in the True Block Scale Continuation Project will focus on improving the understanding of flow and transport in the background fracture (BG#1) tested during 2004. JNC will improve the micro-structural and hydrostructural models developed during the project, and prepare reports and professional publications from the work.

6.6.3 Task Force on Modelling Groundwater Flow and Transport of Solutes

JNC will continue to participate in the Äspö Task Force on Groundwater Flow and Transport of Solutes during 2005. Activities during 2005 will focus on the Task 6 – Performance assessment modelling using site characterisation data. 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 2005, JNC will study the implications of site characterisation for safety assessment modelling within the context of the sub-tasks 6D, 6E, and 6F. JNC will simulate radionuclide and tracer transport on time scales of site characterisation and safety assessment within a 200 m scale block of "semi-synthetic" Äspö granite.

JNC modelling during 2005 is expected to primarily consist of detailed FracMan discrete fracture network transport simulations. All simulations will be carried out with the complex hydrostructural model defined in sub-task 6C. Simulations will be designed to identify the role of site characterisation to reduce uncertainties in safety assessments, particularly during the early stages of site characterisation.

6.7 Nagra

Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, has the task to provide scientific and technical basis for the safe disposal of radioactive waste in Switzerland. Nagra has had agreements with SKB for participation in Äspö HRL since 1994 to include mutual co-operation and participation in Äspö HRL and Grimsel Test Site projects. The last agreement expired 2003 and Nagra has now left the central and active core of participants.

6.7.1 Task Force on Engineered Barrier Systems

Nagra is taking part in the Task Force on Engineered Barriers during 2005.

6.8 OPG

In January 2004, Ontario Power Generation Inc. (OPG) signed a five-year agreement with SKB for participation in the Äspö HRL. The prime objective of OPG's participation at Äspö HRL is to enhance the Canadian technology base for a deep geologic repository through international co-operation projects. The committed work on Äspö HRL projects to be carried out in 2005 is described below. Other tasks are under discussion.

6.8.1 Large Scale Gas Injection Test

OPG joined the Lasgit project in late 2004. In 2005, OPG intends to provide modelling support. The first task is the selection of a gas migration model and adaptation of this model to include processes considered to be relevant for the experiment.

6.8.2 Task Force on Engineered Barrier Systems

OPG is in the process of joining this Task Force. We have proposed to participate in the THM modelling Task, using Codebrite. We have also proposed to provide experimental data from the isothermal test and the buffer/container test as benchmark cases for the Task Force. These were large-scale *in situ* tests conducted at the AECL URL.

6.8.3 Äspö Pillar Stability Experiment

In 2004, OPG's provided a calibrated AECL linear variable differential transformer (LVDT) instrument and technical support for its installation. This instrument was removed when the test was concluded and shipped back to AECL for re-calibration. In 2005, the results will be analysed and reported at the annual project workshop.

6.8.4 Long Term Diffusion Experiment

In 2004, OPG provided a review of the SKB experiment plan, based on experience with long-term *in situ* diffusion experiments in Canadian Shield granite at the AECL URL. In those experiments, complementary laboratory tests were made to compare with the results from the *in situ* diffusion tests.

As part of the present agreement, a complementary laboratory based diffusion experiment programme has been initiated at AECL. The rock samples from Äspö HRL arrived in late fall, and the experiments have been initiated. These experiments will continue in 2005.

6.9 Posiva

Posiva's co-operation with SKB has deepened due to the new co-operation agreement during the year 2002. The main focus of the co-operation has been on encapsulation and repository technology. Posiva also contributes to several of the research projects within Natural barriers. The implementation and construction of the underground rock characterisation facility Onkalo at Olkiluoto in Finland give new possibilities to co-operate within the research and development of underground construction technology.

The organisation is participating in the following projects:

- Technology: Prototype Repository, KBS-3 method with horizontal deposition, Large Scale Gas Injection Test, Injection grout for deep repositories, Long Term Test of Buffer Material, Cleaning and sealing of boreholes.
- 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.

Posiva's co-operation is divided between Äspö HRL and more generic work that can lead to demonstrations in Äspö HRL. The work planned to be performed within the different projects during 2005 is described below.

6.9.1 Prototype Repository

This co-operation concentrates to the ongoing Prototype Repository experiment, but utilises also the additional results available from the Long Term Test of Buffer Materials (LOT). Work will be performed on geochemical data-interpretation and modelling in collaboration with SKB.

The basic tools for the data-interpretation of geochemical reactions are a critical data evaluation and inverse (mass-balance) modelling attempts. The interpretation aims at determine the prevailing geochemical reactions within the backfill system.

The data-interpretation task needs data from chemically analysed samples, and it can be applied to various parts of the Prototype Repository (e.g. tunnel backfill, repository near field, and deposition holes). There are already some gas and few water sample results available. There are a number of groundwater results available from the repository bedrock surroundings. If there are time dependent changes in these sampling results, the reasons for these changes may become topical issues. In addition, the LOT experiment has produced plenty of results about the behaviour of canister buffer. These results will be utilised, when appropriate, in current studies. In 2005, the next extraction of a LOT-parcel will produce new series of data.

In the modelling task hypothesised (or identified) geochemical processes are used to predict final water or gas compositions. The processes (utilised in the planned calculations) are prospected and verified as much as possible within the data-interpretation task. The data-interpretation task is of primary concern at the beginning of studies.

There has been an earlier batch reaction oriented attempt to model porewater compositions and solid phase equilibria in the Prototype Repository /Luukkonen, 2004/. Re-valuation of these modelling results could be a starting point to the new modelling attempts. However, the ambitions in calculations should be adjusted to the amount of available control points, as well as, to the frequencies of the control samplings. Eventually, the prediction versus outcome comparisons are necessary in this modelling task.

6.9.2 Long Term Test of Buffer Material

Posiva has participated in this project since 1999. The work is performed at VTT and the aim is to produce knowledge about the evolution of the chemical conditions in bentonite.

During the first phase, methods were developed for the studies of bentonite pore water. Those results have been reported /Muurinen, 2001/. The developed methods were utilised when the parcel A0 was excavated in October 2001 and the results have been reported in a Posiva Working Report.

The planning of the extraction of a five-year parcel will start during 2005 and the extraction is planned to be in September. Clay Technology takes care of the extraction and cutting of the parcel. VTT's representative follows the uplift and takes care of the shielding of the VTT's samples and their transportation to Finland.

According to the preliminary plan bentonite samples to be studied in Finland will be taken from seven different bentonite blocks (10, 12, 16, 18, 24, 32 and 34). The size of the samples is determined by the size of the transportation vessel (20 cm in diameter and 13 cm in height). The additives and the ampoules for water sampling will be left in the clay. Oxygen will be removed with nitrogen flushing from the transportation vessels. Each sample will be cut into smaller pieces in a nitrogen glove box in order to avoid changes caused by diffusion. Simultaneously the ampoules will be removed to avoid suction of the water into the bentonite.

Pore water will be squeezed from 15 samples. They will be selected so, that one can obtain information about the effects caused by the additives and the distance from the heater/rock. The chemistry of the waters in the ampoules will be studied and compared with the pore waters. Similar methods will be used as for the parcel A0. The water contents and exchangeable cations will be determined in the same samples from which the pore waters will be squeezed.

6.9.3 Cleaning and sealing of boreholes

Phase 2 of the project ended in 2004 and a SKB´s report presenting a basic concept for sealing of boreholes with a length of up to about 1,500 m will be issued. The proposed principle is that a plugged hole must not serve as a continuous flow path for groundwater but be sealed to get the same or lower conductivity than the surrounding rock. Three main procedures are required: 1) clearing and stabilisation of the boreholes, 2) construction and emplacement of plugs, and 3) sealing and securing of the uppermost parts, which will be exposed to the external processes.

Construction and emplacement of plugs can be different in different parts of the holes. A basic concept is proposed that is based on the use of highly compacted smectite clay where tight seals are needed and on casting cement-stabilised plugs where the holes pass through fracture zones.

6.9.4 KBS-3 method with horizontal emplacement

The demonstration phase of the KBS-3H-project includes test boring at Äspö, planning the construction of the emplacement equipment, and safety evaluations. This project will be jointly executed by SKB and Posiva and have a common steering group. Posiva's main involvement in the project will be the evaluation of the long-term safety aspects.

6.9.5 Large Scale Gas Injection Test

This project will be jointly executed by SKB and Posiva and have a common steering group. The installation phase of the experiment is planned to be completed before the summer and the artificial water saturation of the buffer will start thereafter. The gas injection tests will start when the buffer is fully water saturated.

6.9.6 Äspö Pillar Stability Experiment

The objective of Posiva's work is to contribute to the planning and steering of the project. According to the current situation the Finnish contribution to the complementary modelling work will be decided later.

6.9.7 True Block Scale Continuation

From Posiva's point of view this project is useful for learning more about groundwater flow and tracer transport in a network of fractures. This can be used as a basis for flow and transport conceptualisation in performance assessment.

The predicted True Block Scale Continuation tracer tests (BS2b tests) will be evaluated and reported during 2005.

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

Task 6E and 6F modelling will be finalised and reported during 2005. Task 6E is about the modelling of the radionuclide transport through a fracture network at performance assessment conditions. Task 6F includes simplified transport calculations for model comparison and sensitivity analysis.

6.9.9 Task Force on Engineered Barrier Systems

Posiva is taking part in the Task Force on Engineered Barriers in the part of THM modelling of processes during water transfer in buffer, backfill and near-field rock. During the year 2005 the purpose is to simulate the THM(C) behaviour of the EBS in KBS-3V and KBS-3H concepts, including the effects caused by the installation gaps. The computer code, which is used in the simulations, is FreeFEM++.

These investigations are connected to the work, which is done in the NF-Pro EC-project and in the Antti Lempinen's doctoral thesis (Thermo-Hydro-Mechanical Analyses of KBS-3V deposition hole). The thesis will also be published as a Posiva report during the next year.

6.9.10 Injection grout for deep repositories

The project Injection grout for deep repositories aims at achieving some well quantified, tested and approved low-pH injection grouts that can be used in the construction of a deep repository. The project is a joint project between Posiva, SKB and Numo in Japan. A pre-study was carried out in 2001, followed by a feasibility study in 2002–mid 2003. The project is divided into four sub-projects: 1) Low-pH cementitious injection grout for larger fractures, 2) Non-cementitious low-pH injection grout for smaller fractures, 3) Field testing in Finland, and 4) Field testing in Sweden. The sub-project connected to Äspö HRL was completed in 2004. No activities are planned at Äspö HRL during 2005.

Posiva is responsible for implementation of SP1 − Low-pH cementitious injection grout for larger fractures, and SP3 − Field-testing in Finland. The aims are to develop low pH grout for sealing wider fractures (> 100 µm) in the bedrock surrounding the deep repository and to perform a demonstration.

The scope for the year 2005 is to finish the project. Due to the results gained in the first pilot test it was noticed that small adjustment with the workability properties is still required before the execution of the small scale field test that is planned to be done in early spring 2005.

6.10 Rawra

Radioactive Waste Repository Authority (Rawra) is the state organisation is the state organisation in the Czech Republic responsible for the management of activities related to the disposal of radioactive waste.

6.10.1 Task Force on Engineered Barrier Systems

Rawra is taking part in the Task Force on Engineered Barriers in the part of gas migration in buffer with the computer code Gold Sim.

7 Environmental research

7.1 General

Äspö Environmental Research Foundation was founded 1996 on initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its resources available for national and international environmental research. SKB's economic engagement in the foundation was concluded in 2003 and the activities are now concentrated on the Äspö Research School.

7.2 Äspö Research School

Kalmar University's Research School in Environmental Science at Äspö HRL, called Äspö Research School, started in October, 2002. This School is the result of an agreement between SKB and Kalmar University. It combines two important regional resources, i.e. Äspö HRL and Kalmar University's Environmental Science Section. The activity within the School will lead to: (a) development of new scientific knowledge, (b) increase of geo and environmental scientific competence in the region and (c) utilisation of the Äspö HRL for environmental research.

Present status and Scope of work for 2005

Currently the scientific team consists of a professor of Environmental geology, three assistant supervisors and six Ph.D. students. The research activity focuses on biogeochemical systems, in particular in the identification and quantification of dispersion and transport mechanisms of contaminants (mainly metals) in and between soils, sediments, water, biota and upper crystalline bedrock. In addition to financial support from SKB and University of Kalmar, the School receives funding from the city of Oskarshamn.

There are currently a variety of research activities at sites outside Äspö HRL. These activities have resulted in several scientific publications, and the first Ph.D. dissertation will take place in 2005. In the Äspö HRL, however, the activities are as yet minor. A Ph.D. project focusing on hydrogeology is currently being planned (to be initiated in early 2005). Sampling of ground waters together with professor Karsten Pedersen´s group took place in spring (results as yet to be interpreted), and a strategy for interpreting existing hydrochemical data on transition metals have been made.

The goal during 2005 is to employ a research assistant and more Ph.D. students. The final goal of ten Ph.D. students can hopefully be reached in the year 2006 if the planned research activities are appropriate and the finances are sufficient.

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