International
Progress Report

IPR-06-16

Äspö Hard Rock Laboratory

Status Report
April – June 2006

Svensk Kärnbränslehantering AB

September 2006

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Laboratory

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Overview

The Äspö Hard Rock Laboratory (HRL) constitutes an important part of SKB's work to design and construct a geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site.

The plans for SKB's research and development of technique during the period 2005–2010 are presented in SKB's RD&D-Programme 2004 /SKB 2004/. The information given in the RD&D-Programme related to Äspö HRL is annually detailed in the Äspö HRL Planning Report /SKB 2006/.

This Äspö HRL Status Report is a collection of the main achievements obtained during the second quarter 2006.

Geoscience

Geoscientific research is a natural part of the activities at Äspö HRL and is conducted in the fields of geology, hydrogeology, geochemistry (with emphasis on groundwater chemistry) and rock mechanics. The major aims are to establish and maintain geoscientific models of the Äspö HRL rock mass and to establish and develop the understanding of the Äspö HRL rock mass properties as well as the knowledge of applicable measurement methods. Studies are performed within the projects: Geological Mapping and Modelling, Method Development of a New Technique for Underground Surveying, Seismic Influence on the Groundwater System, Inflow Predictions, Hydro Monitoring Programme, Monitoring of Groundwater Chemistry, Rock Mechanics and Äspö Pillar Stability Experiment.

Buffer materials and backfill technology

Before building a final repository, where the operating conditions include the deposition of one canister per day, further studies of the behaviour of the buffer and backfill under different installation conditions are required. SKB has decided to build a Bentonite Laboratory at Äspö designed for studies of buffer and backfill materials. The laboratory, a hall with dimensions 15×30 m, will include two stations where the emplacement of buffer material at full scale can be tested under different conditions. The hall will also be used for testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

Natural barriers

Many experiments in Äspö HRL are related to the rock, its properties and *in situ* environmental conditions. The goals are to increase the scientific knowledge of the safety margins of a final repository and to provide data for performance and safety assessment. The experiments performed at conditions expected to prevail at repository depth are: Tracer Retention Understanding Experiments (True Block Scale Continuation, True-1 Continuation and Completion), Long Term Diffusion Experiment, Colloid Project, Microbe Project, Matrix Fluid Chemistry Continuation and Radionuclide Retention Experiments.

Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are one main purpose of the Äspö HRL. The major project is the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes.

Engineered barriers

One of the goals for Äspö HRL is to demonstrate technology for and function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a real repository. A number of large-scale field experiments are therefore conducted at Äspö HRL: Prototype Repository, Long Term Test of Buffer Material, Backfill and Plug Test, Canister Retrieval Test, Temperature Buffer Test, KBS-3 Method with Horizontal Emplacement, Large Scale Gas Injection Test, In Situ Corrosion Testing of Miniature Canisters, Cleaning and Sealing of Investigation Boreholes, Alternative Buffer Materials, Rock Shear Experiment and Earth Potentials. THM processes and gas migration in buffer material are addressed in the Task Force on Engineered Barrier Systems.

Äspö facility

Important parts of the Äspö facility are the administration, operation, and maintenance of instruments as well as development of investigation methods. The Public Relations and Visitor Services 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.

Environmental research

On the initiative of the Äspö Environmental Research Foundation, the University of Kalmar has set up the Äspö Research School. The research school has a special interest in the transport of pollutants and their distribution in rock, groundwater and biosphere. The research school is co-financed by the municipality of Oskarshamn, SKB and the University of Kalmar.

International co-operation

The Äspö HRL has so far attracted considerable international interest. Nine organisations from eight countries participate in the co-operation or in Äspö HRL related activities, apart from SKB, during 2006.

Contents

1 General

The Äspö Hard Rock Laboratory (HRL), in the Simpevarp area in the municipality of Oskarshamn, constitutes an important part of SKB's work with design and construction of a deep geological repository for final disposal of spent nuclear fuel.

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. 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. The rock volume and the available underground excavations have to be divided between all the experiments performed at the Äspö HRL. In Figure 1-1, the allocation of a selection of the experimental sites in Äspö HRL is shown.

The Äspö HRL and the associated research, development and demonstration tasks, managed by the Repository Technology Department within SKB, have so far attracted considerable international interest. During 2006, nine organisations from eight countries participate in the co-operation or in Äspö HRL-related activities.

SKB's overall plans for research, development and demonstration during the period 2005–2010 are presented in SKB's RD&D-Programme 2004 /SKB 2004/. The planned activities related to Äspö HRL are detailed on a yearly basis in the Äspö HRL Planning Report. The role of the Planning Report is also to present the background and objectives of each experiment and activity. This Status Report concentrates on the work in progress and refers to the Planning Report /SKB 2006/ for more background information. The Annual Report will in detail present and summarise new findings and results obtained during the present year.

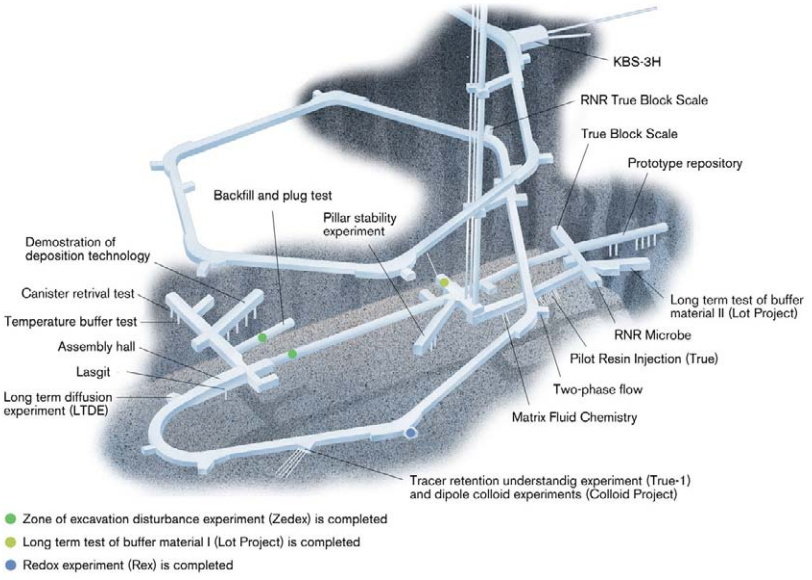


Figure 1-1 *Allocation of some of the experimental sites in Äspö HRL from -220 m to -450 m level.*

2 Geoscience

Geoscientific research is a natural part of the activities at Äspö HRL and is conducted in the fields of geology, hydrogeology, geochemistry (with emphasis on groundwater chemistry) and rock mechanics. Studies are performed in laboratory and field experiments as well as by modelling work. The major aims can be summarised as:

- Establish and develop the understanding of the Äspö HRL rock mass properties as well as the knowledge of applicable measurement methods.
- Establish and maintain geoscientific models of the Äspö HRL rock mass.

The activities further aim to provide geoscientific base data and to ensure high quality of experiments and measurements related to geosciences.

2.1 Geology

2.1.1 Geological Mapping and Modelling

The shallow niche NASQ0036A in the TASQ-tunnel

All rock surfaces and drill cores at Äspö are mapped. This is done in order to increase the understanding of geometries and properties of rock types and structures, which is subsequently used as input in the 3D-modelling together with other input data.

Modelling tasks are performed both in the general geological 3D-model of the Äspö rock volume (the former GeoMod-project) and in more detailed scale on smaller rock volumes.

Achievements

At present all rock surfaces and drill cores from the Äspö rock volume are mapped. This includes the new niche (NASQ0036A) for the Alternative Buffer Material project in the TASQ-tunnel (the latter excavated for the Äspö Pillar Stability Experiment). Some earlier mappings as well as the latest niche mapping are, however, still not digitised and associated geological data not entered into the TMS (Tunnel Mapping System). The data bases on the two TMS-computers are named tms-1.mdb and tms-2.mdb.

The drill cores from the ongoing core disking project in the TASQ-tunnel have all been logged in the BIPS/Bore map system by personnel from Vattenfall Power Consultant AB (former SwedPower AB). Some samples for thin sections have also been taken. The work with the geological model of TASQ-tunnel as well as of the rest of the tunnel system at the -450 m level of Äspö HRL continues. Complementary data and drawings from TMS have been delivered to Vattenfall Power Consultant AB in Gothenburg.

GeoVista AB has not yet completed the report concerning the true width of deformation zones by using magnetic anisotropy (AMS). The sampling took place in the TASA-tunnel.

2.1.2 RoCS – Method Development of a New Technique for Underground Surveying

Laser scanner (left) combined with digital camera on a separate tripod (middle) in the TASQ-tunnel

A feasibility study concerning geological mapping techniques is performed besides the regular mapping and modelling tasks. The project is conducted as an SKB-Posiva joint-project.

The major reasons for the RoCS (Rock Characterization System) 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, areas where the present mapping technique may not be adequate.

In 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.

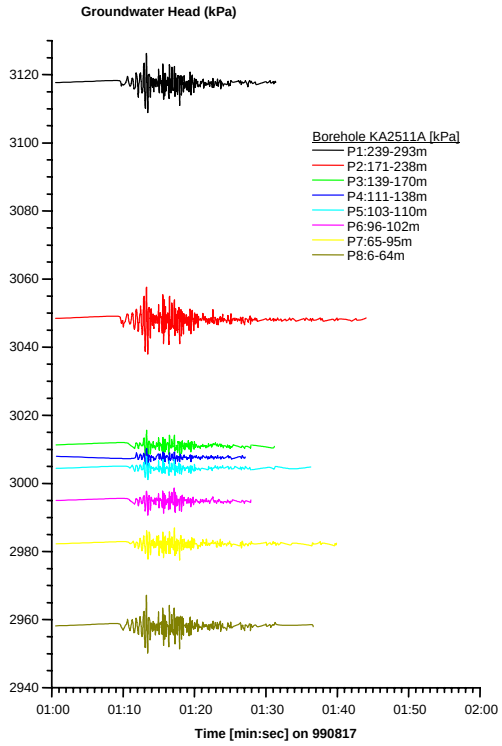
Achievements

The report concerning the RoCS feasibility study, phase 1, has been sent on review to BGS (British Geological Service). A meeting was held at Äspö HRL on the 1st of June 2006 where among other things reporting and how to proceed with the project were discussed.

Laser scanning combined with digital photography has been performed in the excavated shallow niche NASQ0036A (for the Alternative Buffer Material project) in the TASQ-tunnel and in the tunnel itself. The work, that only partly is a concern of RoCS, was executed by the firm ATS (Advanced Technical Solutions AB) in three stages; one before excavation and two after excavation of the niche. The purpose of this scanning is to get the TASQ-tunnel and niche with its installations documented in 3D. The promising results were presented at a meeting held at Äspö HRL on the 2nd of June 2006. The results can be used for e.g. tests on geological mapping, calculations of rock volume and tunnel geometries. Thus, the results can be of interest for personnel involved in RoCS as well as for people involved in e.g. design and maintenance work.

2.2 Hydrogeology

2.2.1 Seismic Influence on the Groundwater System



Hydraulic response at Äspö HRL to the Kocaeli earthquake in Turkey

The Hydro Monitoring System (HMS) registers at the moment the piezometric head in about 280 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. The seismic events also include blasting activities in and around the Äspö HRL.

By analysing the data on changes in the piezometric head at Äspö, connections to specific seismic events are expected to be established. The work is a reference for the understanding of dynamic influences on the groundwater around a final repository.

Achievements

Data are in the same way as earlier stored in HMS, waiting for future analyses.

2.2.2 Inflow Predictions

SKB has conducted a number of large field tests where predictions of inflow into tunnels or deposition holes have been a component: Site characterisation and validation tests in Stripa, Prototype Repository and Groundwater degassing and two-phase flow experiments in Äspö HRL. 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 to predict inflow is of importance from several aspects:

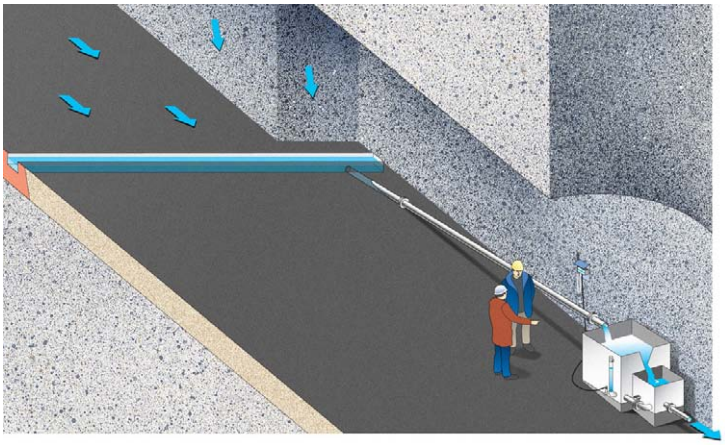
- Evaluation of experimental results from Äspö HRL. A good understanding of the mechanisms controlling inflow would improve the possibilities for good experimental set-ups and accurate result interpretation.
- Evaluation and comparisons between potential repository sites. It is desirable to be able to predict the inflow 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.

Achievements

A report about the hydro-mechanical data acquisition project at the Äspö pillar stability site is available /Mas Ivars 2005/. In this project a large field experiment was conducted with the aim of acquiring hydro-mechanical data during the drilling of the de-stressing slot at the pillar. To better understand the data acquired, a three dimensional mechanical modelling study of the de-stressing of the APSE pillar has been carried out using the code 3DEC /Itasca 2003/. The results from this modelling exercise show the stress redistribution in the tunnel during the drilling of the de-stressing slot. The report has been finalised and is under revision for publishing.

For the next step, two 30 mm diameter boreholes have been drilled. These two boreholes intersected a very conductive fracture where flow and displacements were monitored during the de-stressing of the pillar. Coupled stress-flow laboratory tests have been conducted on three large fracture samples from the mentioned boreholes. The surfaces of the fracture walls have been scanned using a 3D-laser scanner so the geometrical properties of the fracture plane can be well characterised. Variograms and contour maps of the aperture have been produced for each fracture. The results of the coupled stress-flow laboratory tests have been analysed and, at present, the report on this project is under revision for publishing.

2.2.3 Hydro Monitoring Programme



The monitoring of water level in surface boreholes started in 1987 while the tunnel excavation began to affect the groundwater level in many surface boreholes during the spring 1991. The computerised Hydro Monitoring System (HMS) implemented in the Äspö HRL and on the nearby islands was introduced in 1992. The HMS collects data on-line of pressure, levels, flow and electrical conductivity of the groundwater. Manual levelling is also obtained from the surface boreholes on a regular basis. The data are recorded by numerous transducers installed in boreholes, of which many are equipped with hydraulically inflatable packers, and in the tunnel. The number of boreholes included in the monitoring programme has gradually increased and comprise boreholes in the tunnel in the Äspö HRL as well as surface boreholes on the islands of Äspö, Ävrö, Mjälen, Bockholmen and some boreholes on the mainland at Laxemar. Groundwater pressure or levels are measured by about 280 transducers. Water seeping through the tunnel walls is diverted to trenches and further to 25 weirs where the flow is measured. All data are transmitted to the main office at Äspö, by cable or radio.

Weekly quality checks of preliminary groundwater head data are performed. Absolute calibration of data is performed three to four times per year. This work involves comparison with groundwater levels checked manually in boreholes.

Achievements

The system has been performing well and the monitoring points from the previous year have been maintained. However, maintenance and improvements are continuously made on the monitoring system to increase the performance. Work has been initiated to make the management of the system better and more effective. The system will continue to provide basic hydrogeological data and support the experiments undertaken. A report describing instrumentation, measurement methods and summarising the monitoring during 2004 is available /Nyberg et al. 2005/, and a report for 2005 is being produced.

Quality checks and calibrations are regularly made for data from the tunnel and the surface boreholes, the latest took place in April and May respectively.

2.3 Geochemistry

2.3.1 Monitoring of Groundwater Chemistry

During the Construction Phase of the Äspö HRL, different types of water samples were collected and analysed with the purpose of monitoring the groundwater chemistry and its evolution as the construction proceeded. At the beginning of the Operational Phase, sampling was replaced by a groundwater chemistry monitoring programme, aiming at a sufficient cover of the hydrogeochemical 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.

Achievements

The annual water sampling campaign is in the same way as earlier years scheduled to take place in September – October. Last year the sampling started the 31st August and was finalised in the middle of October. The results are available in a chemistry report.

2.4 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 2006 work will be performed within the following projects:

- Coupled processes in rock including dynamic processes at natural conditions.
- Stress measurements and stress interpretation methods.
- Äspö Pillar Stability Experiment.

2.4.1 Stress Measurements - Core Disking

The purpose of the project is to study the conditions under which core disking occur by drilling in the vicinity of the area for the Äspö Pillar Stability Experiment.

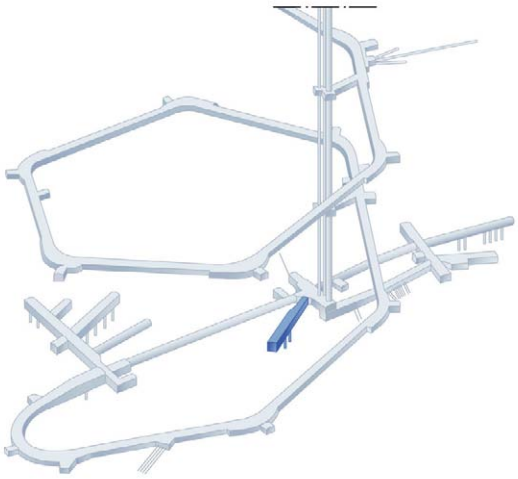
A total of four holes were drilled vertically in the tunnel floor (KQ0062G05, KQ0062G06, KQ0061G10 and KQ0062G04). Core disking in solid and hollow cores was observed in the first three of these. Two successful installations of the Borre probe used for stress measurements were made.

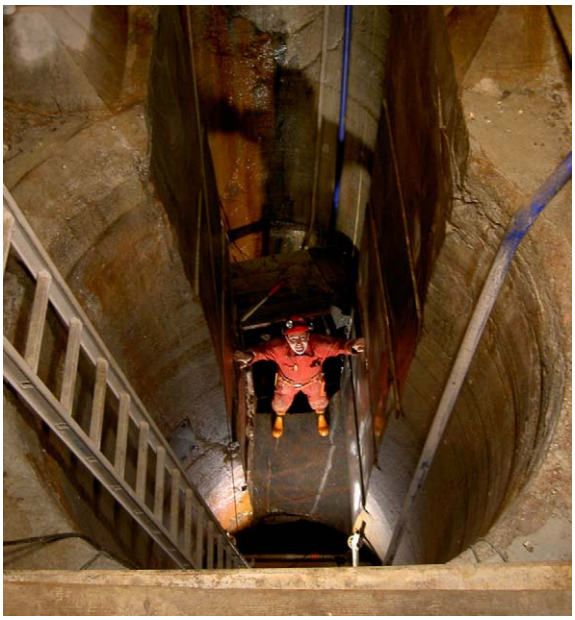
Achievements

Most of the observed core disking appears to be associated with discontinuities in the rock mass. Stress measurements were made in two boreholes, however, only the results from one borehole may be reliable.

It was concluded that there is a need for an updated geological model over the fracturing in the investigated area to enable an interpretation of the results. However, the update of the geological model has been delayed due to conflict of resources within geology during the 2nd quarter. The updated model is due to August 2006.

2.4.2 Äspö Pillar Stability Experiment





The major aims with the Pillar Stability Experiment are to demonstrate the capability to predict spalling in fractured rock mass and the effect of backfill on the propagation of micro cracks. The experiment is a complement to an earlier study performed at URL in Canada.

A new tunnel was excavated at Äspö HRL to ensure that the experiment was carried out in a rock mass with a virgin stress field. The site is located at the -450 m level. The pillar was created between two vertical deposition holes drilled in the floor of the tunnel.

The stress in the pillar was further increased by a thermal load to reach a stress state that induced brittle failure/spalling. One of the boreholes was subjected to an internal water pressure via a rubber bladder giving a confining pressure of 0.7 MPa.

The heating phase of the experiment was finished in mid July 2004. Spalling occurred to almost five metres depth in the open borehole and good measuring series were achieved with all the instruments used. Five pillar blocks were sawn and in January 2005 all blocks were lifted up.

Achievements

Draft journal papers describing the design of the experiment and the determination of the spalling strength of the pillar have been written and will be submitted for review in August. A conference paper describing the thermal back calculation has been presented at the GeoProc 2006 conference in Nanjing, China.

The reporting of the detailed geological mapping of the pillar is finished and is published as an International Progress Report /Lampinen 2006/. The results from the mapping have been used to produce a 3D model of the pillar geology in Surpac Surveying Software. The model also includes acoustic events from the experiment. The model enhances the understanding of the geology in the pillar.

3 Buffer materials and backfill technology

Before building a final repository, where the operating conditions include the deposition of one canister per day, further studies of the behaviour of the buffer and backfill under different installation conditions are required. SKB has decided to build a Bentonite Laboratory at Äspö designed for studies of buffer and backfill materials. The laboratory, a hall with dimensions 15×30 m, will include two stations where the emplacement of buffer material at full scale can be tested under different conditions. The hall will also be used for testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

Achievements

As reported in the previous status report two project leaders and one industry-funded Ph.D. student have been recruited to the group Technology and Science at Äspö HRL. The whole body of the three new employees will be engaged in new experiment to be accomplished in the Bentonite Laboratory.

The two project leaders have continued their work in subprojects within the SKB project BACLO (Backfilling and Closure of the Deep Repository) Phase III. When waiting for the facilities in the new Bentonite Laboratory some initial experiments/studies have been initiated in temporarily halls and in the tunnel TASO at the -220 m level, i.e. in the tunnel close to the Canister Retrieval Test in the Äspö HRL.

A study plan (draft) has been elaborated for the industry-funded Ph.D. student. It is focused on Crystal Chemical studies of swelling clay minerals. The Ph.D. student will be registered at the department Polymer and Materials Chemistry, Faculty of Engineering (LTH) at Lunds University. The Ph.D. student will also be assisted by expertise at Clay Technology in Lund.

The Bentonite Laboratory is now under construction and is expected to be ready the 1st of December. The construction activities on the site were initiated in May by starting the excavation of rock to prepare for the construction of the foundation plate and the two vertical deposition holes beneath the foundation plate (Figure 3-1 and Figure 3-2).

Figure 3-1 *The area of the location for the Bentonite Laboratory was uncovered in May and the drilling of holes for the excavation of the rock started in early June.*

Figure 3-2 *The excavated cavity in the rock is about 8 m deep and will host the two deposition holes beneath the foundation slab. The rock excavation work was finalised in the end of June.*

4 Natural barriers

At the Äspö HRL, experiments are performed at conditions that are expected to prevail at repository depth. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The goals are to increase the scientific knowledge of the safety margins of the repository and to provide data for performance and safety assessment and thereby clearly present the role of the geosphere for the barrier functions: isolation, retardation and dilution. As an example, the processes that influence migration of species along a natural rock fracture are shown in Figure 4-1.

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.

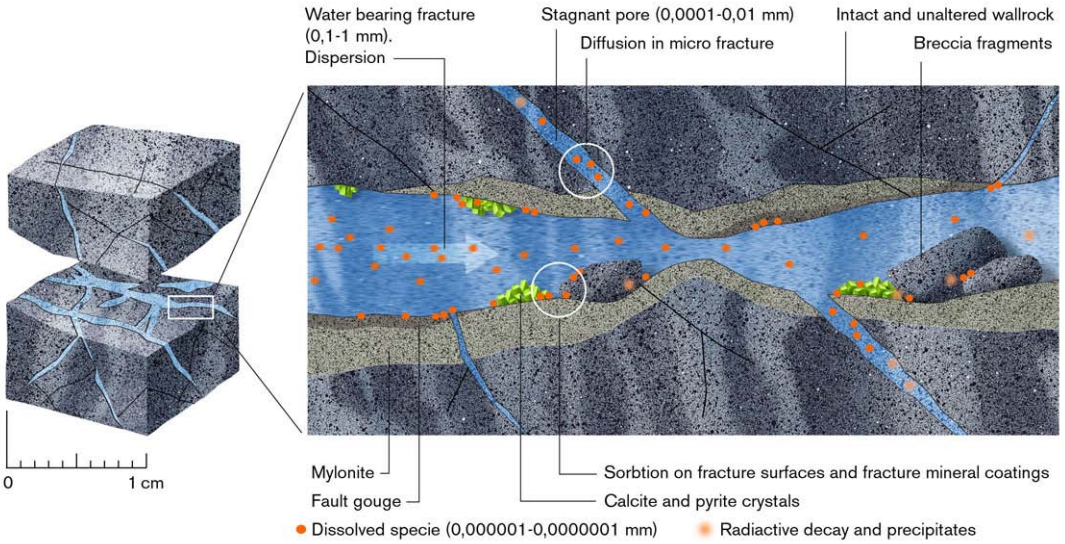
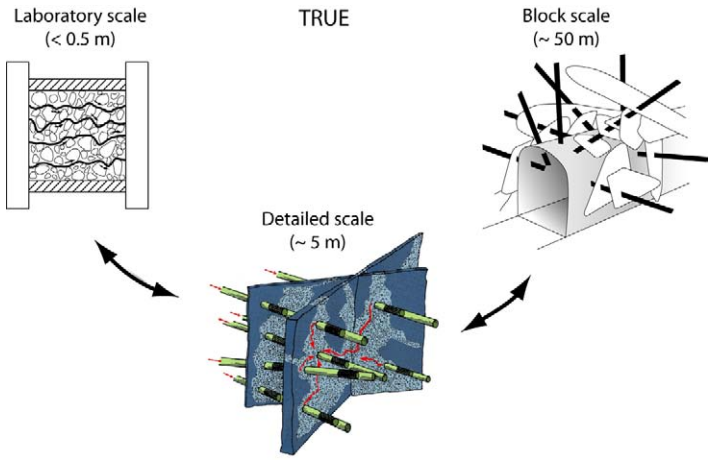


Figure 4-1 *Processes that influence migration of species along a natural rock fracture.*

4.1 Tracer Retention Understanding Experiments



Tracer tests with non-sorbing and sorbing tracers are carried out in the True family of projects. These are conducted at different scales; laboratory scale (< 0.5 m), detailed scale (<10 m) and block scale (up to 100 m) with the aim to improve understanding of transport and retention in fractured rock. The work includes building of hydrostructural models and conceptual microstructure models. Numerical models are used to assess the relative contribution of flow-field related effects and acting processes (diffusion and sorption) on *in situ* retention.

The first *in situ* experiment (True-1) performed in the detailed scale and the True Block Scale series of experiments have come to their respective conclusion.

Complementary field work and modelling are currently performed as part of two separate but closely coordinated continuation projects. The True Block Scale Continuation project aims at obtaining additional understanding of the True Block Scale site. In the True-1 Continuation and Completion projects the objectives are to obtain insight in the internal structure of the investigated feature and to study fixation of sorbing radioactive tracers. Prior to the resin injection in Feature A complementary hydraulic and tracer tests are performed to better understand Feature A and its relation to the surrounding fracture network. In addition, a dress rehearsal of *in situ* resin injection is realised through a characterisation project focused on fault rock zones.

4.1.1 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.

In the aftermath to the BS2 project a discussion has been in process to set up a second step of continuation of the True Block Scale (BS3). This step would not have specific experimental components, but rather emphasise consolidation and integrated evaluation of all relevant True data and findings collected thus far. This integration would not necessarily be restricted to True Block Scale, but could also include incorporation of True-1 and True-1 Continuation results.

Achievements

Remaining contributions to the final report (BS2a and BS2b) are received and edition work has been initiated. During the first two quarters only minor work has been done due to heavy engagement of SKB consultants in the ongoing site investigations and modelling.

4.1.2 True-1 Continuation

The True-1 Continuation project is a continuation of the True-1 experiments and the experimental focus is primarily on the True-1 site. The continuation includes performance of the planned injection of epoxy resin in Feature A at the True-1 site and subsequent overcoring and analysis (True-1 Completion, see below). In addition, this project includes production of a series of scientific articles based on the True-1 project and, furthermore, performance of the Fault Rock Characterisation project, the latter in parts a dress rehearsal for True-1 Completion.

Achievements

True-1 Continuation achievements include:

- Two of the three scientific papers on the True team analysis of the True-1 experiments have been submitted to the editors of WRR:

  Part 1) Experimental results, conceptual model and effective parameter estimation
  Part 2) Micro-scale characterisation retention parameters
- The principal achievements of the True-1 Completion subproject are accounted for below in Section 4.1.3.
- No work has been performed within the Fault Rock Zones Characterisation subproject.

4.1.3 True-1 Completion

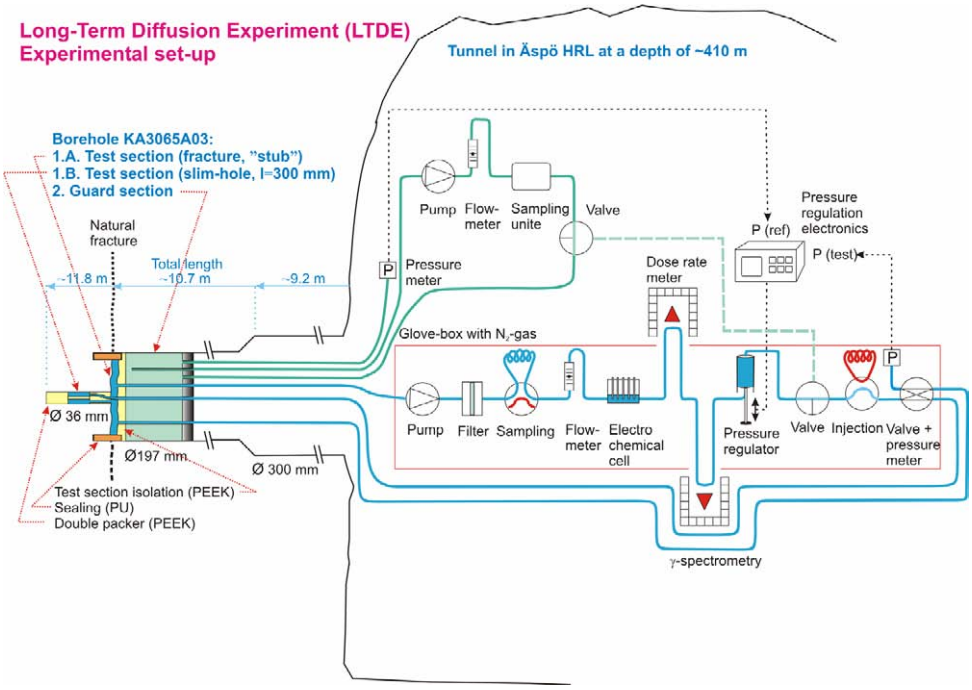
True-1 Completion is a sub-project of the True-1 Continuation project with the experimental focus placed on the True-1 site. True-1 Completion will be performed at the True-1 site and will be a complement to already performed and ongoing projects. The main activity within True-1 Completion is the injection of epoxy with subsequent over-coring of the fracture and following analyses of pore structure and, if possible, identification of sorption sites. Furthermore, several complementary *in situ* experiments will be performed prior to the epoxy injection. These tests are aimed to secure important information from Feature A and the True-1 site before the destruction of the site, the latter which is the utter consequence of True-1 Completion.

Achievements

As a result of the Task Force meeting in Paris in March a set of multi-hole reciprocal cross flow tests has been performed at the True-1 site. The multi-hole reciprocal cross flow tests aims to examine and evaluate the effects of channelling in a single fracture, Feature A. The tests were performed in KXTT1 - KXTT5 and KA3005A under ambient (natural) and pumped conditions using a non-sorbing dye-tracer and sorbing metal complexes. The field tests included six hydraulic interference tests with measurements of both flow and pressure responses. The test also includes injection of sorbing, inactive, metal complexes. The injection of metal complexes will be made once or twice in each section with the purpose of mapping flow paths to be traced in future excavations of Feature A.

The planned start of the CEC-test has been postponed due to malfunctioning equipment and observed changes of Feature A. The surprisingly low recovery of injected tracer in the performed pre-tests may be explained by the observed physical changes of Feature A. In order to evaluate the changes the result of performed complementary tests will be compared with the results from earlier tests.

4.2 Long Term Diffusion Experiment



This experiment is performed to investigate diffusion and sorption of solutes in the vicinity of a natural fracture into the matrix rock and directly from a borehole into the matrix rock.

The aims are to improve the understanding of diffusion and sorption processes and to obtain diffusion and sorption data at *in situ* conditions.

A core stub with a natural fracture surface is isolated in the bottom of a large diameter telescoped borehole and a small-diameter borehole is drilled through the core stub and beyond into the intact unaltered bedrock. Tracers will be circulated over a period of 5-7 months after which the borehole is over-cored and analysed for tracer content.

Achievements

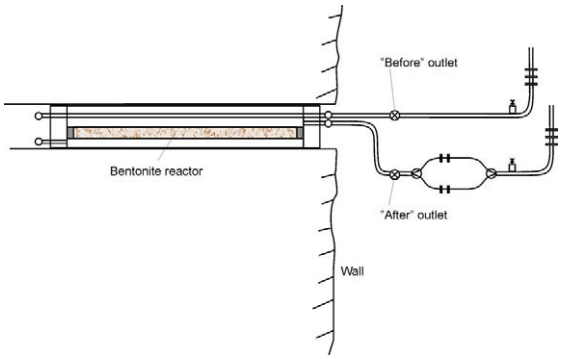
Complementary measures on the test equipment have been carried out as a preparation for the forthcoming main sorption diffusion experiment:

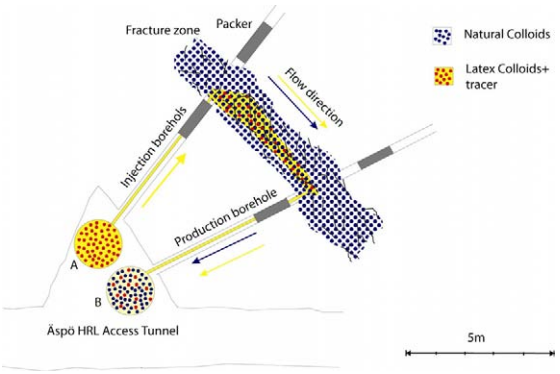
- Rearrangement of the placement of the electrochemical flow cell in the glove box in order to improve the practical work in the glove box and to reduce disturbances in the measurements.
- Improve cooling device in the experimental container in order to reduce the temperature from 30 ºC to 16-20 ºC.
- Identify and take measures to stop the small leakage in the circulation and pressure regulating equipment in the experimental container
- Update some of the automatic alarm functions in the system.

Radionuclide tracers for the main experiment have been selected and procured. In total 22 radionuclides including the range from non-sorbing (^{36}Cl, ^{35}S) to strongly sorbing (^{175}Hf, ^{236}U). At the experimental site and at Baslab preparations have been made for carrying out injection of the radionuclide tracers and sampling during the course of the experiment.

4.3 Colloid Project

Borehole specific measurements ***Colloid dipole experiment***





In the Colloid Project the concentration, stability and mobility of colloids in the Äspö environment are studied. The project comprises studies of the potential of colloids to enhance solute transport and the potential of bentonite clay as a source for colloid generation. The Colloid Project includes laboratory experiments, background colloid measurements, borehole specific measurements, colloid dipole experiments and *in situ* experiments where the colloidal effect on actinide transport in a water bearing fracture will be studied.

Achievements

There are ongoing experiments on bentonite colloid migration in a water bearing fracture which is performed by AECL. Results indicate that bentonite colloids in diluted water filtrate, so that the smaller colloids in the size distribution are mobile, while the larger ones are trapped in the fracture. Bentonite and latex colloids behave in a similar way in the experiments with high pump flows. Experiments with bentonite colloids in more saline waters will follow.

Migration experiments with latex colloids in Feature A at True-1 are completed but yet not completely evaluated. Preliminary results show early breakthrough of a minor part of the latex colloids with mean sizes of 50 and 100 nm, followed by the major part delayed compared to the reference conservative tracer uranine.

The effect of Ca and Na on bentonite colloids stability has been tested in the laboratory. The cation exchange capacity (CEC-value) for Ca and Na will be evaluated from the laboratory tests.

The influence of the presence of minerals on bentonite colloidal stability is tested in the laboratory and results under evaluation.

4.4 Microbe Project

The Microbe Project has been initiated in the Äspö HRL for studies of the microbial activity in groundwater at *in situ* conditions. The major objectives are to:

- Offer proper circumstances for research on the effect of microbial activity on the long-term chemical stability of the repository environment.
- Provide *in situ* conditions for the study of bio-mobilisation of radionuclides.
- Present a range of conditions relevant for the study of bio-immobilisation of radionuclides.
- Enable investigations of bio-corrosion of copper under conditions relevant for a high level radioactive waste repository.
- Constitute a reference site for testing and development of methods used in the site investigations.

The main Microbe site is on the -450 m level where a laboratory container with benches, an anaerobic gas box and an advanced climate control system is located. Three core drilled holes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures are connected to the Microbe laboratory via tubing. Each borehole has been equipped with a circulation system offering 2,112 cm^2 of test surface.

Retention of naturally occurring trace elements in the groundwater by Biological Iron Oxides (Bios) is investigated at a site at tunnel length 2,200 m. There is a vault with a borehole that delivers groundwater rich in ferrous iron and iron oxidising bacteria. The borehole is connected to two 200 × 30 × 20 cm artificial channels that mimic ditches in the tunnel. The channels have rock and artificial plastic support that stimulate Bios formation.

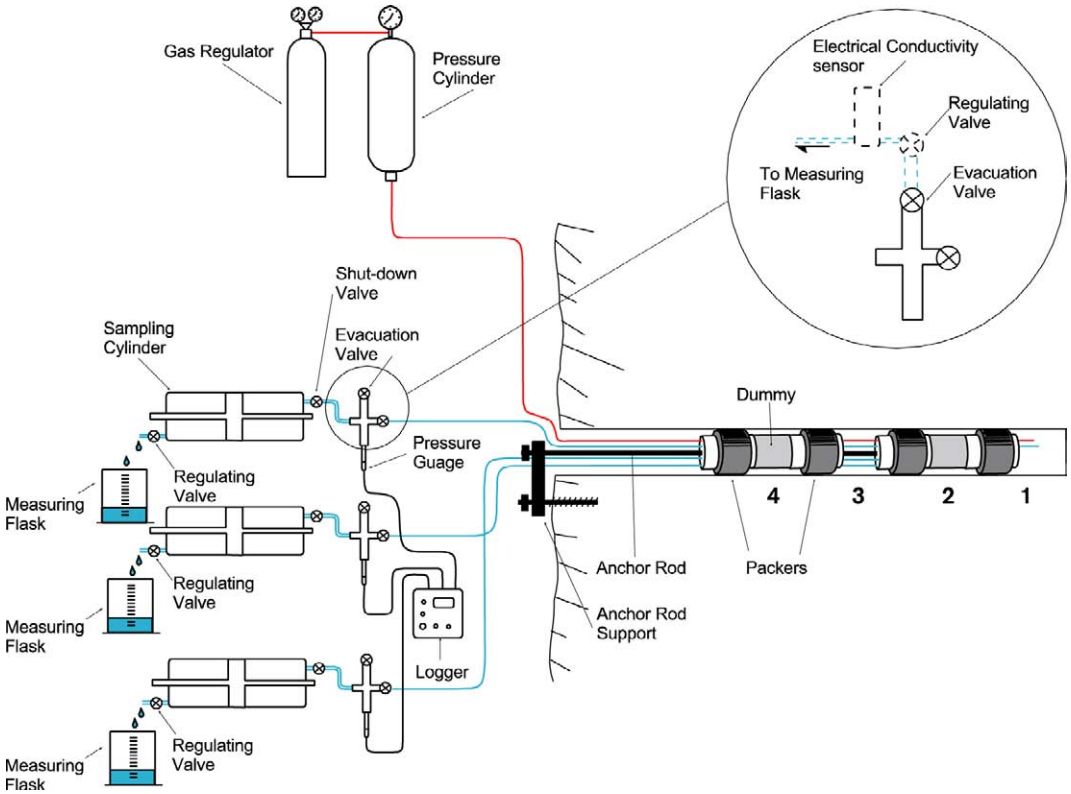
Achievements

Drilling of boreholes for the Minican project created a significant drainage of the fractures from which Microbe is taking its groundwater. That disturbance has now been fixed. New characterisations were performed during spring 2006 and they have now been completed.

New groundwater chemistry analyses (Class V) have been performed. They show that a significant up-coning has been on-going during 2005. New characterisations of micro organisms have also been performed. The microbial populations have stabilised on new, higher levels as a result of the up-coning of deeper groundwater.

A first set of experiments for quantitative analysis of microbial activity was started in March 2006. The experiments went exceptionally well. Sulphide and acetate production rates have been obtained as a function of available energy sources. The first quantitative experiment set was decommissioned on June 20th. New experiments have been designed and will start in the middle of August 2006.

4.5 Matrix Fluid Chemistry Continuation



The main objectives of the Matrix Fluid Chemistry experiment are to understand the origin and age of fluids/groundwaters in the rock matrix pore space and in micro-fractures, and their possible influence on the chemistry of the groundwaters from the more highly permeable bedrock.

Matrix fluids are sampled from a borehole drilled into the rock matrix. Fluid inclusions in core samples have also been studied to determine their contribution, if any, to the composition of the matrix fluids/groundwaters.

A first phase of the project is finalised and reported /Smellie *et al*. 2003/. The major conclusion is that pore water can successfully be sampled from the rock matrix and there is no major difference in chemistry compared to groundwaters from more highly conductive fracture zones in the near-vicinity.

Achievements

During this quarter the hydraulic tests have continued in the matrix borehole (KF0051A01) focussing on isolated sections containing thin microfractures all less than 1 mm in width. Preliminary results using pressure pulse tests (Table 4-1) and constant pressure injection tests (Table 4-2) show transmissivities ranging from 6.9×10^{-14} to 1.9×10^{-13} m^2s^{-1}, and 6.7×10^{-14} to 2.1×10^{-13} m^2s^{-1}, respectively. For the pulse tests a 'Mylonite' section, representing a microfracture-free matrix rock section, was measured. Interestingly the transmissivity in this section is close to that of some of the microfracture-bearing borehole sections (i.e. features A and B), see Table 4-1.

Furthermore, these hydraulic tests are in accordance with earlier performed predictions and hydraulic transmissivities determined from inflow rates. According to inflow rates the hydraulic transmissivity is in the order of 1×10^{-14} to 1×10^{-13} m^2s^{-1} for both microfracture-free and microfracture-bearing borehole sections in KF0051A01.

On May 16th, following readjustment of the borehole equipment, similar hydraulic testing commenced in the microfracture-free borehole sections, i.e. those sections already sampled for matrix pore water during the earlier Matrix Fluid Chemistry Experiment. These tests are scheduled to be finalised in August 2006.

Table 4-1 Results from pressure pulse tests in borehole KF0051A01.

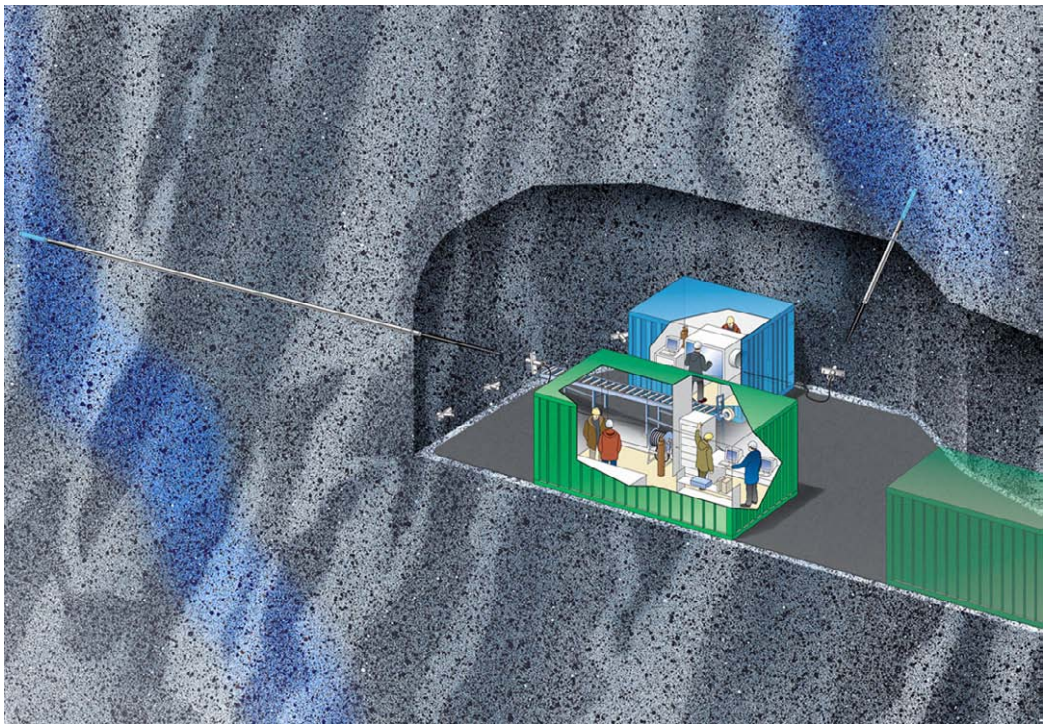
Classification	Section	Borehole length (m)	Hydraulic transmissivity (m^2/s)
Feature F, thin micro fractures	1	9.65 – 11.80	6.9×10^{-14}
Mylonite, microfracture-free	2	7.95 – 8.65	7.9×10^{-14}
Feature B, thin micro fracture	3	5.36 – 6.95	1.2×10^{-13}
Feature A, thin micro fracture	4	3.76 – 4.36	1.9×10^{-13}

Table 4-2 Results from constant pressure injection tests in borehole KF0051A01.

Classification	Section	Borehole length (m)	Transmissivity 2-D flow* (m^2/s)	Transmissivity 3-D flow** (m^2/s)
Feature B, thin micro fracture	3	5.36 – 6.95	2.9×10^{-13}	2.1×10^{-13}
Feature A, thin micro fracture	4	3.76 – 4.36	1.2×10^{-13}	6.7×10^{-14}

** /Todd 1980/ ** /Moye 1967/*

4.6 Radionuclide Retention Experiments



Radionuclide Retention Experiments are carried out with the aim to confirm results of laboratory studies *in situ*, where natural conditions prevail concerning e.g. redox conditions, contents of colloids, organic matter and bacteria in the groundwater.

The experiments are carried out in special borehole laboratories, Chemlab 1 and Chemlab 2, designed for different kinds of *in situ* experiments. The laboratories are installed in boreholes and experiments can be carried out on bentonite samples and on tiny rock fractures in drill cores.

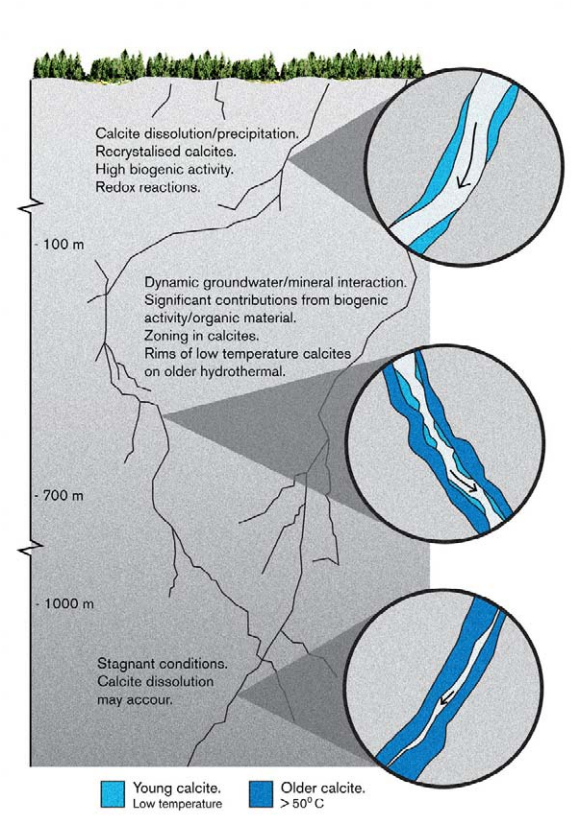
Chemlab 1:
- Investigations of the influence of radiolysis products on the migration of the redox-sensitive element technetium in bentonite (finalised).
- Investigations of the transport resistance at the buffer/rock interface (planned).

Chemlab 2:
- Migration experiments with actinides in a rock fracture (almost finalised).
- Study leaching of spent fuel at repository conditions (planned).

Achievements

The results from the final field experiment on actinide migration has been evaluated and reported by Forschungszentrum Karlsruhe (FZKA). The final report will be based on this and five earlier FZKA-reports. There has been no work carried out in the project during the second quarter.

4.7 Padamot



Potential calcite-groundwater interaction at various depths at Äspö.

Padamot (Palaeohydrogeological Data Analysis and Model Testing) investigates changes in groundwater conditions as a result of changing climate. Because the long term safety of an underground repository depends on the stability of the repository environment, demonstration that climatic impacts attenuate with depth is important. Currently, scenarios for groundwater evolution relating to climate changes are poorly constrained by data and process understanding.

The objectives of Padamot are to:

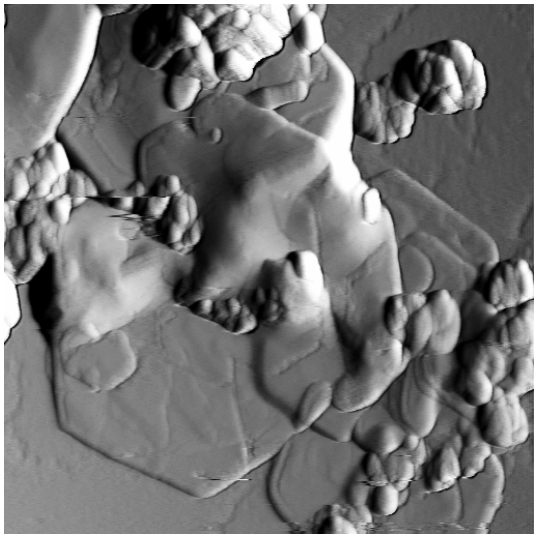
- Improve understanding and prioritise palaeo-hydrogeological information for use in safety assessments.
- Collect chemical/isotopic data using advanced analytical methods.
- Construct a database of relevant information and develop numerical models to test hypotheses.
- Integrate and synthesise results to constrain scenarios used in performance assessments.
- Disseminate the results to the scientific community.

The EC-part of the project was finalised and reported in 2005. The present project comprises analytical and modelling tasks. Deep borehole cores from rocks at the Äspö HRL and Laxemar (KXL01) are used in the analytical study.

Achievements

The experiences concerning methodology for palaeohydrogeological studies based on fracture mineralogy and geochemistry from the Padamot and former Equip projects are used within the SKB site investigations. A paper describing the methodology is presently being prepared. The project is also moving into a new phase where uranium series measurements carried out with different techniques will be applied on fracture material from a surface borehole drilled at Äspö (KAS17). Sampling will occur during the summer. Uranium series measurements can provide redox information (by detecting U removal or uptake) and even more important give time constraints on these processes. It is thereby an important tool in characterising the evolution of the redox front.

4.8 Fe-oxides in Fractures



Atomic Force Microscopy image of green rust sulphate. Image is 2.5 x 2.5 microns

Proof of reducing conditions at repository depth is fundamental for the safety assessment of radioactive waste disposals. Fe(II) - minerals are common in the bedrock and along fracture pathways and constitute a considerable reducing capacity together with organic processes. Another area of interest is the radionuclide retention capacity provided by Fe-oxides and -oxyhydroxides in terms of sorption capacity and immobilisation.

The basic idea of the project is to examine Fe-oxide fracture linings, in order to explore for suitable palaeo-indicators for their formation conditions, while at the same time learning about the behaviour of trace component uptake in general, both from the natural material as well as through testing of behaviour in controlled parametric studies in the laboratory.

Achievements

During the last quarter most emphasis has been on continued reporting and publication. Of the papers listed last quarter and given below in Table 4-3, Dideriksen *et al.*, 2006 has been accepted for publication. In addition, Dideriksen and Stipp, 2006 will soon be published as an Äspö IPR report (IPR-06-09).

Future plans were discussed at a meeting held in Copenhagen on March 3rd. A project continuation proposal with the title "To Establish the Penetration Depth of Oxidising Waters below Ground" was submitted to SKB in March 2006 and provisionally accepted on May 30th. This will commence during the next quarter.

Table 4-3 Reporting in progress

Scientific papers for publication in Geochimica et Cosmochimica Acta

Skovbjerg L, Stipp S, Utsunomiya S, Ewing R, 2006. The Mechanisms of Reduction of Hexavalent Chromium by Green Rust Sodium Sulphate: Formation of Cr-goethite (Resubmitted in February 2006).

Dideriksen K, Christiansen B, Baker J, Frandsen C, Balic-Zunic T, Tullborg E, Mørup S, Stipp S, 2006. Fe-oxide fracture-fillings as a palæo-temperature and redox indicator: Structure, crystal form, REE content and Fe isotope composition **(Accepted for publication, May** 2006).

Reports for publication in the Äspö International Progress Report series

Dideriksen K, Stipp S, 2006. Iron Oxides in Fractures at Äspö. A feasibility study to test the possibility of finding a geothermometer or a palaeo-redox indicator. (IPR-06-09).

Dideriksen K, Christiansen B, Skovbjerg L, Sonne L, Hansson E, Stipp S, Tullborg E-L, 2006. Fe-oxide Report: Progress to the end of 2004: Scope, Results and Perspectives (May 2005).

4.9 Swiw-test with Synthetic Groundwater

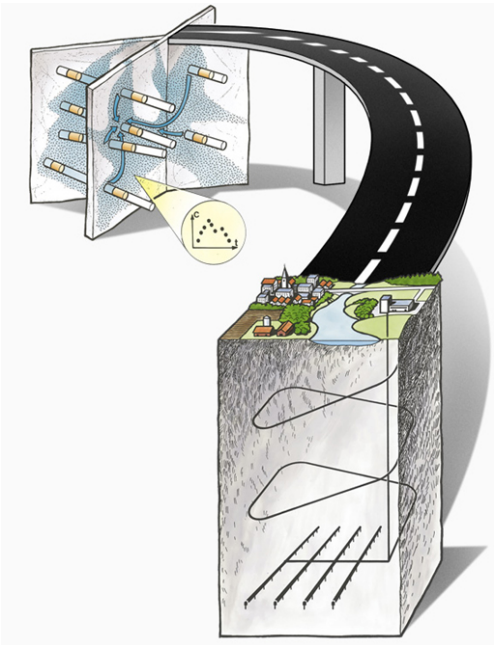
The project constitutes a complement to performed tests and studies on the processes governing retention, e.g. the True-1 and the True Block Scale experiments. This project aims to deepen the understanding for the processes governing retention. Swiw-tests (single well injection withdrawal) with synthetic groundwater facilitate the study of diffusion in stagnant water zones and in the rock matrix. It also facilitates the possibility to test the concept of measuring fracture aperture with the radon concept.

The location for the tests will be the True Block Scale site and the well characterised Structures #19 and #20. The two structures, have been object to a large number of tracer tests, possess different characteristics and are located on different distances from the tunnel. The revisit of the True Block Scale site facilitates the unique possibility to ”calibrate” the concept of single hole tracer tests, Swiw, to multiple borehole tracer tests. The results from such a calibration can be applied directly to the Swiw-tests performed within the SKB site investigation programme.

Achievements

The main part of 2006 will be devoted to a feasibility study, determination of scope and planning of the work ahead. However, no work has been done in the project during the second quarter.

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



The Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes is a forum for the organisations supporting the Äspö HRL to interact in the area of conceptual and numerical modelling of groundwater flow and transport of solutes in fractured rock.

The Task Force shall propose, review, evaluate and contribute to the modelling work in the project. In addition, the Task Force shall interact with the principal investigators responsible for carrying out experimental and modelling works for Äspö HRL.

The work within the Äspö Task Force constitutes an important part of the international co-operation within the Äspö Hard Rock Laboratory.

Achievements

In the Task Force, work has been in progress in Task 6 − Performance Assessment Modelling Using Site Characterisation Data, and in Task 7, which addresses a long-term pumping test in Olkiluoto, Finland. The status of the specific modelling tasks is given within brackets in Table 4-4. The 21st Task Force meeting was hosted by Andra in Paris on 6-9th March, and recently the minutes and the proceedings from the meeting are written and distributed.

Task 6 tries to bridge the gap between Performance Assessment (PA) and Site Characterisation (SC) models by applying both approaches for the same tracer experiment. It is hoped that this will help to identify the relevant conceptualisations (in processes/structures) for long term PA predictions and identify site characterisation data requirements to support PA calculations. The review reports for Tasks 6A, 6B and 6B2 /Hodgkinson and Black 2005/ and Task 6C /Black and Hodgkinson 2005/ are available. It has been decided that Tasks 6D, 6E, 6F and 6F2 are to be reported together, and the work with this combined report is in progress. The review report for Task 6D, 6E and 6F is available as a draft. A summary of the outcome of Task 6 will be published in a scientific paper. In addition, some modelling groups have indicated interest in publishing papers in the same scientific journal, and in conjunction with the summary paper. The 21st Task Force meeting was in a way the grand final for Task 6.

Task 7 addresses modelling of the KR24 long-term pumping test at Olkiluoto in Finland. The task will focus on methods to quantify uncertainties in PA-type approaches based on SC-type information; along with being an opportunity to increase the understanding of the role of fracture zones as boundary conditions for the fracture network and how compartmentalisation affect the groundwater system. The possibilities to extract more information from interference tests will also be addressed. A task description for the sub-task 7A has been sent out to the modellers and preliminary results from the modelling were presented at the 21st Task Force meeting in Paris, March 2006. Work is ongoing to update the task definition of Task 7A and preparations are made for a workshop in Finland.

Table 4-4 Task descriptions and status of the specific modelling sub-tasks.

6A	Model and reproduce selected True-1 tests with a PA model and/or a SC model to provide a common reference. (External review report printed).
6B	Model selected PA cases at the True-1 site with new PA relevant (long term/base case) boundary conditions and temporal scales. This task serves as means to understand the differences between the use of SC-type and PA-type models and the influence of various assumptions made for PA calculations for extrapolation in time. (External review report printed).
6C	Develop semi-synthetic, fractured granite hydrostructural models. Two scales are supported (200 m block scale and 2000 m site-scale). The models are developed based on data from the Prototype Repository, True Block Scale, True-1 and Fracture Characterisation and Classification project (FCC). (External review report printed).
6D	This sub-task is similar to sub-task 6A and is using the synthetic structural model in addition to a 50 to 100 m scale True-Block Scale tracer experiment. (Draft reports available and review in progress).
6E	This sub-task extends the sub-task 6D transport calculations to a reference set of PA time scales and boundary conditions. (Draft reports available and review in progress).
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. (Draft reports available and review in progress).
7	Long-term pumping experiment. (Preliminary results presented at TF#21).

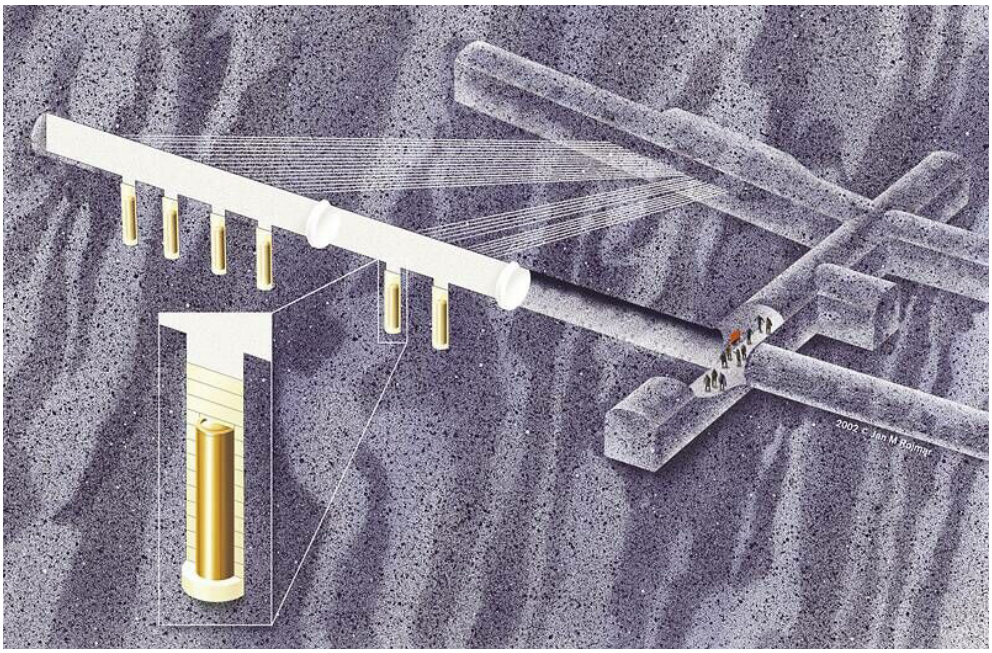
5 Engineered barriers

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

It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL, see Figure 5-1. The experiments focus on different aspects of engineering technology and performance testing and will together form a major experimental programme.

Figure 5-1 *Deposition equipment in position (KBS-3H).*

5.1 Prototype Repository



The Prototype Repository is located in the TBM-tunnel at the -450 m level and includes six full scale deposition holes. The aims of the Prototype Repository are to demonstrate the integrated function of the repository components and to provide a full-scale reference for comparison with models and assumptions.

The Prototype Repository should, to the extent possible, simulate the real repository system regarding geometry, materials and rock environment.

Instrumentation is used to monitor processes and properties in the canister, buffer material, backfill and the near-field rock. The evolution will be followed for a long time.

The inner tunnel (Section I) was installed and the plug cast in 2001 and the heaters in the canisters were turned on one by one. The outer tunnel (Section II) was backfilled in June 2003 and the tunnel plug with two lead-throughs was casted in September the same year.

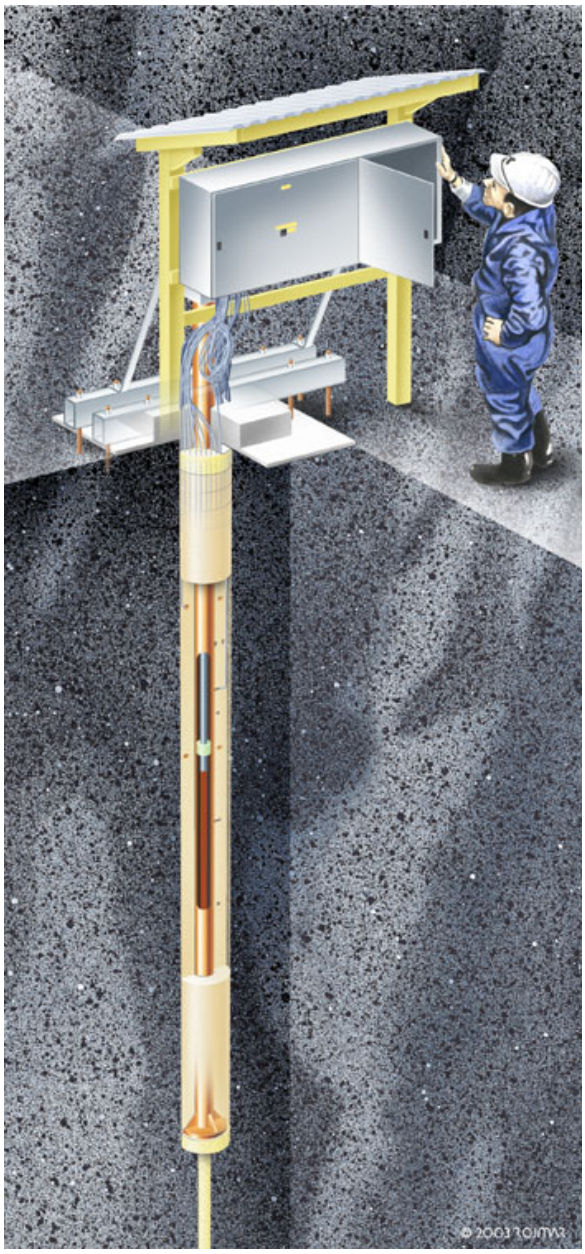
Achievements

The data collection system comprises temperature, total pressure, pore water pressure, relative humidity and resistivity measurements in buffer and backfill, as well as temperature and water pressure measurements in boreholes in the rock around the tunnel. The collection of data is in progress and the work with data report No. 14 covering the period up to December 2005 has been finalised /Goudarzi and Johannesson 2005/. Overhauling of the data acquisition system is in progress and hydraulic tests of the rock mass have been performed.

Hydraulic tests (Test campaign 6) of the rock around the Prototype Repository have been performed. The objective of the tests is to estimate the transmissivity of the rock. Water sampling and chemical analysis of water from boreholes in section 1 and 2 of the Prototype Repository and the G-tunnel have started (Campaign No. 3). This work will be finalised during the summer and reported later this year. A program for sampling and analyses of gases and micro organisms in the backfill and buffer has started and the first campaign has been finalised. This work has been reported in a technical document. Later, when more campaigns have been completed, the work will be published in an International Progress Report.

A thermal FEM model for the Prototype Repository including the rock, backfill, buffer and the six canisters has been developed and the reporting of the work is ongoing. Furthermore, the THM modelling of the buffer in deposition hole 1 and 3 has been initiated.

5.2 Long Term Test of Buffer Material



The Long Term Test of Buffer Material aims to validate models and hypotheses concerning mineralogy and physical properties in a bentonite buffer.

The test parcels containing heater, central tube, clay buffer, instruments and parameter controlling equipment are placed in boreholes with a diameter of 300 mm and a depth of around 4 m.

Temperature, total pressure, water pressure and water content, are measured during the heating period. 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 mineralogical analyses and physical testing of the buffer material are made.

The test parcels are also used to study related processes such as bentonite diffusion properties, microbiology, copper corrosion and gas transport in buffer material under conditions similar to those expected in a deep repository.

Achievements

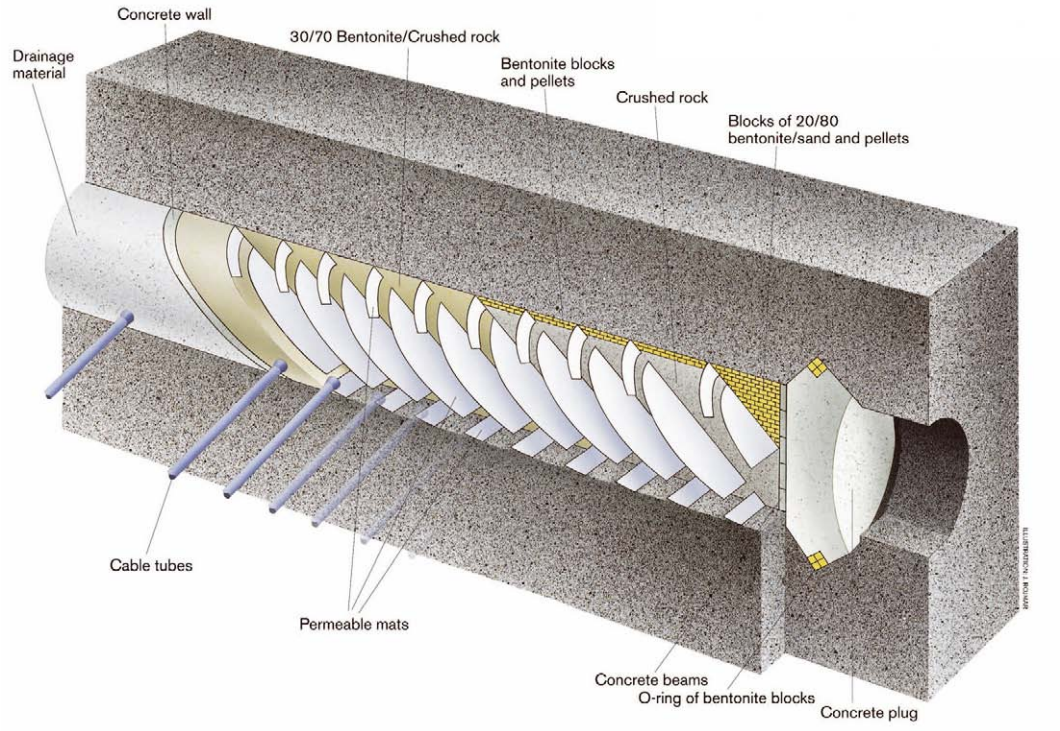
Parcel A2 has been retrieved successfully. The first general analyses show that the bentonite buffer was fully water saturated and that all material can be used for the analyses. Test material has been distributed to laboratories in Sweden, Finland, Switzerland, Germany and France. The main efforts concern chemical/mineralogical alteration of the buffer material, but minor studies will also be made on cation diffusion, bacterial activity/survival and copper corrosion. Preliminary reports concerning bacteria and water chemistry are at hand, and the laboratory part of the cobalt diffusion test has been finalised. All other planned tests and analyses are ongoing (Table 5-1). Interesting preliminary results have been noticed concerning ceased copper corrosion, increased cation exchange capacity and cementation effects in the inner warmer part of the bentonite.

Table 5-1 Test series for the Long Term Test of Buffer Material.

Type	No.	max T (°C)	Controlled parameter	Time (years)	Remark
A	1	130	T, $[K^+]$, pH, am	1	Reported
A	0	120-150	T, $[K^+]$, pH, am	1	Analysed
A	2	120-150	T, $[K^+]$, pH, am	5	Terminated (uptake January 2006)
A	3	120-150	T	5	On-going
S	1	90	T	1	Reported
S	2	90	T	5	On-going
S	3	90	T	>>5	On-going

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

5.3 Backfill and Plug Test



The Backfill and Plug Test includes tests of backfill materials, emplacement methods and a full-scale plug. The inner part of the tunnel is filled with a mixture of bentonite and crushed rock (30/70) and the outer part is filled with crushed rock and bentonite blocks and pellets at the roof.

The integrated function of the backfill material and the near-field rock in a deposition tunnel excavated by blasting is studied as well as the hydraulic and mechanical functions of the full-scale concrete plug.

The entire test set-up with backfill, instrumentation and casting of the plug was finished in the end of September 1999 and the wetting of the 30/70 mixture through filter mats started in late 1999.

The backfill was completely water saturated in 2003 and flow testing for measurement of the hydraulic conductivity has been running since late 2003.

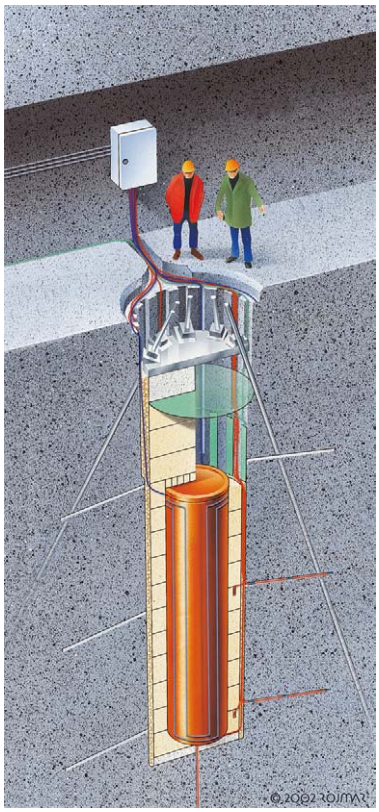
Achievements

Water saturation, water pressure and swelling pressure in the backfill as well as water pressure in the surrounding rock have been continuously measured and registered. The sensors data report No:12 covering the period up to 1st of January 2006 is available /Goudarzi *et al.* 2006a/.

Flow testing of the backfill materials between the mats has been finalised in two directions. Additional flow testing in individual points is running and so far the results support those from the flow tests between the mats.

In addition to the field testing, laboratory experiment and modelling with the aim to evaluate the hydraulic conductivity of the backfill materials are in progress but are delayed.

5.4 Canister Retrieval Test



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.

In the Canister Retrieval Test two full-scale deposition holes have been drilled, at the -420 m level, for the purpose of testing technology for retrieval of canisters after the buffer has become saturated.

These holes have been used for studies of the drilling process and the rock mechanical consequences of drilling the holes.

Canister and bentonite blocks were emplaced in one of the holes in 2000 and the hole was sealed with a plug, heater turned on and artificial water supply to saturate the buffer started.

In January 2006 the retrieval phase was initiated. The saturation phase had, at that time, been running for more than five years with continuous measurements of the wetting process, temperature, stresses and strains.

Achievements - Saturation phase

Excavation and sampling of bentonite buffer started in January and have been going on during the first and second quarter. The measurements with the remaining transducers continued during the excavation and retrieval until all transducers were recaptured in order to yield as much information as possible about the effect of the pressure decrease during excavation. Modelling of wetting and homogenisation of the buffer during the saturation process is in progress, although delayed.

Achievements - Retrieval phase

During the first quarter of 2006 the retrieval phase of the project was initiated. The buffer was manually excavated down to half the canister height and approximately 1,500 bentonite samples have been taken. The buffer is analysed in order to investigate density, water content, microbiological activity, copper migration etc. The analyses will continue during 2006. During the second quarter the disintegration of the remaining bentonite was conducted as well as the retrieval of the canister (Figure 5-2). The canister will be thoroughly examined at the canister laboratory. To give answers to the question of the environment within the canister during the test period the canister was punctured and gas samples was sent to analysis.

A heater study has also been initiated in order to investigate the cause of the heater failure. So far problems with the power cables have been identified. Further examinations will be conducted to rule out or verify problems with the heater itself.

The upcoming activities are further analysis of the buffer, analyses of the canister and the properties of the surrounding rock in the deposition hole.

Figure-5-2 *Retrieval of the canister at 12th of May 2006.*

5.5 Temperature Buffer Test

The French organisation Andra carries out the Temperature Buffer Test (TBT) at Äspö HRL in co-operation with SKB.

The aims of the TBT are to evaluate the benefits of extending the current understanding of the THM behaviour of engineered barriers during the water saturation transient to include high temperatures, above 100°C.

The scientific background to the project relies on results from large-scale field tests on EBS, notably Canister Retrieval Test, Prototype Repository and Febex (Grimsel Test Site).

The test is located in the same test area as the Canister Retrieval Test, which is in the main test area at the -420 m level.

The TBT experiment includes two heaters in the axis of the deposition hole, one on top of the other, separated by a compacted bentonite block. The heaters are 3 m long and 610 mm in diameter and are constructed in carbon steel. Each one simulates a different type of confinement system: a bentonite buffer only (bottom section) and a bentonite buffer with inner sand backfill (upper section).

An artificial water pressure is applied in a slot between the buffer and rock, which is filled with sand and functions as a filter.

Achievements

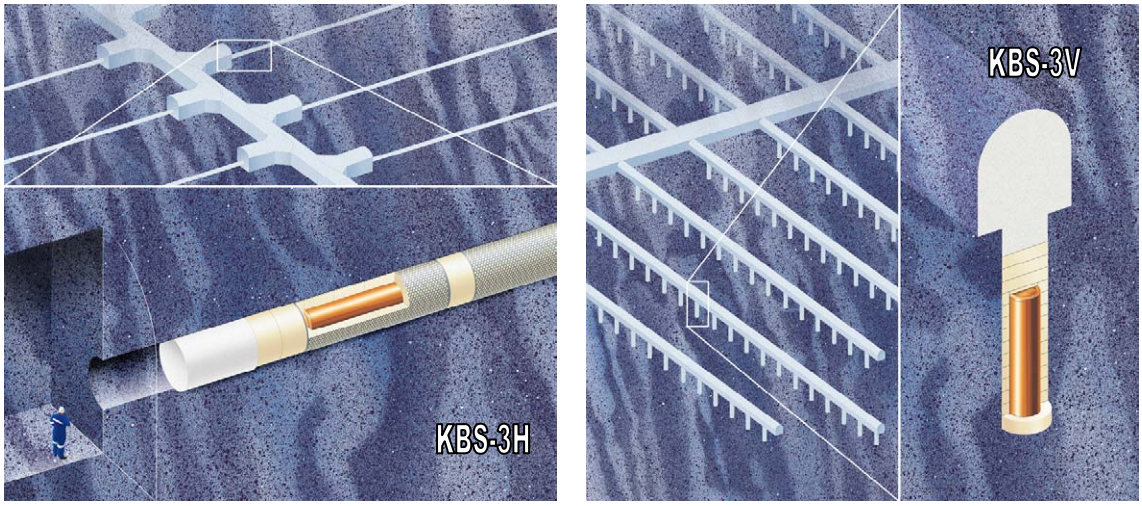
The Temperature Buffer Test is in the operation and data acquisition phase since March 2003. The collection of data is continuing and data report No. 7 covering the period up to 1st of January 2006 is available /Goudarzi *et al.* 2006b/. Data acquisition is continuously ongoing and data is reported on a monthly basis. The data link from Äspö to Andra's head office in Paris has been functioning well.

The artificial watering and evaluations are in progress and the bentonite around the upper heater appears to be close to saturated, whereas the innermost parts of the blocks around the lower heater still are unsaturated.

The outputs from the heaters were increased from 1,500 to 1,600 W on 9th June, 2006. This was a thermal compensation for the termination of the Canister Retrieval Test. Moreover, the filter tips in the sand filter were back-flushed during May – June 2006.

A modelling meeting was held at Äspö HRL on April 27th, 2006. The main subject for this meeting was the TBT_3 mock-up test, conducted by CEA, and blind predictions were presented and compared with experimental results. The field experiment will be revisited in the next modelling task. This will focus on replicating high-confidence experimental results.

5.6 KBS-3 Method with Horizontal Emplacement



The possibility to modify the reference KBS-3 method and make serial deposition of canisters in long horizontal deposition holes (KBS-3H), instead of deposition of single canisters in vertical deposition holes (KBS-3V), is studied in this project.

One reason for proposing the change is that the deposition tunnels in KBS-3V are not needed if the canisters are disposed in long horizontal deposition holes and the excavated rock volume and the amount of backfill can be considerably reduced. This in turn reduces the environmental impact during the construction of the repository and also the construction costs.

The site for the demonstration of the method is located at -220 m level. A niche with a height of about 8 m and a bottom area of 25×15 m forms the work area. Two horizontal deposition holes have been excavated, one short with a length of about 15 m and one long with a length of about 95 m. The deposition equipment will be tested in the long hole and the short hole will be used for testing of a low-pH shotcrete plug and of different drift components.

The KBS-3H project is partly financed by the EC-project Esdred – Engineering studies and demonstration of repository designs.

Achievements

During the second quarter of 2006 work has been focused on the following parts:

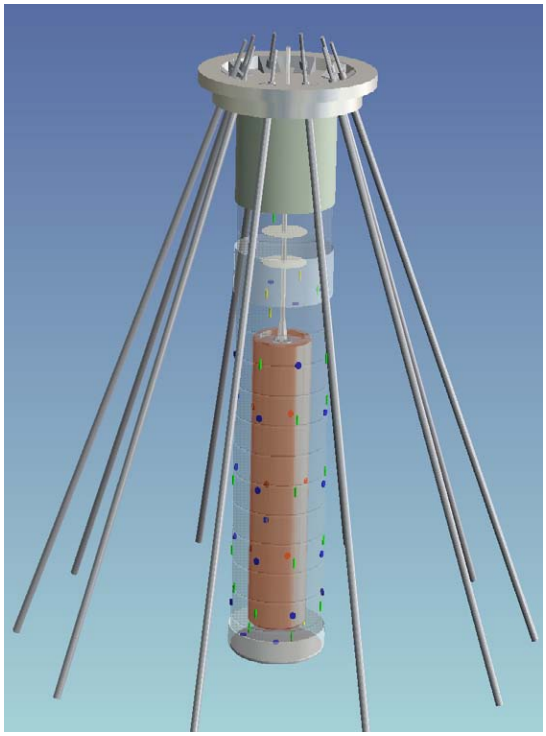
- Preparation of the deposition equipment for the Site Acceptance Test (SAT).
- Dismantling of low pH shotcrete plug.
- Low-pH shotcrete rock support.

After the delivery the manufacture of the deposition equipment (CNIM) started with the hydraulic and electric connections. There are problems with the balance/rotation system for handling the Supercontainer. A meeting was held on 1st - 2nd of June with participants from CNIM where suggestions of different solutions were discussed. Tests were performed with a balanced container with water cushion configuration in parallel (left/right) and also in configuration where the cushions were separated left and right In both cases the container could in a static situation be balanced with the help of the counterweight (were done May 29th). However in both cases, as soon as the container was moved forward or backward, the container started turning. CNIM will review the tests and modifications of the slide plate will be done late June and a third actuator is planned to be installed in to middle of August. The final SAT (Site Acceptance Test) is planned to August 29th – September 15th.

The dismantling of the low-pH shotcrete plug started May 15th by Aitemin. The dismantling were planned to answer questions like void between concrete and rock, adherence between concrete layers, leakage from membrane and behaviour of the plug after the pressure test. Inclined grout holes were drilled from the plug into the rock and after that, resin grouting was planned. However, the injection failed because the use of a not suitable resin and the equipment was not right for this kind of work. Horizontal holes were drilled through the plug to investigate the leakage that was discovered during the pressure test with water and tracer. The cores showed that the adherence between the layers was no good and any tracers from the leakage was not to be found. After that, an entrance hole to the chamber was done to see the membrane and also to inspect the behaviour of the plug. The inspection showed that the gap between layer one and two was about 20-30 mm and the upper part of the plug had no adherence to the rock. The dismantling of the whole plug was finished 16th June and the drill cores are sent to Aitemin for analyses.

The niche NASA 1504A was prepared for test of the low-pH shotcrete rock support during April and the shotcrete test where done 27th -28th May. The sample test and adhesion test were performed 7th of June and evaluation is ongoing.

5.7 Large Scale Gas Injection Test



Layout of the Lasgit experiment conducted in the assembly hall area at the -420 m level.

Current knowledge pertaining to the movement of gas in a compact buffer bentonite is based on small-scale laboratory studies. These diagnostic tests are designed to address specific issues relating to gas migration and its long-term effect on the hydro-mechanical performance of the buffer clay.

Laboratory studies have been used to develop process models to assess the likely implications of gas flow in a hard-rock repository system. While significant improvements in our understanding of the gas-buffer system have taken place, a number of important uncertainties remain. Central to these is the issue of scale and its effect on the mechanisms and process governing gas flow in compact bentonite. The question of scale-dependency in both hydration and subsequent gas phases of the test history are central issues in the development and validation of process models aimed at repository performance assessment. To address these issues, a Large Scale Gas Injection Test (Lasgit) has been initiated. Its objectives are:

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

Lasgit is a full-scale demonstration project (performed under ambient isothermal conditions) conducted in the Assembly Hall Area of the Äspö HRL at a depth of 420 m. Interstitial water has been introduced into the system since February 2005. When the buffer is fully saturated a series of gas injection tests will be undertaken to examine the mechanisms governing gas flow in KBS-3 bentonite.

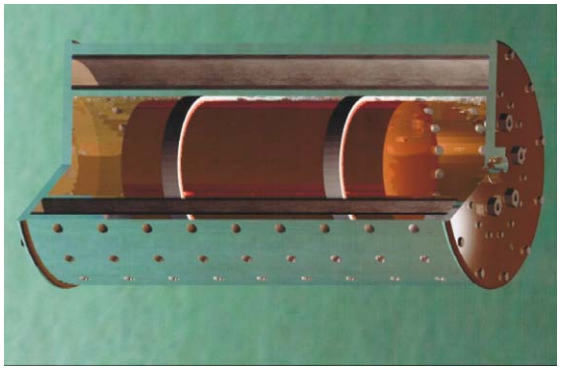
Achievements

During 2005 the resaturation phase of the Lasgit experiment was examined using numerical models developed with the Tough2 code and the EOS3 equation of state module. A series of model runs were performed examining the sensitivity of the system to a number of factors including the role of hydraulic fractures intersecting the deposition hole and the importance of the permeability of the zone adjacent to the canister. At the end of March 2006 "multi-completion" packers were installed in each pressure relief hole (PRH). During this reporting quarter individual packers have been inflated in an incremental manner. Changes in porewater pressure within the deposition hole and the packer arrays have been monitored with time in order to examine the connectivity of the fracture systems. This data also provides information on the local porewater pressures in the immediate vicinity of the deposition hole.

Monitored values of axial and radial stress have progressively increased since closure of the deposition hole. Radial stress measured on the canister surface is comparable with the average value of radial stress monitored on the rock face. Analysis of the volumetric flow rate data indicates a higher permeability zone in the region of the system around the canister. Sensors monitoring canister position clearly show that movements of the canister are sensitive to changes in pore water pressure.

Results from the Lasgit project were presented at both the American Nuclear Society meeting in Las Vegas and at the Technical Evaluation Forum meeting in Äspö during May 2006.

5.8 In Situ Corrosion Testing of Miniature Canisters



Miniature canister with support cage

Borehole drilling

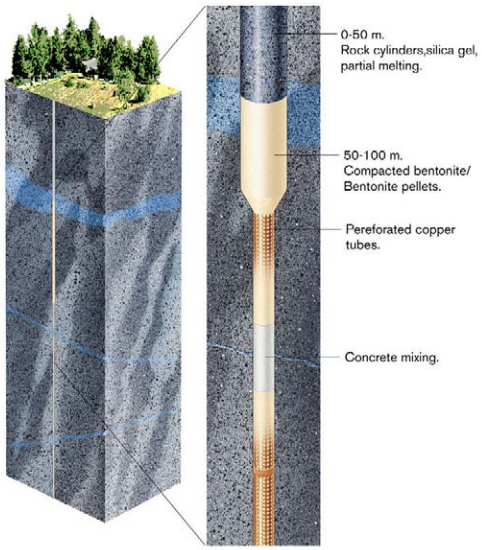
This project (MinCan) is designed to provide information about how the environment inside a copper canister containing a cast iron insert would evolve if failure of the outer copper shell were to occur. The development of the subsequent corrosion in the gap between the copper shell and the cast iron insert would affect the rate of radionuclide release from the canister. The information obtained from the experiments will be valuable in providing a better understanding of the corrosion processes inside a failed canister.
Miniature canisters with a diameter of 14.5 cm and containing 1 mm diameter defects in the outer copper shell are being set up in five boreholes with a diameter of 30 cm and a length of 5 m at the Äspö HRL. The canisters will be mounted in support cages, which will contain bentonite clay, and will be exposed to natural reducing groundwater. Together with corrosion test coupons which will also be in the boreholes, the canisters will be monitored for several years. The corrosion will take place under realistic oxygen-free repository conditions that are very difficult to reproduce and maintain for long periods of time in the laboratory.

Achievements

The MiniCan experiment was initiated in 2005, when five boreholes (76 mm diameter) were drilled in a niche at tunnel length 3,384 m (NASA) and the components and support cages of the canister experiments were designed. Five miniature canisters and the first support cage have been fabricated. The other four support cages will be fabricated after the first experiment has been assembled and tested.

Some problems have been experienced with excess water emerging from the rock faces around the boreholes. Therefore, the rock volume where the boreholes are drilled will be grouted to a depth of 1 m in order to get a higher groundwater pressure in the boreholes. The experiment will be installed and initiated during 2006. The remaining activities will comprise reaming of the last part of the boreholes to 302 mm, followed by emplacement of the support cages containing the miniature canisters and installation of the monitoring instrumentation. The first phase of the experiment is planned to run for five years.

5.9 Cleaning and Sealing of Investigation Boreholes



A project, with the aim to identify and demonstrate the best available techniques for cleaning and sealing of investigation boreholes, was initiated in 2002.

The project comprises three phases.
Phase 1 was mainly an inventory of available techniques, and the aim of Phase 2 was to develop a complete cleaning and sealing concept. Phase 3 comprises large-scale testing of the sealing concept in boreholes.

A laboratory test program on candidate sealing materials is part of the project. Short and long boreholes from the surface and from tunnels underground, will be used to demonstrate the plugging concept.

The project is run in co-operation between SKB and Posiva.

Achievements

The third phase of the project has been initiated and the status of the ongoing project is given below:

Sub-project 1 – comprises the engineering of design solutions of borehole plugs of clay and cement. Chemical studies of the quarts/cement mixing for the plug has been done by the Swedish cement and concrete research institute and samples have also been sent to Germany. Results from the studies have been delivered in a short working report. Erosion test by using a backpressure on the copper/bentonite plug, in order to simulate the increasing hydraulic head during the installation in the hole have been finished .The results show that approximately 8-10% of the bentonite will be eroded during installation of a plug to 1,000 meters depth. If dried and super compacted bentonite is used, the final density will still be acceptable. Improvement and manufacturing of "bentonite container" for placing clay plugs in deep holes without perforated copper tubes is ongoing. Same techniques and equipments could be used for placement of cement/quartz plugs in the boreholes.

Sub-project 2 – comprises plugging and testing of eight 5 m deep, 76-80 mm diameter boreholes at Äspö HRL. The aim is to test simpler sealing techniques that can be applied in shorter boreholes, especially in holes drilled from a repository. Hydraulic characterisation of the boreholes has been finished. A programme for plugging and testing the holes, together with prediction of maturation of the bentonite, has been presented. Hydraulic jack equipment and different clay plugs have been manufactured and are ready for installation and testing. Two new short boreholes for investigation of physical and chemical interaction of quartz/cement and clay plugs have been drilled at the -220 m level. Clay plugs are finished and ready for installation. The boreholes could act as a complement to the test in the borehole at Onkalo in Finland (OL-KR24).

Sub-project 3 – comprises preparation, stabilisation and installation of plugs in the 76 mm wide borehole OL-KR24 at Onkalo. The field work in the borehole was finished in December 2005. Information from the work will be compiled in a report together with predictions of the maturation of the bentonite. A symposium was held in early May in Finland.

Sub-project 4 – has the aim to test the feasibility of candidate techniques intended for mechanical securing of the tight seals emplaced lower in deep boreholes. Designing of equipment for enlarging boreholes (194-300 mm), in order to construct a mechanical blocking in the upper part of the boreholes is ongoing. Coredrilling of three 200 mm boreholes at -450 m level have been finished during the period. The purpose of the boreholes is to determine the strength of the plug/rock contact. Percussion drilling of two 200 mm wide boreholes at the surface for testing the enlarging equipment is in progress.

5.10 Alternative Buffer Materials

In the Alternative Buffer Materials project different types of conceivable buffer materials will be tested in field scale. The aim is to further investigate the properties of the alternatives to the SKB reference MX-80 material.

The project will be carried out using material that according to laboratory studies are conceivable buffer materials. The experiment will be carried out in the same way and scale as the Long Term Test of Buffer Material (see section 5.2).

The objectives are to:

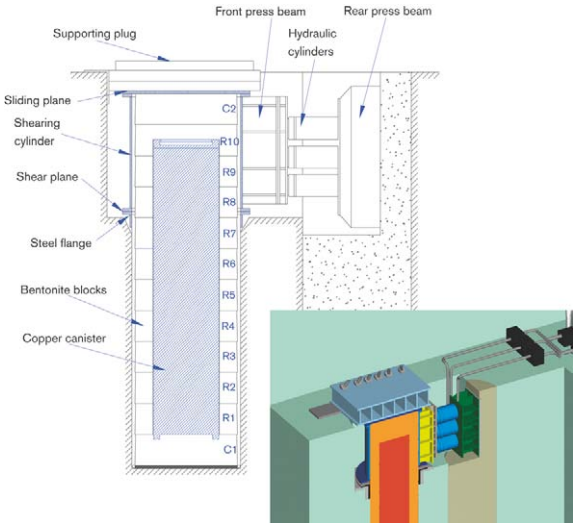
- Verify results from laboratory studies during more realistic conditions with respect to temperature, scale and geochemical circumstances.
- Discover possible problems with manufacturing and storage of bentonite blocks.
- Give further data for verification of thermo-hydro-mechanical (THM) and geochemical models.

Achievements

Excavation of the experiment site, located in the TASQ tunnel at 450 meters depth, has been completed during the second quarter of 2006. The deposition holes have been drilled and are awaiting BIPS measurement and characterisation.

Buffer materials have been purchased and block pressing will commence during the summer. The international project members are contributing with the materials they wish to test.

5.11 Rock Shear Experiment



The Rock Shear Experiment (Rose) 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. Such a displacement may be caused by an earthquake and the test set-up need to provide a shearing motion along the fracture that is equal to the worst expected shearing motion in real life.

The *in situ* test set-up is planned to be installed at the Äspö Pillar Stability site. Two full scale deposition holes already exist with a rock pillar of one metre in between. One deposition hole will be used for the buffer and canister, while the other deposition hole is used for the shearing equipment.

Achievements

A pre-study of design and feasibility is completed and reported. The main conclusion is that the test is feasible. A preliminary decision to realize the plans has been taken but the time schedule is not yet set. No work has been done in 2006 so far.

5.12 Earth Potentials

The main objective of the project is to identify the magnitude of potential fluctuations and stray currents at repository depth. The causes to these effects may be Geomagnetically Induced Currents (GIC) or man-made stray current sources. The aim is also to find out the problems these effects could cause in a deep repository. The project will include the following investigations:

- Electromagnetic induced currents from natural sources.
- Electrochemical reactions in soil and rock.
- The transition from ion transfer in bentonite to electron transport in copper.
- Impact of copper ions on bentonite properties.
- Physical and chemical interactions between copper and bentonite.
- Basic processes in clay that are exposed to direct current (DC).
- Microbes as electron transmitters.

Achievements

The laboratory experiments, performed at Clay Technology in Lund, on the impact of copper ions on bentonite properties are finished. The complementary studies are finished and a draft report was presented at a meeting in June.

A new setup for testing of electric behaviours between copper and bentonite has been developed at the Corrosion Institute in Stockholm. Some results were presented at a meeting in June. The testing will take some time because the measurements have to be done after the oxygen is gone.

Measurements of natural electromagnetic fields (magneto telluric technique), by Uppsala University, have been finished and the report has been delivered.

5.13 Task Force on Engineered Barrier Systems

The Task Force on Engineered Barrier Systems (EBS) is a natural continuation of the modelling work in the Prototype Repository Project, where also modelling work on other experiments, both field and laboratory tests, are conducted. The Äspö HRL International Joint Committee has decided that in the first phase of this Task Force (period 2004-2008), work should concentrate on:

Task 1 THM modelling of processes during water transfer in buffer, backfill and near-field rock. Only crystalline rock is considered initially, although other rock types could be incorporated later.

Task 2 Gas transport in saturated buffer.

The objectives of the Tasks are to: (a) verify the capability to model THM and gas migration processes in unsaturated as well as saturated bentonite buffer, (b) refine codes that provide more accurate predictions in relation to the experimental data and (c) develop the codes to 3D standard (long-term objective).

Beside SKB seven international organisations are participating in the Task Force. These organisations are funding 15 modelling teams.

Achievements

A Task Force meeting was held at Äspö HRL 25th-26th April. At this meeting the results of the different groups modelling of the Benchmark 1 tests were treated.

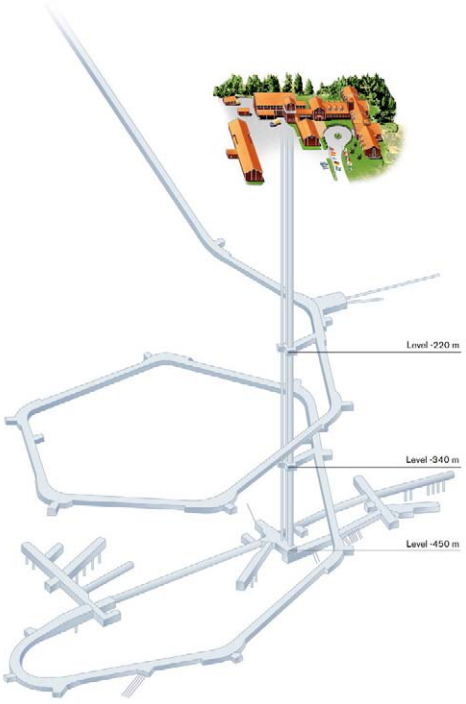
For Task 1 (THM) the modelling results of Benchmark 1 (laboratory tests) were reviewed and a third benchmark test presented. It consists of two samples of Febex bentonite enclosed in a membrane without external pressure. The samples were exposed to a temperature gradient without any additional water available. The redistribution of moisture and density was measured. This test will be modelled and the results presented at the next meeting.

For Benchmark 2 (large scale tests) of Task 1 it was decided to use the Canister Retrieval Test and the two URL tests, BCE and ITT, as modelling tasks. The modelling of these tests will start at the end of 2006. For Task 2 (gas) the preliminary results of the modelling of the two benchmark tests were presented at the meeting. The modelling of these tests will continue and a report sent by each team before the next meeting.

6 Äspö facility

Important parts of the Äspö facility are the administration, operation and maintenance of instruments as well as development of investigation methods. The Public Relations and Visitor Services 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.

6.1 Facility Operation



The main goal for the operation of the facility 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 as drainage, electrical power, ventilation, alarm and communications.

Achievements

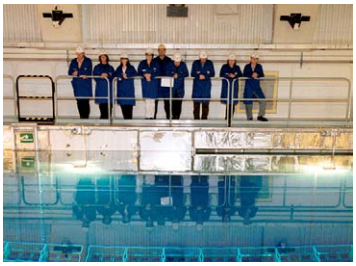
The facility's safety is good, all the operating systems are functioning well. Improvements are being carried out in order to increase operative safety and also to save electricity. Personnel safety has been increased by the introduction of new rules and instructions. A remote system for the registration of personnel and other objects in the below-ground facility has been developed. The system is now being tested and the personnel are being trained in its operation. Routines will be written.

A pre-study for the construction of a reserve power system at the facility has been completed. A new decision is required in order to implement the measures the study recommends. The measures will be implemented during the autumn 2006 and during 2007.

The building of the laboratory for testing of bentonite materials has started and is expected to be ready the 1st of December.

6.2 Public Relations and Visitors Service





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 at Oskarshamn and Östhammar.

The main goal for the information and public relations group at Äspö HRL, is to in co-operation with other departments at SKB, present information about SKB and its activities and facilities.

Achievements

SKB's facilities have been visited by 12,304 persons during the first six months 2006. The numbers of visitors to SKB's main facilities are listed in Table 6-1.

Table 6-1 Number of visitors to SKB facilities

SKB facility	Number of visitors January - June 2006
Central interim storage facility for spent nuclear fuel	1,188
Canister Laboratory	1,654
Äspö HRL	4,324
Final repository for radioactive operational waste (SFR)	4,337

The Äspö day took place the 14th of May and about 170 visitors came. The summer activities with an increased number of guided tours in English to the exhibition "Urberg 500" started in the end of June. Four summer guides have been employed to support the information group during the summer. SKB was represented by the information group at the music festival in Hultsfred in June.

7 Environmental research

7.1 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. Currently the scientific team consists of a professor of Environmental geology (Dr. Mats Åström), a research assistant, four assistant supervisors and five Ph.D. students. The research activities focus 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 the University of Kalmar, the school receives funding from the city of Oskarshamn.

Achievements

During May 2006 the second Ph. D. dissertation took place. The title of the thesis is "Hydrochemical characteristics of boreal and tropical surface and ground waters affected by acid sulphate soils", University of Kalmar, Faculty of Natural Sciences, Dissertations series no 34.

8 International co-operation

Nine organisations from eight countries participate in the Äspö HRL co-operation during 2006, see Table 8-1. Six of them; Andra, BMWi, CRIEPI, JAEA, OPG and Posiva together with SKB form the Äspö International Joint Committee (IJC), which is responsible for the co-ordination of the experimental work arising from the international participation.

Several of the participating organisations take part 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 at gas migration through a buffer.

Table 8-1 International participation in the Äspö HRL projects during 2006.

Projects in the Äspö HRL during 2006	Andra	BMWi	CRIEPI	JAEA	OPG	Posiva	Enresa	Nagra	RAWRA
Geo-science									
Äspö Pillar Stability Experiment					X	X			
Natural barriers									
Tracer Retention Understanding Experiments	X			X		X			
Long Term Diffusion Experiment					X				
Colloid Project		X				X			
Microbe Project		X							
Radionuclide Retention Project		X							
Task Force on Modelling of Groundwater Flow and Transport of Solutes	X		X	X	X	X			
Engineered barriers									
Prototype Repository	X	X		X		X			
Long Term Test of Buffer Material						X		X	
Alternative Buffer Materials	X	X		X		X		X	X
Temperature Buffer Test	X	X					X		
KBS-3 Method with Horizontal Emplacement						X			
Large Scale Gas Injection Test	X	X			X	X			
Task Force on Engineered Barrier Systems	X	X	X		X	X		X	X

Participating organisations:
Agence nationale pour la gestion des déchets radioactifs, Andra, France
Bundesministerium für Wirtschaft und Technologie, BMWi, Germany
Central Research Institute of the Electronic Power Industry, CRIEPI, Japan
Japan Atomic Energy Agency, JAEA, Japan
Ontario Power Generation Inc., OPG, Canada
Posiva Oy, Finland
Empresa Nacional de Residuos Radiactivos, Enresa, Spain
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, Switzerland
Radioactive Waste Repository Authority, Rawra, Czech Republic

9 Documentation

During the period April to June 2006, the following reports have been published and distributed.

9.1 Äspö International Progress Reports

Dideriksen K, Stipp S L S, 2005. Iron oxides in fractures at Äspö. A feasibility study to test the possibility of finding a geothermometer or a palaeo-redox indicator. IPR-06-09, Svensk Kärnbränslehantering AB.

Goudarzi R, Johannesson, L-E, 2005. Prototype Repository. Sensors data report (Period: 010917-051201). Report No:14. IPR-06-06, Svensk Kärnbränslehantering AB.

Haycox J R, Pettitt W S, 2005. Acoustic emission and ultrasonic monitoring during the heating of deposition hole DA3545G01 in the Prototype Repository to March 2005. IPR-05-30, Svensk Kärnbränslehantering AB.

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SKB, 2006a. Äspö Hard Rock Laboratory. Planning Report for 2006. IPR-06-06, Svensk Kärnbränslehantering AB.

SKB, 2006b. Äspö Hard Rock Laboratory. Status Report. January - March 2006. IPR-06-12, Svensk Kärnbränslehantering AB.

9.2 Technical Documents and International Technical Documents

Bergelin A, Jonsson U, Berg C, Wacker P, 2005. Prototype Repository. Water sampling in Prototype Repository and compilation of water chemistry data from Äspö HRL, TD-05-03, Svensk Kärnbränslehantering AB.

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Goudarzi R, Åkesson M, Hökmark H, 2006b. Temperature Buffer Test. Sensors data report (Period: 030326-060101) Report No:7. IPR-06-04, Svensk Kärnbränslehantering AB.

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Mas Ivars D, 2005. Äspö Pillar Stability Experiment. Hydromechanical data acquisition experiment at the APSE site. IPR-05-21, Svensk Kärnbränslehantering AB

Moye D G, 1967. Diamond Drilling for Foundation Exploration. Civil Eng. Trans., Inst. Eng. Australia, Apr. 1967, pp 95-100.

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