International Progress Report

IPR-10-09

Äspö Hard Rock Laboratory

Status Report
September – December 2009

Svensk Kärnbränslehantering AB

May 2010

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

Äspö Hard Rock Laboratory

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Author
Kemakta
Checked by

Approved
Mats Ohlsson

No.

Date
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Date

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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 2008–2013 are presented in SKB's RD&D-Programme 2007 /SKB 2007/. The information given in the RD&D-Programme related to Äspö HRL is annually detailed in the Äspö HRL Planning Report /SKB 2009/.

This Äspö HRL Status Report is a collection of the main achievements obtained during the period September to December 2009.

Geoscience

Geoscientific research is a natural part of the activities at Äspö HRL and is conducted in the fields of Geology, Hydrogeology, Geochemistry 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.

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 ongoing projects and experiments are: Tracer Retention Understanding Experiments, Long Term Sorption Diffusion Experiment, Colloid Transport Project, Microbe Projects, Matrix Fluid Chemistry Continuation, Radionuclide Retention Experiments, Padamot, Fe-oxides in Fractures, Swiw-tests with Synthetic Groundwater and Äspö Model for Radionuclide Sorption. Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are addressed in the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

Engineered barriers

Another goal 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. The ongoing projects and experiments are: Prototype Repository, Long Term Test of Buffer Material, Alternative Buffer Materials, Backfill and Plug Test, Canister Retrieval Test, Temperature Buffer Test, KBS-3 Method with Horizontal Emplacement, Large Scale Gas Injection Test, Sealing of Tunnel at Great Depth, In Situ Corrosion Testing of Miniature Canisters and Cleaning and Sealing of Investigation Boreholes. THM processes and gas migration in buffer material are addressed in the Task Force on Engineered Barrier Systems and in a parallel Task Force geochemical processes in engineered barriers are studied.

Äspö facility

The Äspö facility consists of the Hard Rock Laboratory and the Bentonite Laboratory which were taken into operation in 1995 and 2007 respectively. Important parts of the activities at the Äspö facility are the administration, operation and maintenance of instruments as well as the development of investigation methods. The Public Relations and Visitor Services group is responsible for presenting information about SKB and its facilities. They arrange visits to the facilities all year around as well as special events.

Environmental research

Äspö Environmental Research Foundation was founded 1996 on the initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its resources available for national and international environmental research. During 2003-2008 the activities were concentrated to the Äspö Research School. According to plan the activities in the school were concluded in 2008 and the remaining and new research activities were transferred within the frame of a new co-operation, Nova Research and Development (Nova FoU).

International co-operation

The Äspö HRL has during the years attracted considerable international interest. Eight organisations from seven countries participate in the co-operation or in Äspö HRL related activities, apart from SKB, during 2009.

Contents

1 General

The Äspö Hard Rock Laboratory (HRL), located 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. In the Bentonite Laboratory, taken into operation in 2007, studies on buffer and backfill materials are performed to complement the studies performed in Äspö HRL.

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 are divided between numerous experiments performed at the Äspö HRL. In Figure 1-1, the allocation of the main experimental sites in Äspö HRL is shown.

SKB's overall plans for research, development and demonstration during the period 2008–2013 are presented in SKB's RD&D-Programme 2007 /SKB 2007/. The planned activities related to Äspö HRL are detailed on a yearly basis in the Äspö HRL Planning Report /SKB 2009/. This Status Report presents main achievements during the period September to December 2009. In the Annual Report more detailed information is given of new findings and results obtained during the whole year.

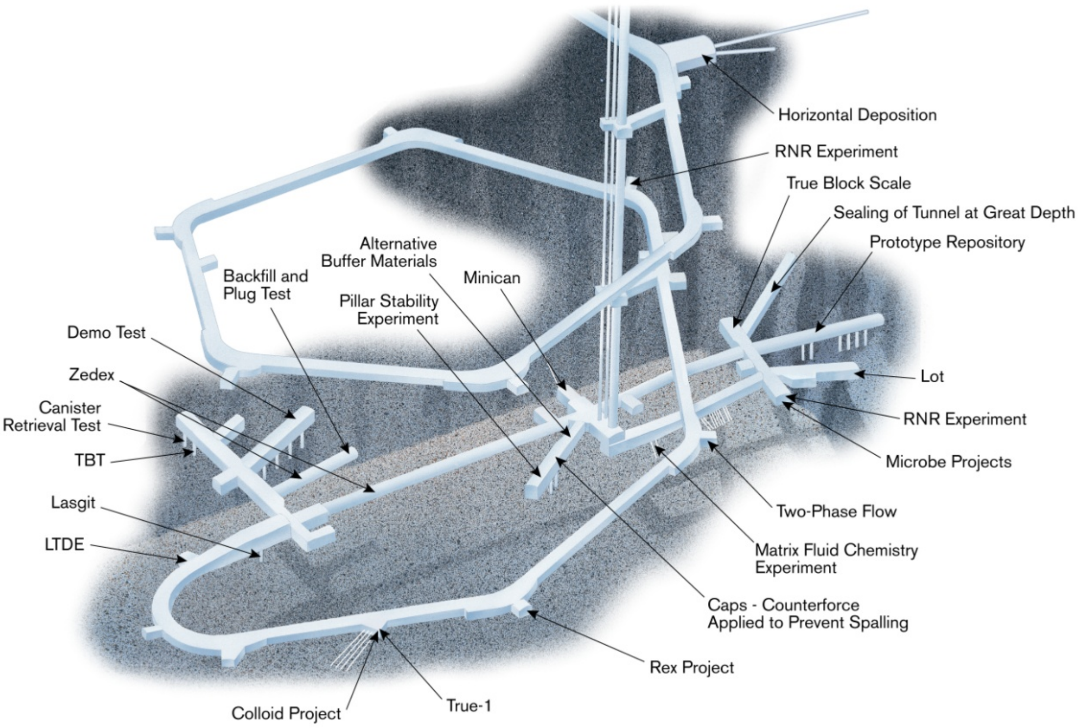


Figure 1-1. *Overview of the Äspö HRL and the allocation of the experimental sites from -220 m to -450 m level.*

2 Geoscience

2.1 General

Geoscientific research is a natural part of the activities at Äspö HRL and is conducted in the fields of geology, hydrogeology, geochemistry and rock mechanics. The studies include laboratory and field experiments, as well as modelling work. The overall aims are to:

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

One main task within the geoscientific field is the development of an Äspö Site Descriptive Model (SDM) integrating the information from the fields of geology, hydrogeology and geochemistry, see Figure 2-1. The SDM will facilitate the understanding of the geological, hydrogeological and geochemical conditions at the site and the evolution of the conditions during operation of Äspö HRL.

The SDM provides basic geoscientific data to support predictions and planning of experiments performed in Äspö HRL. The aim is also to ensure high quality experiments and measurements related to geosciences.

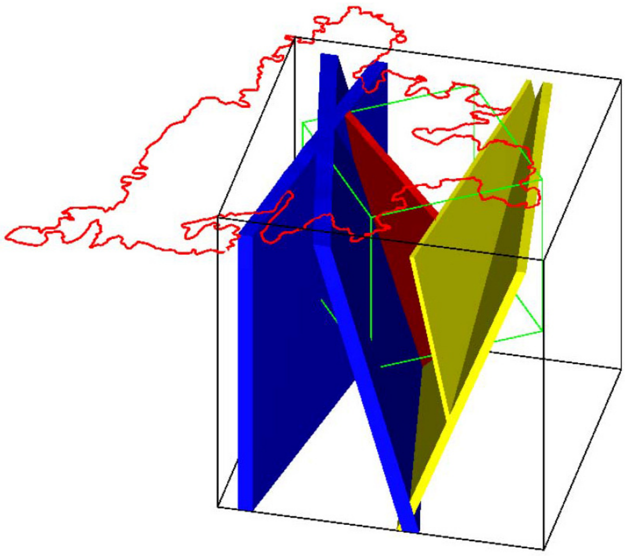
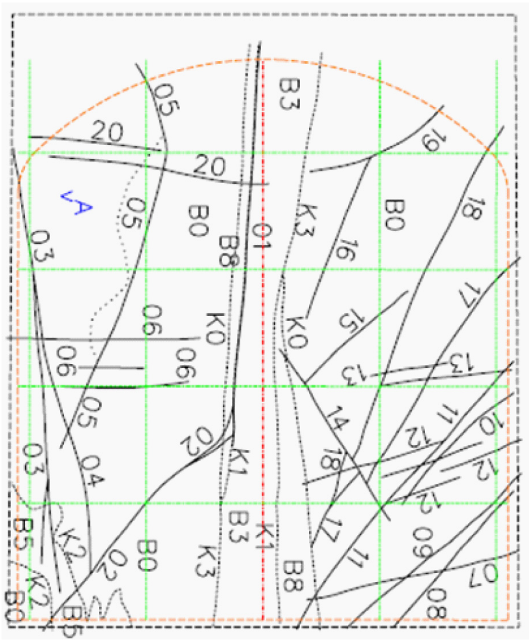


Figure 2-1. *Modelling work to help understand the geological, hydrogeological and geochemical conditions of the Äspö site.*

2.2 Geology

Geological work at Äspö HRL is focused on several main fields. Major responsibilities are mapping of tunnels, deposition holes and drill cores, as well as continuous updating of the geological three-dimensional model of the Äspö rock volume. In addition, the development of new methods in the field of geology is a major responsibility.

2.2.1 Geological Mapping and Modelling



Geological map of the tunnel face at the end section 80.7 m of the Tass-tunnel (B0-B8 refer to rock types, dashed lines with K0-K3 refer to rock boundaries and full or dotted lines with numbers 01-20 refer to fractures).

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 of the rock volume together with other input data.

Achievements

The main activities or achievements during September to December 2009 have been:

- Consensus has been reached concerning the rock type nomenclature used by the site investigation team of Oskarshamn and that used by the geologists at the Äspö HRL. This is essential for the ongoing description of Äspö in the Äspö Site Descriptive Model (SDM). The nomenclature will be used also by the TMS-system (Tunnel Mapping System) and the Boremap core logging system.
- New rock type codes have been implemented in the TMS-system. These codes are the same as those used by Boremap. This will for example simplify the transfer of geological data from the TMS to the SKB database Sicada.
- The Boremap and Petrocore (the old core logging system) tables in the SKB database Sicada have been updated to the site investigation programme nomenclature, which means that all used rock type codes now are the same.
- The great number of photos taken during the mapping of the Tasa-tunnel at Äspö HRL since early 90th have earlier been digitised and are now organised and labelled. The work proceeds with the minor tunnels and deposition holes.

- The modelling work that commenced in 2005 concerning water bearing fractures at the -450 m level is finished. Adjustments of the report after having been reviewed are still going on, but no progress has been made lately.
- The report concerning the geological mapping of the Tass-tunnel is now in preparation.

2.2.2 Rocs – Method Development of a New Technique for Underground Surveying

A 3D view of the inner section of the Tasq-tunnel (combination of laser scanning and digital photography).

A feasibility study concerning geological mapping techniques has been completed /Magnor et al. 2007/. Based on the knowledge from the feasibility study SKB has commenced a new phase of the Rocs project.

The purpose is to investigate if a new system for rock characterisation has to be adopted when constructing a final repository. The major reasons for the 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. These aspects all represent areas where the present mapping technique may not be adequate.

The project will concentrate on finding or constructing a new geological underground mapping system. Laser scanning in combination with digital photography will, at least at the time being, be a part of that system. The resulting mapping system shall operate in a colour 3D environment where the xyz-coordinates are known.

Achievements

SKB has decided to develop a geological mapping system of their own, based on the principles of the Boremap-core logging system and photogrammetry. SKB has chosen digital photogrammetry in favour of laser scanning.

The report concerning laser scanning combined with digital photography in the Tasq-tunnel is now published /Berlin & Hardenby 2008/.

2.3 Hydrogeology

The objectives of the hydrogeological work are to:

- Establish and develop applicable methods for measurement, testing and analysis for the understanding of the hydrogeological properties of the Äspö HRL rock mass.
- Ensure that experiments and measurements in the field of hydrogeology are performed with high quality.

The main tasks are firstly to continue work for further development of quality control and quality assurance procedures in the field of hydrogeology and secondly to upgrade the Äspö Site Descriptive Model. The main features are the inclusion of additional data collected from various experiments and the adoption of modelling procedures developed during the site investigations. The intention is to develop the model into a dynamic working tool suitable for predictions in support of the experiments in the laboratory as well as to test hydrogeological hypotheses. Another part of the work with the site description is the continued development of a more detailed model of hydraulic structures at the main experimental sites.

Achievements - Äspö Site Descriptive Model

A number of quality issues with the basic datasets have been addressed and resolved. Some initial pre-modelling runs were performed with SKB's numerical flow and transport code Darcy Tools.

2.3.1 Hydro Monitoring Programme

The hydro monitoring programme is an important part of the hydrogeological research and a support to the experiments undertaken in Äspö HRL. The monitoring of water level in surface boreholes started in 1987 while the computerised Hydro Monitoring System (HMS) was introduced in 1992.

The HMS collects data on-line of pressure, levels, flow and electrical conductivity of the groundwater. The data are recorded by numerous transducers installed in boreholes. 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. To date the monitoring programme comprises a total of about 140 boreholes (about 40 surface boreholes and 100 tunnel boreholes). Many boreholes are equipped with inflatable packers, dividing the borehole into sections. Water seeping into the tunnel is diverted to trenches and further to 25 weirs where the flow is measured.

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

The data collected in HMS is transferred to SKB's site characterisation database, Sicada.

Achievements

The hydrogeological monitoring have been ongoing, monitoring points were maintained and performed well, particularly the tunnel installed equipment. Quality issues with the monitoring database (HMS) in respect to being incomplete and not harmonised with the activity database (Sicada) have been resolved.

Borehole TV logging with BIPS has been performed in KAS09 mainly to support the hydraulic characterisation. The BIPS logging showed however cavities which could hazard Posiva Flow Logging (PFL) in the borehole. PFL will therefore not be performed in the borehole.

The refurbishing of boreholes KAS03 and KAS09 is underway. New equipment was installed in KAS03, due to be operative early next year. Thereafter KAS09 is due for installation.

The monitoring is reported every four-month period through quality control documents and on an annual basis, describing the measurement system and basic results. The annual report for monitoring year 2009 is underway, preliminarily due for publication in April 2010.

2.4 Geochemistry

The major aims with the geochemistry work are to:

- Establish and develop the understanding of the hydrogeochemical properties of the Äspö HRL rock volume.
- Maintain and develop the knowledge of applicable measuring and analytical methods.
- Ensure that experimental sampling programmes are performed with high quality and meet overall goals within the field area.
- Provide hydrogeochemical support to active and planned experiments at Äspö HRL.

An important part is the compilation of geochemical data for the Äspö Site Descriptive Model. The use of the information generated will facilitate the understanding of the geochemical conditions at the site and the way in which they change during operation. The intention is to develop the model as to be used for predictions, to support and plan experiments, and to test hydrogeochemical hypotheses. This is important in terms of distinguishing undisturbed and disturbed conditions.

Achievements - Äspö Site Descriptive Model

The final documentation of the results from the analyses in the Tass-tunnel from previous years is now available for review. The main report is expected to be finalised during the first four-month period of 2010.

The compilation of the hydrogeochemical data for the Äspö Site Descriptive Model (SDM) is completed and evaluated by use of "explorative analyses". This is made on data from all depths and mixing models are being produced through M3 modelling. When end-members have been chosen (there are some suggestions already), reaction modelling will be done using PhreeqC. Data will soon be available from the Microbe project and the forthcoming work will concentrate on identification and quantification of the ligands.

2.4.1 Monitoring of Groundwater Chemistry

Water sampling in a tunnel at Äspö HRL.

During the Äspö HRL construction phase, water samples were collected and analysed with the purpose of monitoring the groundwater chemistry and its evolution as the construction proceeded. The samples were collected from boreholes drilled from the ground surface and from the tunnel. At the beginning of the Äspö HRL operational phase, sampling was replaced by a groundwater chemistry monitoring programme, with the aim to sufficiently cover the evolution of hydrochemical conditions with respect to time and space within the Äspö HRL.

The monitoring 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. In addition, all ongoing experiments have the possibility to request sampling of interest for their projects.

Achievements

The monitoring campaign was completed this autumn and data is now being quality assured for Sicada. The results are expected to be reported during the first four-month period of 2010. The monitoring programme will be evaluated and is suggested to be redesigned to better fit the current need for the ongoing and planned experiments at Äspö HRL.

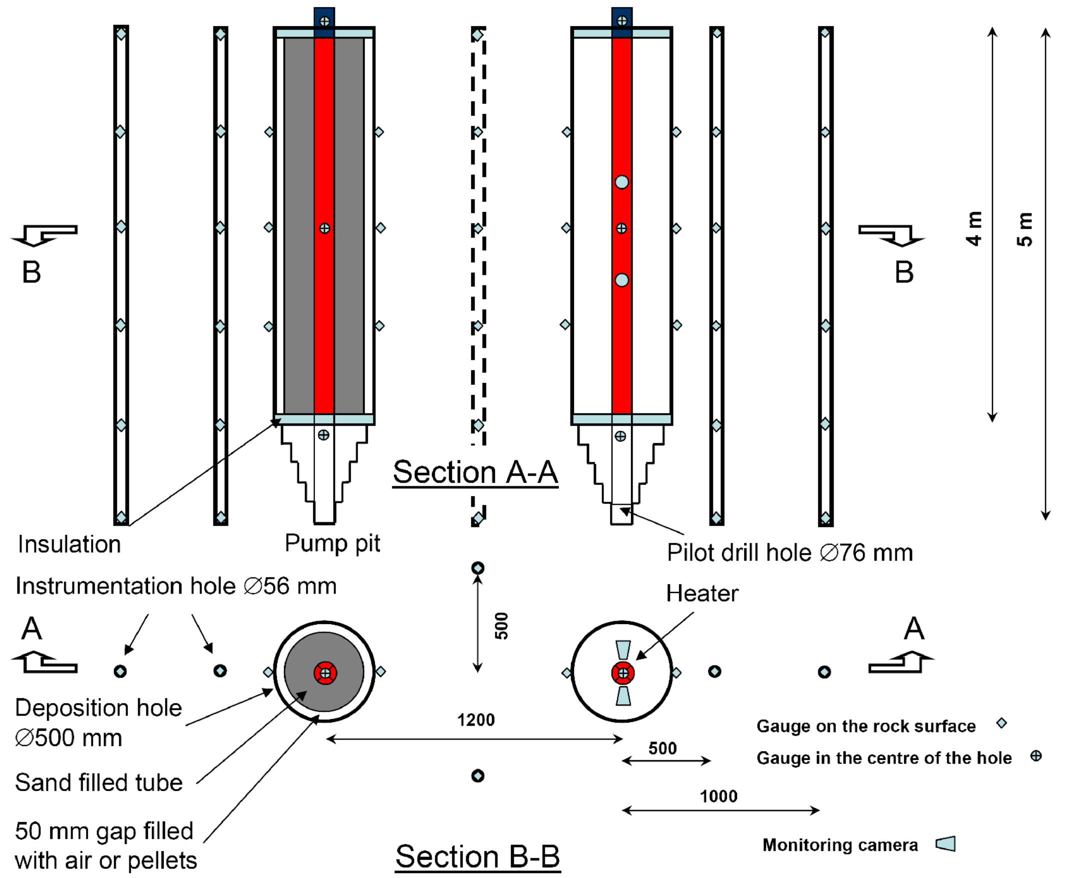
2.5 Rock Mechanics

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 mainly 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.

A project called Caps (Counterforce Applied to Prevent Spalling) comprising field tests in Äspö HRL and numerical modelling is ongoing and is described in the section below.

2.5.1 Counterforce Applied to Prevent Spalling



Configuration of the test holes and the positioning of instruments in the experiments in the Tasq-tunnel as original design with one open and one pellet filled hole. In reality the tests have been performed in two pairs of open holes and two pairs of pellet filled holes.

The field experiment within Counterforce Applied to Prevent Spalling (Caps) has been initiated as a demonstration experiment to determine if the application of dry bentonite pellets is sufficient to suppress thermally-induced spalling in KBS-3 deposition holes. The experience gained from the Äspö Pillar Stability Experiment, conducted between 2002 and 2006, indicated that spalling could be controlled by the application of a small confining pressure in the deposition holes.

The field experiment includes four pairs of heated half-scale KBS-3 holes and is carried out as a series of demonstration tests in the Tasq-tunnel at Äspö HRL.

Each test consists of two heating holes of 0.5 m diameter and 4 m depth separated by a 0.7 m pillar, which are surrounded by a number of boreholes for installation of temperature gauges.

The first step in the testing sequence includes heating of one pair of open holes to ensure that spalling will occur and can be observed in the test holes. The next step includes heating and observation of spalling in separate pair of holes. A 50 mm gap created between a large inner tube and the borehole wall is filled with a loosely placed pellets substitute. The final step is a complementary test that is carried out to address questions that arise during the previous tests.

Achievements

The post characterisation of the geometry of the spalled notches in the heating holes was completed by mid-September 2009. The work was carried out successfully and the geometry of the notches is now well documented in all the heating holes. The developed documentation is exemplified below by a projection of the notches created in heating hole KQ0051G04 based on the laser scanning, and by a cross-section in the same heating hole based on the photographing with thin lighted slot, see Figure 2-2 and Figure 2-3, respectively.

The evaluation of the test results, as well as the reporting of the field results has been in progress during the last four-month period. A memo which outlines the field experiment was completed by October and a draft of the final report was ready for review at the beginning of December.

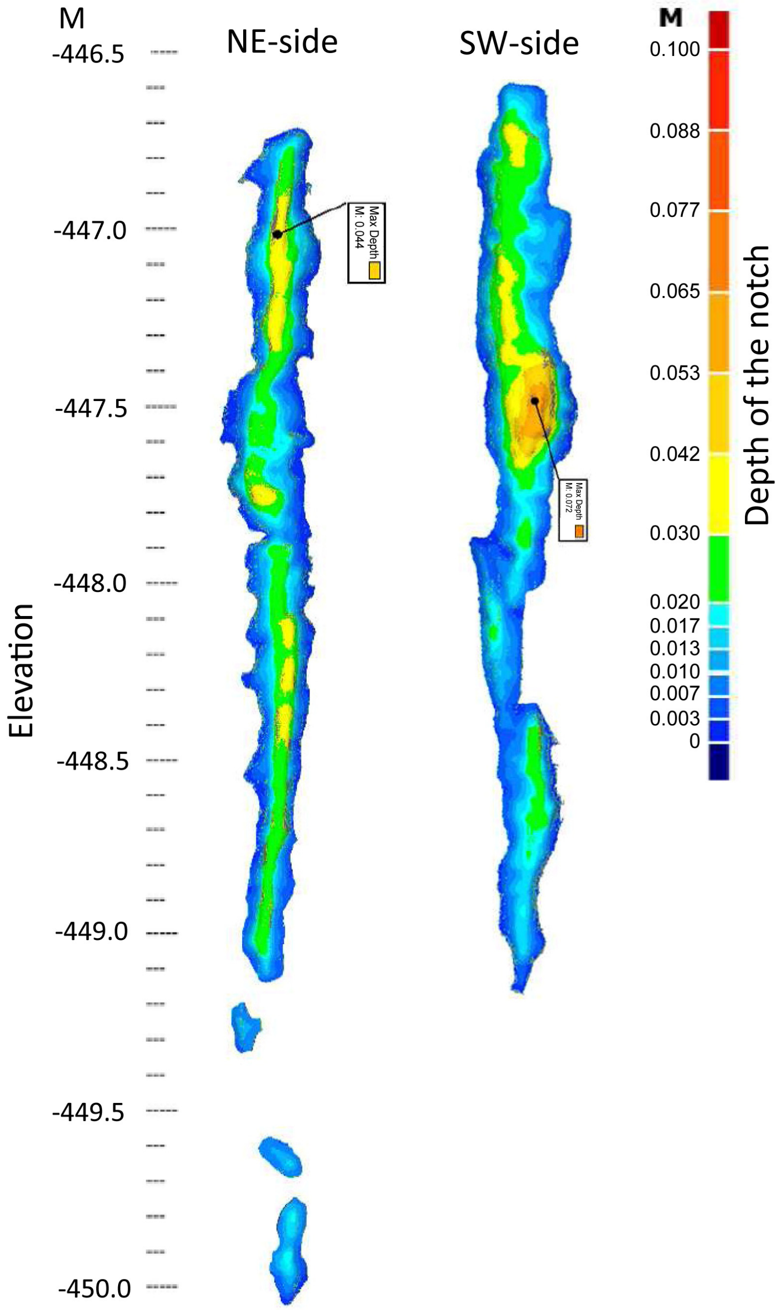


Figure 2-2. *Projection from the outside of the notches developed in KQ0051G04 based on laser scanning. The notches developed in this heating hole had the largest dimensions of all notches created in the heating holes. The notch depth is indicated by the colour.*

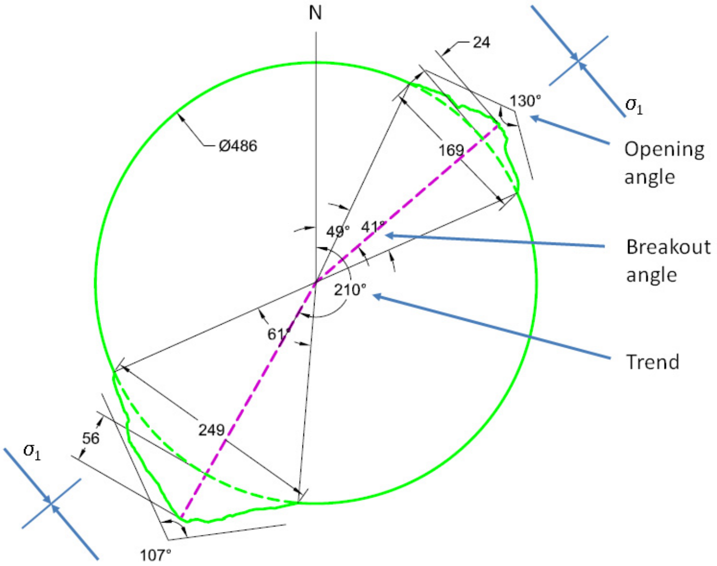


Figure 2-3. *Cross-section on level -447.5 m where the largest dimension of the SW-notch was determined in KQ0051G04 based on the photographing with a thin lighted slot. The trend of the major principal stress is also indicated in the figure.*

3 Natural barriers

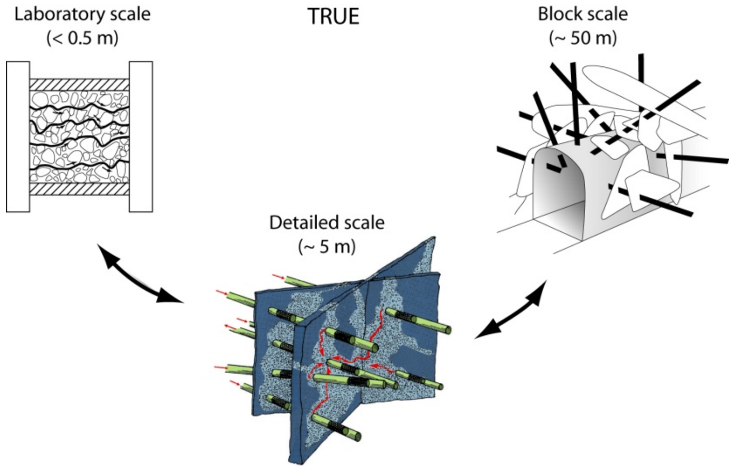
3.1 General

Experiments at the Äspö HRL 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 (Figure 3-1). 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.

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 3-1. *Fracture surface with thin coating of mainly chlorite, calcite, clay minerals and epidote. The length of the base of the photograph is 46 mm.*

3.2 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) /Winberg et al. 2000/ performed in the detailed scale and the TRUE Block Scale series of experiments /Winberg et al. 2003/ have come to their respective conclusion.

Complementary field work and modelling have been performed as part of two separate, but closely coordinated, continuation projects. The TRUE Block Scale Continuation (BS2) project, which was a continuation of TRUE Block Scale (BS1), aimed at obtaining additional understanding of the TRUE Block Scale site /Andersson et al. 2007/.

A further extension of the TRUE Block Scale Continuation (BS3) involves production of peer-reviewed scientific papers accounting for the overall TRUE findings, and in particular those of BS1 and BS2.

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.

Additional work includes complementary laboratory sorption investigations on fracture rim and fault gouge materials, plus a series of three scientific articles on the TRUE-1 experiment.

3.2.1 TRUE Block Scale Continuation

In the aftermath to the BS2 project, a second step of the continuation of the TRUE Block Scale (BS3) was set up. This step has no specific experimental components and emphasise consolidation and integrated evaluation of all relevant TRUE data and findings collected thus far. This integration is not necessarily restricted to TRUE Block Scale, but may include incorporation of relevant TRUE-1 and TRUE-1 Continuation results.

The planned series of articles covering the TRUE Block Scale experiments have been transformed into one two-part series of papers entitled *Transport and retention from single to multiple fractures in crystalline rock at Äspö (Sweden):*

I. *Evaluation of tracer test results and sensitivity analysis*

II. *Fracture network flow simulations and global retention properties*

This series is flanked by a standalone paper entitled *The role of enhanced porosity adjacent to fractures for tracer transport in crystalline rock*.

A second step in the scientific reporting of the TRUE experiments is the production of a more high-profiled paper directed to the general scientific public. The tentative title of this paper, aimed at the journal Science is entitled *Evaluating the actinide barrier function of crystalline rock using field-scale tracer tests*. This paper is seconded by a paper submitted to Geophysical Research Letters entitled *Evidence of diffusion-controlled radionuclide retention in crystalline rock obtained from tracer tests*.

Achievements

The paper directed to Geophysical Research Letters show convincingly that diffusion-controlled retention is required to explain the retention observed for the more strongly sorbing tracers utilised in the TRUE experiments. This analysis is in the paper directed towards Science expanded to show that the predicted field-scale retention of the actinides Am and Pu expressed in terms of fractional mass recovery and normalised peak arrival time comply with the simple diffusion-controlled retention model applied.

During the period the paper on the role of the enhanced porosity zone and the two papers analysing the TRUE Block Scale tracer tests have been accepted for publication in Water Resources Research. Furthermore, the paper directed to Geophysical Research Letters has been completed and submitted. A first draft of the updated version of the paper directed to Science has been completed and will be circulated within the project team early 2010.

3.2.2 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 included performance of epoxy resin in Feature A at the TRUE-1 site and subsequent overcoring and analysis (TRUE-1 Completion). In addition, this project includes the production of a series of scientific articles on the TRUE-1 project, complementary laboratory sorption measurements on rim zone and fault gouge materials, and the Fault rock zones characterisation project.

Achievements

During the last four month of 2009, the report with the title *Characterisation and quantification of resin-impregnated fault rock pore space using image analysis* /Hakami and Weixing 2005/ has been finalised, printed and distributed.

In addition to the report planned to be completed as part of TRUE-1 Completion, two additional reports remain to be completed, a final report of the Fault rock zones characterisation project and the report providing the results of the complementary laboratory sorption measurements.

3.2.3 TRUE-1 Completion

TRUE-1 Completion is a sub-project of the TRUE-1 Continuation project and is a complement to already performed and ongoing projects. The main activity within TRUE-1 Completion was the injection of epoxy with subsequent overcoring of the fracture and following analyses of pore structure and, if possible, identification of sorption sites. Furthermore, several complementary in situ experiments were performed prior to the epoxy injection. These tests were aimed to secure important information from Feature A and the TRUE-1 site before the destruction of the site.

Achievements

Major activities during the last four month of 2009 were the analyses of cores from the boreholes KXTT3 and KXTT4. The majority of analyses are finalised, but not all due to limitation in human resources. Reporting of the analyses will therefore not be completed according to previous time table. Some preliminary results from the last four-month period are:

- Radioactive Cs is heterogeneously distributed in Feature A in KXTT4 with higher concentrations close to the injection borehole but also in the expected flow direction.
- Radioactive Cs in Feature A' in KXTT4 is found close to the injection borehole.
- Some parts of Feature A in KXTT4 includes only low levels of radioactivity. This may open up for additional mineral analyses compared to the original plan.
- The character of the main fracture of Feature A in KXTT3 and KXTT4 is rather similar according to image analysis.
- There is a rather substantial difference between the character of Feature A and A' according to image analysis.

3.3 Long Term Sorption Diffusion Experiment

Drilling of sample cores from matrix rock surrounding the test section in the small diameter extension borehole.

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 were circulated over a period of 6 ½ months after which the borehole was over cored. This activity is followed by analyses of tracer content.

Small diameter (24 mm) sample cores have been extracted from the 1.1 m long and 278 mm diameter large core retrieved from the over coring. 34 sample cores have been extracted both from the fracture surface on the core stub and from the matrix rock surrounding the test section in the small diameter (36 mm) extension borehole.

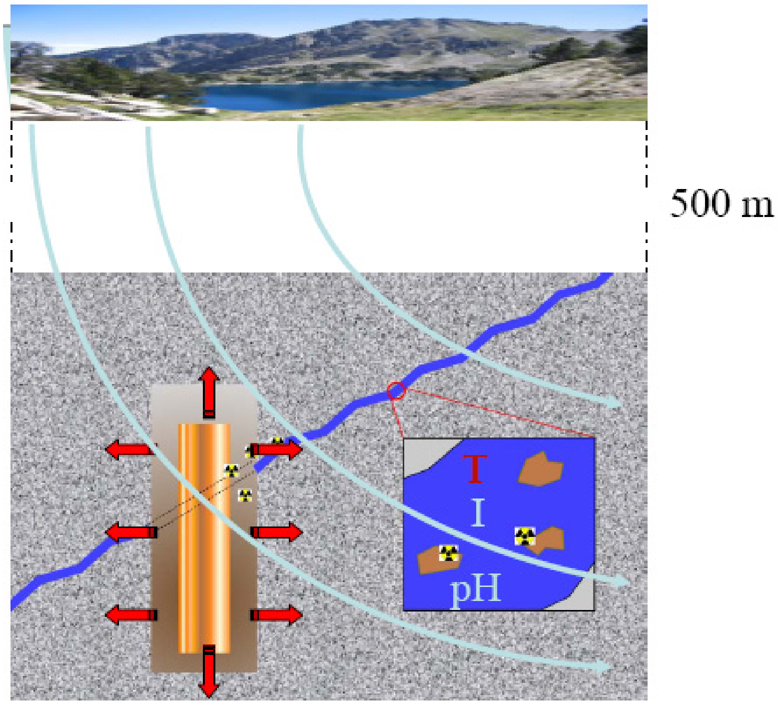
Achievements

The crushed and intact rock slices selected for analysis have been measured by HPGe for γ-emitting tracers and the results are under evaluation.

Leaching and subsequent analysis of ^{36}Cl has been done for the crushed rock slices of five selected sample cores. Leaching is ongoing for intact rock slices of four selected sample cores.

The batch sorption tests and sorption/diffusion tests with intact rock pieces from the core of the small diameter extension borehole, the replica core stub and the pilot borehole core, were finalised in late April. Some completing sampling and tracer analysis have been done and is ongoing, as well as evaluation of the resulting data.

3.4 Colloid Transport Project



The Colloid Transport Project is a continuation of the Colloid Dipole Project, which was ended in the beginning of 2008. The overall goal for the Colloid Transport Project is to answer the questions when colloid transport has to be taken into account in the safety assessment, and how the colloid transport can be modelled.

In the beginning of the lifetime of a deep repository, in bedrock with groundwater of high ionic strength, bentonite and natural colloids are not stable, and colloid transport can be neglected. Of special concern is bentonite erosion, since that could lead to a decrease of the barrier function of the bentonite buffer.

In the scenario of intrusion of dilute glacial water the conditions for colloids stability drastically changes and the transport of colloids might be the limiting factor.

In the case of a leaching canister, the bentonite colloids can possibly facilitate the transport of sorbed radionuclide towards the biosphere. In the project, also the transport of organic colloids and other natural colloids are studied and their effect on especially actinide mobility.

The ambition is further to include studies on the transport of colloids which are formed in the spent nuclear fuel.

Achievements

Mockup tests of erosion/generation of Na- and Ca-montmorillonite show that the gel propagation is significantly affected by the groundwater composition. The difference between gel propagation rate in a dilute water and Grimsel groundwater, with 0.001 M Na and 0.0001 M Ca is large. The montmorillonite colloid concentrations outside a bentonite barrier will be at least one magnitude lower in contact with Grimsel groundwater compared to deionised water. The Ca- bentonite acts as expected very differently from the Na-bentonite. A report is under review and a manuscript under preparation.

Bentonite erosion experiments have been performed in the Quarried Block with MX-80 in contact with Grimsel groundwater. The results from the experiments are evaluated and a report is under review.

Sorption experiments of colloids on fracture filling materials such as quartz and biotite have been performed to study sorption of colloids at different groundwater conditions

(0.001 M ionic strength and pH range 4-10). In addition, transport experiments of latex- and montmorillonite colloids have been performed to study retention mechanisms such as sorption and filtration. Two publications have been sent in and are under review.

3.5 Microbe Projects

Microorganisms interact with their surroundings and in some cases they greatly modify the characteristics of their environment. Several such interactions may have a significant influence on the function of a repository for spent fuel /Pedersen 2002/. There are presently four specific microbial process areas identified that are of importance for proper repository functions. They are: bio-mobilisation of radionuclides, bio-immobilisation of radionuclides, microbial effects on the chemical stability of deep groundwater environments and microbial corrosion of copper.

The study of microbial processes in the laboratory gives valuable contributions to our knowledge about microbial processes in repository environments. However, the results obtained by laboratory studies must be tested in a repository like environment. The reasons are several. Firstly, at repository depth, the hydrostatic pressure reaches close to 50 bars, a setting that is very difficult to reproduce in the laboratory. The high pressure will influence chemical equilibrium and the content of dissolved gases. Secondly, the geochemical environment of deep groundwater, on which microbial life depends and influence, is complex. Dissolved salts and trace elements, and particularly the redox chemistry and the carbonate system are characteristics that are very difficult to mimic in a university laboratory. Thirdly, natural ecosystems, such as those in deep groundwater, are composed of a large number of different species in various mixes /Pedersen 2001/. The laboratory is best suited for pure cultures and therefore the effect from consortia of many participating species in natural ecosystems cannot easily be investigated there. The limitations of investigations arrayed above in a laboratory situated on ground have resulted in the construction and set-up of an underground laboratory in the Äspö HRL tunnel. The site is denoted the Microbe Laboratory and is situated at the -450 m level, see below.

Three circulation systems in the laboratory.

The Microbe Laboratory has been installed in the Äspö HRL for studies of microbial processes in groundwater under in situ conditions.

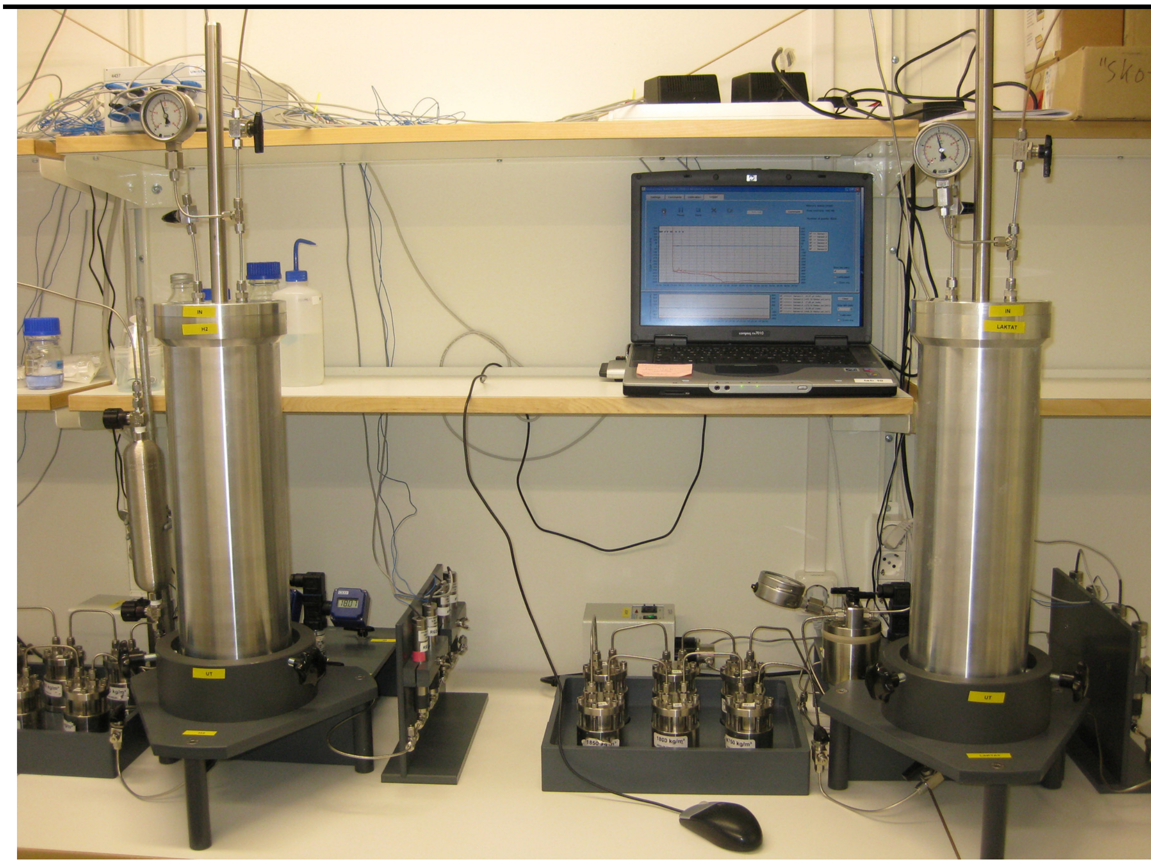
The Microbe site is at the -450 m level where a laboratory container with benches and an advanced climate control system is located.

Three boreholes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures are connected to the Microbe Laboratory via tubing. The laboratory is equipped with six circulation systems offering 2,112 cm^2 of test surface (three systems are shown in the image to the left).

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.

3.5.1 Micored



Experimental set-up for analysis of the influence of hydrogen and lactate on growth of sulphate reducing bacteria under pressure. The growth circulations are monitored by micro-electrodes for measurement of redox potential and pH.

Microorganisms can have an important influence on the chemical situation in groundwater. Especially, they may execute reactions that stabilise the redox potential in groundwater at a low and, therefore, beneficial level for the repository.

It is hypothesised that hydrogen and possibly also methane from deep geological processes contributes to the redox stability of deep groundwater via microbial turnover of this gas. These metabolisms will generate secondary metabolites such as ferrous iron, sulphide, acetate and complex organic carbon compounds.

The work within the Micored project will:

- Clarify the contribution from microorganisms to stable and low redox potentials in groundwater.
- Demonstrate and quantify the ability of microorganisms to consume oxygen in the near-and far-field areas.
- Explore the relation between content and distribution of gas and microorganisms in deep groundwater.
- Create clear connections between investigations of microorganisms in the site investigations for a future repository and research on microbial processes at Äspö HRL.

Achievements

Two series of experiments have been performed where the influence of hydrogen, acetate and lactate on growth of sulphate reducing bacteria (SRB) has been investigated with groundwater from KJ0050F01 and KJ0052F01. The growth was followed by analysis of DNA specific for SRB and gases. Redox potential was analysed with microelectrodes and with field electrodes. The experiments were successful and data analysis is presently ongoing. A third series is planned to start in March 2010.

3.5.2 Micomig

Sampling a new-drilled fracture surface for microbial presence and activity using DNA/RNA analysis methods.

Microbes can mobilise trace elements. Firstly, unattached microbes may act as large colloids, transporting radionuclides on their cell surfaces with the groundwater flow. Secondly, microbes are known to produce ligands that can mobilise soluble trace elements and that can inhibit trace element sorption to solid phases.

A large group of microbes catalyse the formation of iron oxides from dissolved ferrous iron in groundwater that reaches an oxidising environment with oxygen. Such biological iron oxide systems (Bios) will have a retardation effect on many radionuclides.

Biofilms in aquifers will influence the retention processes of radionuclides in groundwater. Previous research at Äspö HRL indicated that biofilms may enhance or retard sorption, depending on the radionuclide in question.

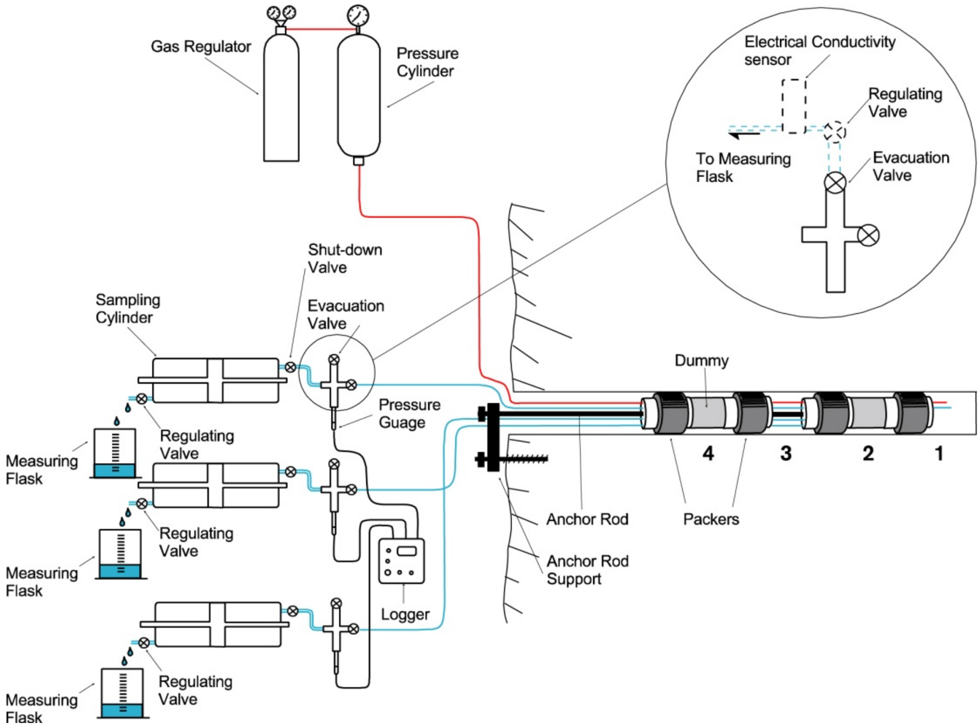
The work within Micomig will:

- Evaluate the influence from microbial complexing agents on radionuclide migration.
- Explore the influence of microbial biofilms on radionuclide sorption and matrix diffusion.

Achievements

In a recent investigation, six drill cores were retrieved from the Äspö HRL tunnel from a depth of 186 m below ground. Intersected, water conducting fractures in the cores were sampled for nucleic acids by DNA extraction from collected fracture surface material. Polymerase Chain Reaction (PCR) primers for amplification of a conserved stretch of the 16S rRNA gene were used to analyse diversity of fracture surface biofilm DNA with cloning and sequencing. Primers for real time, quantitative PCR were designed and optimised for biomass quantification using 16S rRNA genes for domain *Bacteria* and for quantification of sulphate reducing bacteria (SRB) using adenosine-phosphosulphate reductase genes (*apsA*). The results from analysis of intrinsic biofilms on rock aquifer surfaces were compared to results from similar analyses of biofilms on glass surfaces in laminar flow reactors installed with circulating groundwater from the -450 m level at the Microbe site. The experimental objectives with these flow reactors were to investigate the influence of hydrogen and acetate additions on biofilm diversity and activity. The outcome of this study is presently compiled in a manuscript for publication as an original scientific paper.

3.6 Matrix Fluid Chemistry Continuation



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

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

A continuation phase of the project started 2004 with the aim to focus on areas of uncertainty which remain to be addressed:

- The nature and extent of connected porewaters in the Äspö bedrock.
- The nature and extent of the microfracture groundwaters which penetrate the rock matrix and the influence of these groundwaters on the chemistry of the porewaters.
- The confirmation of rock porosity values previously measured in the earlier studies.

Achievements

A draft report concerning the interpretation of the hydraulic tests is available. The report entitled *Further characterisation of the matrix fluid borehole (KF0051A01) and determination of the hydraulic conductivity in matrix rock* will be printed as an International Technical Document.

3.7 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 for instance bentonite samples and on tiny rock fractures in drill cores.

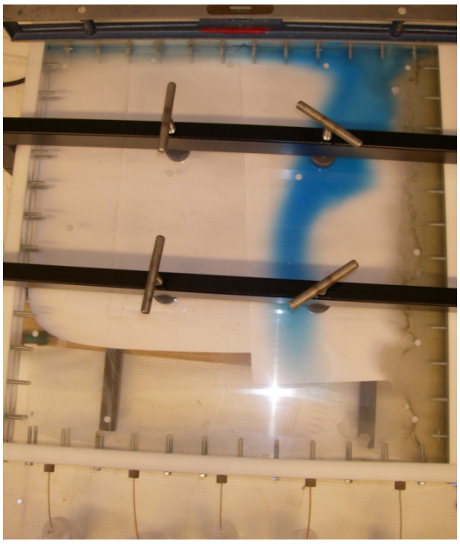
Experiments in Chemlab 1:

- 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 interface between buffer and rock (planned, see section 3.7.1).

Experiments in Chemlab 2:

- Migration experiments with actinides in a rock fracture (almost finalised).
- Study of spent fuel leaching at repository conditions (planned, see section 3.7.2).

3.7.1 Transport Resistance at the Buffer Rock Interface



The equipment intended for the laboratory experiments. The equipment is currently used in another SKB project, Bentonite Erosion.

If a canister fails and radionuclides are released, they will diffuse through the bentonite buffer. If there is a fracture intersecting the deposition hole, the water flowing in the fracture will pick up radionuclides from the bentonite buffer.

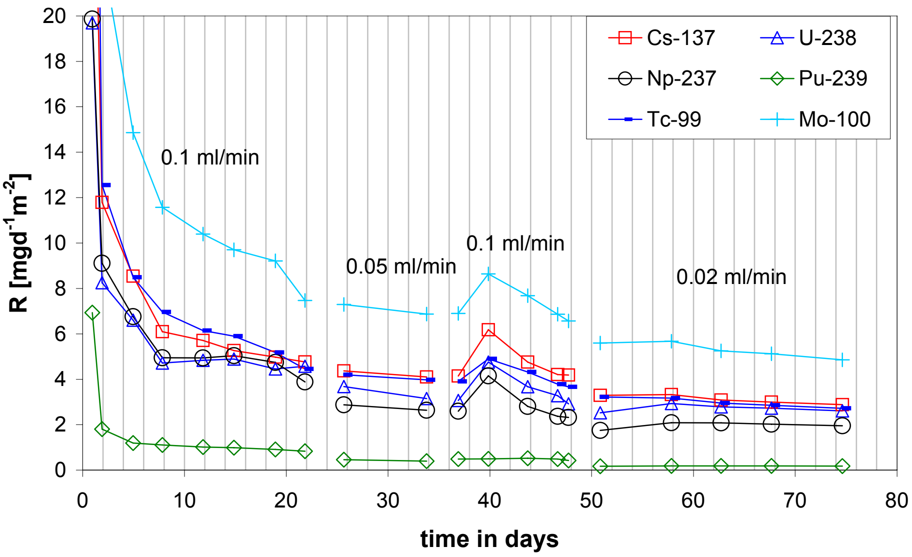
The transport resistance is concentrated to the interface between the bentonite buffer and the rock fracture. The mass transfer resistance due to diffusion resistance in the buffer is estimated to only 6% and the diffusion resistance in the small cross section area of the fracture in the rock to 94% /Neretnieks 1982/. The aim of the Transport Resistance at Buffer-Rock Interface project is to perform studies to verify the magnitude of this resistance.

The experiment will be performed in the laboratory, where a fracture is simulated as a 1 mm space between two Plexiglas plates. The equipment includes a water pump for very low flow rates. The design of field experiments depends on the outcome of the laboratory experiments.

Achievements

The laboratory studies have started and kinetic studies on the dissolution rate of the dye initially selected as tracer is ongoing.

3.7.2 Spent Fuel Leaching



Dissolution rates based on different monitors. The spent fuel was leached with 10 mM $NaHCO_3$ under oxidising conditions. Constant dissolution rates could be achieved after some days.

In the Spent Fuel Leaching experiments, to be performed within the framework of the programme for in situ studies of repository processes, the dissolution of spent fuel in groundwater relevant for repository conditions will be studied. The objectives of the experiments are to:

- Investigate the leaching of spent fuel in laboratory batch experiments and under in situ conditions.
- Demonstrate that the laboratory data are reliable and correct for the conditions prevailing in the rock.

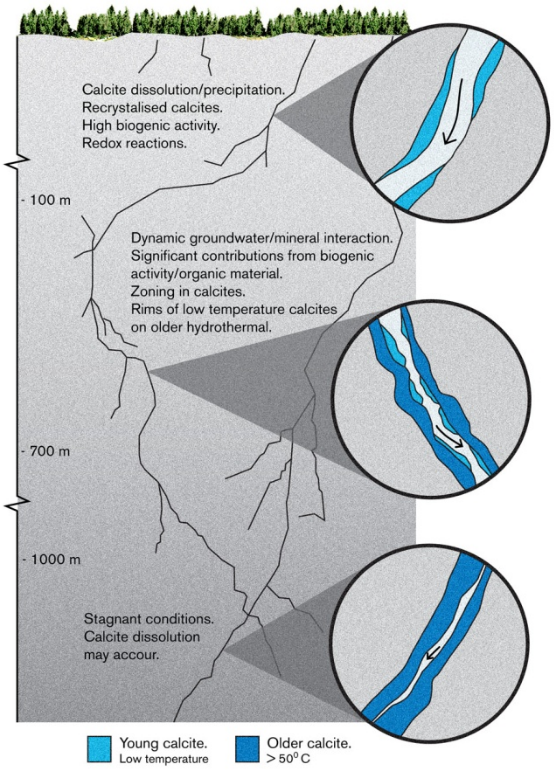
The in situ experiments will be preceded by laboratory experiments where the scope is both to examine parameters that may influence the leaching as well as testing the equipment to be used in the field experiments.

In the field experiments spent fuel leaching will be examined with the presence of H_2 (in a glove box situated in the gallery) as well as without the presence of H_2 (in Chemlab 2).

Achievements

A test plan for a pre-study is under preparation and the pre-study will be performed during 2010.

3.8 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 EC-part of the project was finalised and reported in 2005. The Padamot continuation project comprises:

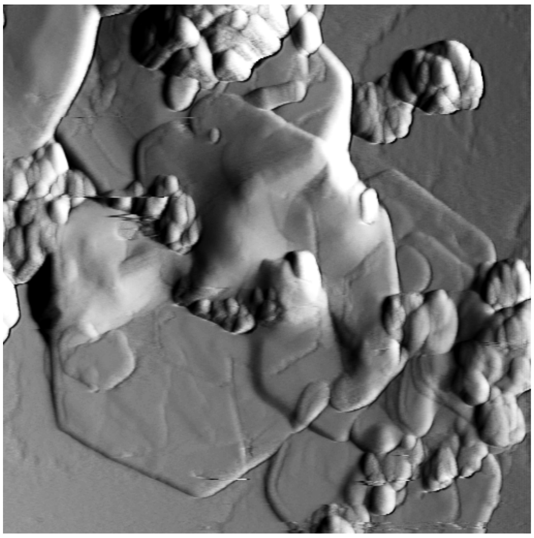
- Further developments of analytical techniques for uranium series analyses applied on fracture mineral samples and inter laboratory comparisons.
- The use of these analyses for determination of the redox conditions during glacial and postglacial time.
- A summary of the experiences from the palaeohydrogeological studies carried out at Äspö.

The analyses are carried out on split samples of fracture material from a surface borehole drilled at Äspö (KAS17). This borehole penetrates the large E-W fracture zone called the Mederhult zone.

Achievements

Based on the results from this project a sophisticated sampling procedure has been suggested in order to avoid sampling disturbances of the trace elements (and especially the uranium series isotopes). The idea is to vacuum seal the samples as soon as possible after drilling. This has been tested on a number of samples from a new borehole. The samples are now stored in nitrogen atmosphere in a glow box. The final reporting of the project will be performed during 2010.

3.9 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.

Following the original project, a continuation phase of the project was started. The aim with this phase is to establish the penetration depth of oxidising water below ground level. Oxidising waters may represent present-day recharge, or reflect penetration of glacial melt waters during the last glaciation.

Achievements

The final reporting of the studies on Fe-oxides in fractures is concluded. The results will initially be published as SKB international technical documents and finally as a condensed technical report.

3.10 Swiw-tests with Synthetic Groundwater

Injection of tracer in fracture

The Single Well Injection Withdrawal (Swiw) tests with synthetic groundwater constitute a complement to performed tests and studies on the processes governing retention, e.g. the TRUE experiments as well as Swiw tests performed within the SKB site investigation programme.

The general objective of the Swiw test with synthetic groundwater is to increase the understanding of the dominating retention processes and to obtain new information on fracture aperture and diffusion. The basic idea is to perform Swiw tests with synthetic groundwater with a somewhat altered composition, e.g. replacement of chloride, sodium and calcium with nitrate, lithium and magnesium, compared to the natural groundwater at the site.

Sorbing as well as non-sorbing tracers may be added during the injection phase of the tests. In the withdrawal phase of the tests the contents of the "natural" tracers (chloride sodium and calcium) as well as the added tracers in the pumping water is monitored. The combination of tracers, both added and natural, may then provide desired information on diffusion, for example if the diffusion in the rock matrix or in the stagnant zones dominates.

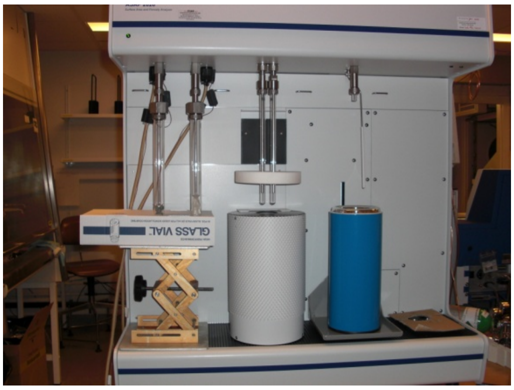
Achievements

The most important achievement during the last four-month period was the decision about site to be used for the field tests within the project. TRUE Block Scale was identified in the feasibility study as a potential test site. However, after completion of the new Tass-tunnel, it was clear that the hydraulic pressure and gradients were affected to a large degree. It was therefore not recommended to perform Swiw test at the TRUE Block Scale site. Instead, other parts of Äspö HRL were considered for selection of test site. In this process, the borehole KA2858A was identified as a promising site for the test with synthetic groundwater and recommended for initial tests.

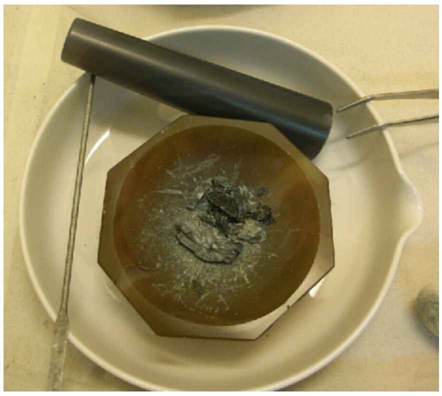
Scoping simulations regarding usage of radon as a tracer in the Swiw tests were also finalised during the last period. Based on these, it was decided that radon not should be used for evaluation of tracer breakthrough during the tests due to limited benefit compared to the expected cost. Instead, only a few samples of radon will be taken and analysed during the Swiw tests.

Based on the project plan and the decisions of test site and usage of radon, an activity plan was prepared for the field activities. These are scheduled to be initiated during the coming four-month period and continue until November 2010.

3.11 Äspö model for radionuclide sorption



Instrument for making surface area determinations.



Powder preparation from a chlorite specimen.

Today, geochemical retention of radionuclides in the granitic environment is commonly assessed using K_d-modelling. However, this approach relies on fully empirical observations and thus to a limited degree contribute to the evaluation of the conceptual understanding of reactive transport in complex rock environments.

In the literature, the process based Component Additivity (CA) approach, which relies on a linear combination of sorption properties of different minerals in a geological material, has been suggested for estimation of sorption properties.

For adoption of this approach to granitic material, the particle size/surface area dependence of radionuclide sorption and effects of grain boundaries need to be resolved. Furthermore, it is desirable to verify sorption of radionuclides to specific minerals within the rock.

The overall objective of this project is to formulate and test process quantifying models for geochemical retention of radionuclides, in granitic environments, using a combined laboratory and modelling approach.

Achievements

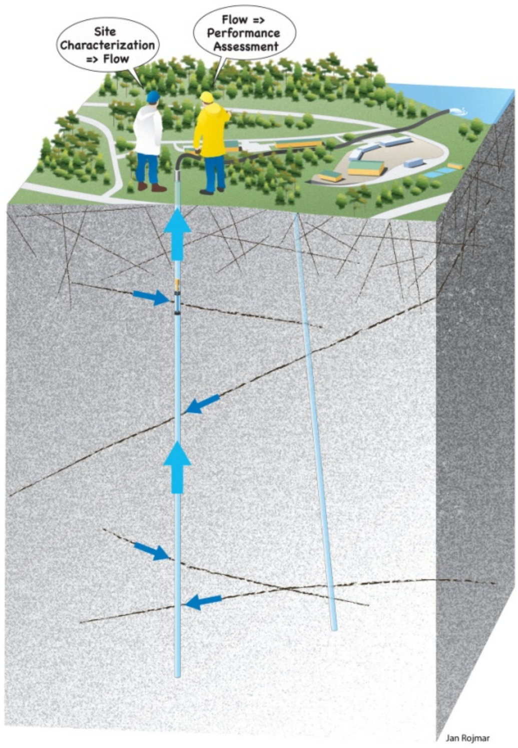
During the period September-December 2009 the preparation and characterisation of acquired pure mineral samples continued. The characterisation aims at confirming the identity of the minerals and determining their chemical composition and purity. Mineral powders were prepared by crushing and sieving the minerals into size fractions. Determinations of the specific surface area of each size fraction of each mineral, using the BET-method, which employs sorption of an inert gas (N_2 or Kr) to the surface of a substrate with known mass, were begun.

As a first step, the two minerals labradorite and magnetite were studied. Labradorite belongs to the plagioclase (feldspar) group of minerals and is one of the major minerals in the host rock at Äspö. Magnetite, on the other hand, generally occurs only in small amounts in the Äspö rock, but is one of the minerals that in the literature is known to be a strong radionuclide sorbent and also to have a comparatively large specific surface area. The alternative use of the gases (N_2 or Kr) gave no significant difference in the surface area determined for the two minerals. However, the precision in the determinations using Kr was better than for N_2. For both minerals it was found, as expected, that the specific surface area increases with decrease in the characteristic size of the particles. Labradorite followed the relation between particle size and specific surface area proposed by /André et al. 2009/. Magnetite, on the other hand, showed a somewhat more complex behaviour, which is currently under further investigation.

For both minerals, a much lower specific surface area was measured on large mineral parallelepipeds of 3×3 cm basis, and about 5 cm long, than expected from extrapolation of experimental results of the smaller particles. This was suggested by /André et al. 2009/, who observed a similar behaviour for granite, to be explained by a disturbed zone at the particle edge, caused by the mechanical treatment of the sample during excavation and sample preparation (sawing and crushing). With relevance for the determination of radionuclide sorption properties of rocks and minerals, this indicates that the radionuclide sorption for intact material may be greatly overestimated if it is based only on extrapolation of laboratory experiments with crushed material. We furthermore note that the surface area of the large mineral pieces are just 2-4% of that of the particle size fraction 0.075-0.125 mm, a size fraction which is representative of particles employed in many radionuclide sorption experiments using crushed rock or mineral samples. This implies that the majority of the surface area in such experiments is associated with fresh mineral surfaces, not originally present, and possibly with different sorption properties from the intrinsic sample.

Results of the experimental work were presented in a poster at Asia-Pacific Symposium on Radiochemistry (APSORC-09) in Napa, California, U.S.A., November 29th - December 4th, 2009, and a manuscript for the conference proceedings volume has been submitted /Dubois et al. 2009/.

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



Task 7 - Reduction of Performance Assessment uncertainty through modelling of hydraulic tests at Olkiluoto, Finland.

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 Task Force constitutes an important part of the international co-operation within the Äspö HRL.

Achievements

During the last four-month period of 2009, work has mainly been performed in Task 7 - Reduction of Performance Assessment (PA) uncertainty through modelling of hydraulic tests at Olkiluoto, Finland. The status of the specific modelling tasks within Task 7 is given within brackets in Table 3-1. In addition, planning and preparations for Task 8 have been ongoing. Task 8 will be a joint effort with the Task Force on Engineered Barriers, and will be addressing the processes at the interface between the rock and the bentonite in deposition holes.

Task 7 is focusing on methods to quantify uncertainties in PA-type approaches based on Site Characterisation (CS) 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 influence the groundwater system. The possibilities to extract more information from interference tests will also be addressed.

The 25th Task Force meeting was held in October, and the venue took place near the Mizunami HRL in Japan. The minutes have been distributed. Planning for a workshop on Task 7 and 8 in Finland has been ongoing.

Table 3-1. Descriptions of the specific modelling sub-tasks in Task 7 and status (within brackets).

7	**Reduction of Performance Assessment uncertainty through modelling of hydraulic tests at Olkiluoto, Finland.**
7A	Long-term pumping experiment. (Final results of sub-task 7A1 and 7A2 are reported as ITDs).
7B	Sub-task 7B is addressing the same as sub-task 7A but in a smaller scale, i.e. rock block scale. Sub-task 7B is using sub-task 7A as boundary condition. (Updated results presented at the 25th Task Force meeting).
7C	Here focus is on deposition hole scale issues, resolving geomechanics, buffers, and hydraulic views of fractures. (Preliminary results presented at the 25th Task Force meeting).
7D	Sub-task 7D concerns integration on all scales (Tentative).

4 Engineered barriers

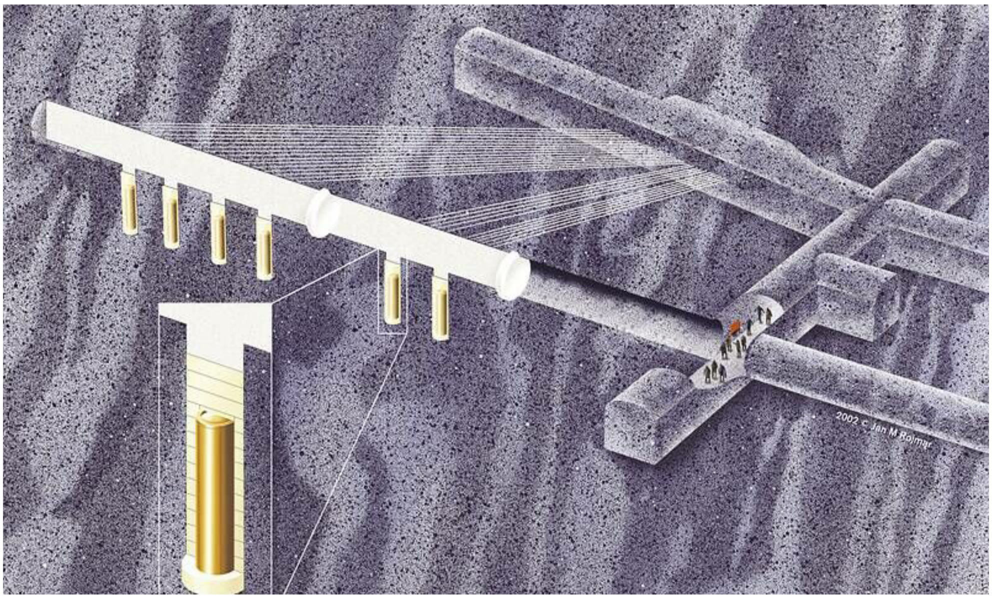
4.1 General

Another goal 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 4-1. The experiments focus on different aspects of engineering technology and performance testing and together form a major experimental programme.

Figure 4-1. *Water filled measuring weir in the project Sealing of Tunnel at Great Depth.*

4.2 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.

The inner tunnel (Section I, canisters #1 - #4) 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, canisters #5 - #6) was backfilled in June 2003 and the tunnel plug with two lead-troughs was cast in September the same year.

Installed 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.

Achievements

The data collection system comprises temperature, total pressure, porewater 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 data report No. 21 covering the period up to June 2009 will be soon be published and the work with the data report covering the period June 2009 to November 2009 is more or less finalised. In addition, overhauling of the data acquisition system is in progress.

Acoustic Emission and Ultrasonic monitoring from the rock around deposition hole 5 and 6 is continuing. Two new reports covering the measuring periods October 2008 to March 2009 and April 2009 to September 2009 have been finalised and will soon be published.

Studies using the thermal FEM model for the Prototype Repository including the rock, backfill, buffer and the six canisters have been reported /Kristensson and Hökmark 2007/. A report concerning 1 D THM modelling of the buffer in deposition hole 1 and 3 will soon be published and a report concerning a 3D TM model of the entire experiment is in progress. In this report the possibility of spalling is investigated and also the stress state on a thought fracture plan is studied. The THM modelling of the Prototype Repository according to the initial planning has been delayed.

Samples of gas and water from the buffer and backfill have been taken and some analyses have been made. The analyses of the samples will continue.

Hydraulic tests (single hole tests) have been performed in order to estimate the transmissivity of the rock around the Prototype Repository. This type of measurement has been made at altogether nine occasions since the start of the test.

4.3 Long Term Test of Buffer Material

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

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

The test concerns realistic repository conditions except for the scale and the controlled adverse conditions in four parcels.

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 other processes in bentonite such as cation diffusion, microbiology, copper corrosion and gas transport under conditions similar to those expected in a deep repository.

Achievements

During the last four month of 2009, the remaining three test parcels have been functioning well, see Table 4-1. The final report on the A2 parcel have been published /Karnland et al. 2009/ and the final report on the A0 parcel is under review. In addition, a PM has been produced concerning data from the tests presented at the copper corrosion seminar arranged by the Swedish National Council for Nuclear Waste.

Table 4-1. Buffer material test series.

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	Reported
A	2	120-150	T, [K^+], pH, am	6	Reported
A	3	120–150	T	>10	Ongoing
S	1	90	T	1	Reported
S	2	90	T	9	Ongoing
S	3	90	T	>10	Ongoing

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

4.4 Alternative Buffer Materials

Installation of one of the three parcels illustrating the mixing of the different compacted buffer discs.

In the Alternative Buffer Materials project different conceivable buffer materials are tested. The aim is to further investigate the properties of the alternatives to the SKB reference bentonite (MX-80). 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.

Eleven different clays were chosen to examine effects of smectite content, interlayer cations and overall iron content. Also bentonite pellets with and without additional quartz are being tested.

The field test started during 2006 and is carried out in the same way and scale as the Long Term Test of Buffer Material (Lot). Three parcels containing heater, central tube, pre-compacted clay, buffer, instruments and parameter controlling equipment have been emplaced in vertical boreholes with a diameter of 300 mm and a depth of 3 m.

Achievements

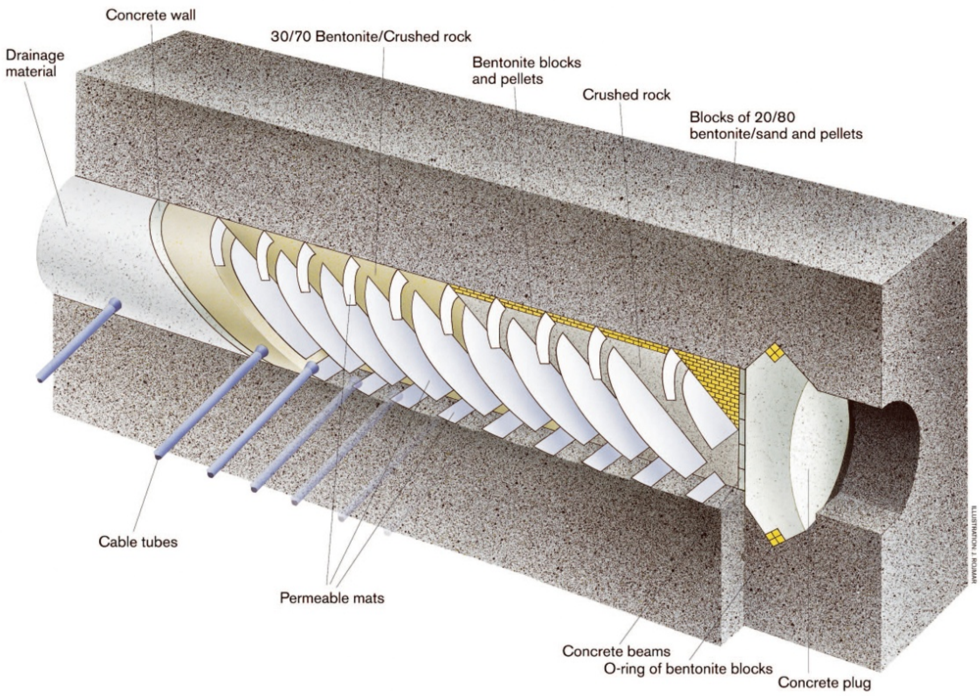
The work with analyses of material from the first test parcel, retrieved in May 2009 after about 18 months test duration at the intended test temperature 130°C, has continued. The analyses are focusing on three materials: MX-80, Deponit CAN and Asha 505. The work is performed by, SKB (mineralogy), Clay Technology AB (physical properties) and MICANS (microbiology). Some preliminary result from the laboratory analyses are:

- The degree of saturation was high in all positions of the test parcel (water content and density has been determined in all blocks).
- Swelling pressure and hydraulic conductivity have been determined in some positions for the three materials of main interest. A slightly decrease in swelling pressure could be determined, especially for the Asha 505 material.
- X-ray Absorption Near Edge Structure (XANES) spectroscopy has been performed. The clay blocks were sampled radially and preliminary results indicate higher Fe(II)/Fe(III) ratio in the vicinity of the iron heater compared to the reference clays. Time-resolved experiments were also performed in contact with oxygen to determine the stability of the Fe(II)-phase(s). These indicate that the Fe(II)/Fe(III) ratio to some extent decrease with time.

Data from the two test packages running have been collected and controlled during the period.

A report, including results from the work with characterisation of the reference materials, the work with termination of test parcel 1 and also results from analyses of the test material is under preparation.

4.5 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 was running between 2003 and 2006.

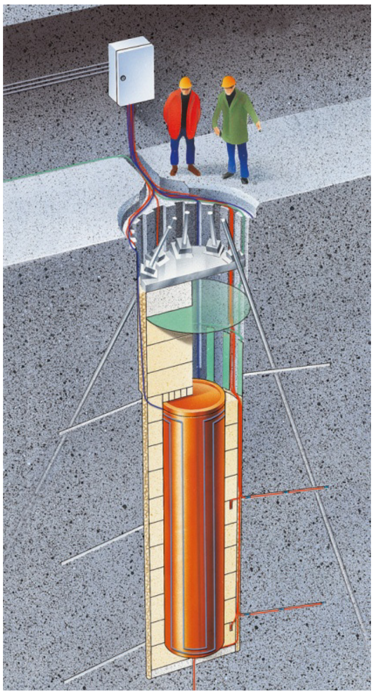
The monitoring comprise continuous measurements and registrations of water pressure and total pressure in the backfill and water pressure in the surrounding rock as well as leakage of water through the plug.

Achievements

The main work has included continuous measurements and registrations of water pressure and total pressure in the backfill and water pressure in the surrounding rock as well as leakage of water through the plug. Some leaking couplings have been taken care of.

Measurement of local hydraulic conductivity in the zone with crushed rock through installed equipments (CT-tubes) is ongoing but delayed.

4.6 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 and the canister was successfully retrieved in May 2006. 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

In the Task Force on Engineered Barrier Systems the teams have continued their modelling of the Canister Retrieval Test (CRT) and presented their new results at the meeting held in Pori, Finland on the 3rd – 4th of November, 2009.

Simulations of the thermal, hydraulic and mechanical processes in CRT are also a part of the work for the safety assessment SR-Site. New simulations of the CRT experiment, with special focus on the homogenisation process, have also been performed exclusively for the safety assessment.

4.7 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 engineered barrier systems, 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 shield (upper section).

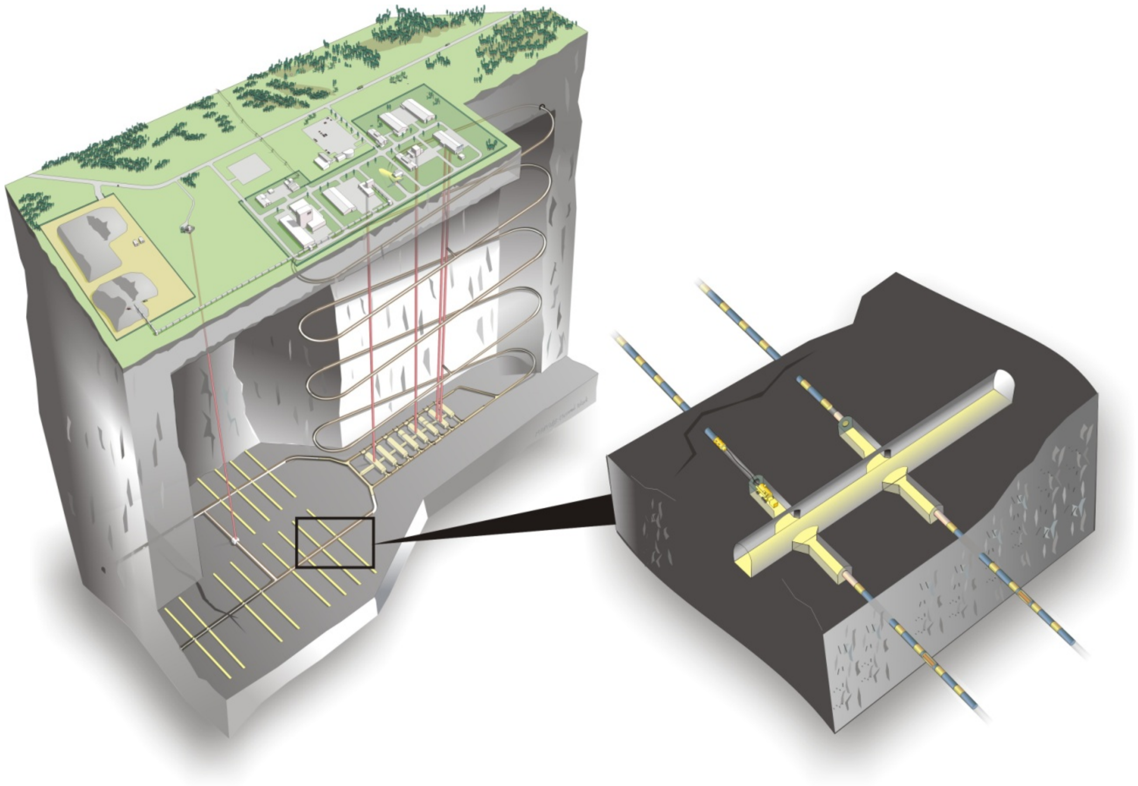
An artificial water pressure is applied in a slot between the buffer and rock, which is filled with sand and functions as a filter.

Data acquisition is continuously ongoing and data is transferred by a link from Äspö to Andra's head office in Paris.

Achievements

The upper part of the TBT experiment has now been dismantled. A number of activities were performed during November and December 2009: the removal of the plug, the removal and the sampling of the top bentonite cylinders (C3/C4), the removal of the sand shield, the retrieval of the upper heater, and finally the removal and the sampling of the upper bentonite rings (R7/R12). A large number of cores have been taken for determination of water content and density. These analyses have been performed concurrently with the dismantling operation. A dismantling meeting was held at Äspö on 15th of December. The dismantling operation is scheduled to be resumed during January 2010 and is anticipated to be completed in February.

4.8 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 different drift components.

The project is a joint project between SKB and Posiva. Now the next phase of the project "Complementary studies of horizontal emplacement KBS-3H" goes on. The main goal of the complementary studies (2008-2010) is to develop the KBS-3H solution to such a state that the decision on full-scale testing and demonstration can be made.

Achievements

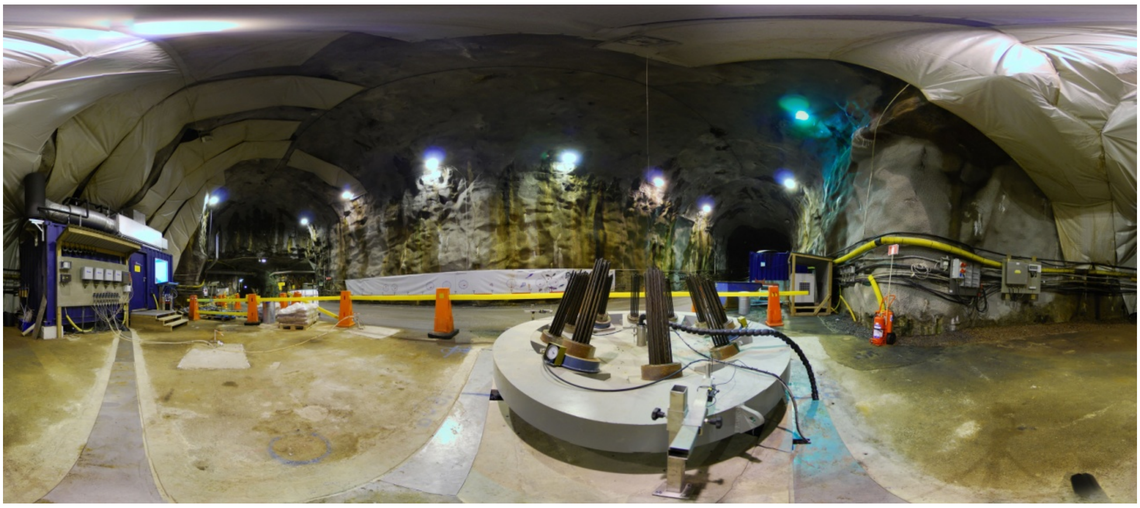
Early summer 2009 the compartment plug casting was post grouted with Silica sol. The reason for this was that the initial test pressurisation showed higher leakages through the casting than the KBS-3H design allows. After the summer vacation the volume behind the compartment plug was once again pressurised (5 MPa) and the leakage measured.

Measurements during the test period show that the post grouting has been effective in reducing the leakage through the compartment plug. During the test period the leakage has decreased, from initial approximately 0.1 L/min to a very low leakage of 0.002 L/min. This result is very good, especially considering that the volume behind the compartment plug is filled only with water, and shows that the compartment plug almost completely seals off the drift. An additional test with bentonite pellets will be done. Upcoming test is done with aim to further reduce the leakage through the plug and to verify the ability to completely fill the volume behind the plug with bentonite pellets.

Buffer erosion tests have been done at Clay Technology in Lund. The small scale tests are made to investigate and resolve an uncertainty issue regarding the ability to fill a compartment with water in the KBS-3H design in accordance with the DAWE concept. Results indicate that the water flow rate do not have any major impact on the level of erosion. However, the salt content of the water does have a significant effect.

At the KBS-3H seminar in Åbo, the next phase of the project was discussed. It was decided that the next project phase should concentrate on full scale sub system tests rather than a complete system test. Several sub system tests were suggested and discussed and are now being incorporated in a test plan for the upcoming project phase.

4.9 Large Scale Gas Injection Test



Panorama of the Large-scale gas injection test (Lasgit) 420 m below ground at Äspö HRL.

Most knowledge pertaining to the movement of gas in a compacted bentonite buffer 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 gas phases of the test history are key 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-3V design concept.
- Examine issues relating to up-scaling and its effect on gas migration and buffer performance.
- Provide information on the process of hydration and gas migration.
- Provide high-quality test data to test/validate modelling approaches.

In February 2005 the deposition hole was closed and the hydration of the buffer initiated.

Thereafter preliminary hydraulic and gas transport tests were performed. These will be repeated as the buffer matures in order to examine the temporal evolution of these properties. Comprehensive series of gas injection tests will be undertaken in the saturated buffer to examine the mechanisms governing gas flow in KBS-3 bentonite.

Achievements

The final third of 2009 involved the continuation of the gas testing that was started on the 28th of May (day 1577). As in previous gas tests, filter FL903 located in the lower filter array of the canister was selected. In contrast to previous tests, neon was selected as the gas permeant so that leakage to the host rock can be monitored.

In the previous third, two pressure ramps were undertaken raising the pressure in filter FL903 to 2,550 kPa and 3,880 kPa respectively (the start gas pressure was 1,300 kPa). At the start of the current reporting period a third pressure ramp was initiated by switching the pumping system into constant flow rate mode. This gradually raised gas pressure to 5,050 kPa over a period of 16 days. As with the previous steps, pressure was then held constant and flow into the clay continually monitored. As observed before, almost instantaneously following the termination of pumping gas flow into the clay dramatically reduced, resulting in a small background flux of gas into the clay.

Pressure was held constant for a total of 52 days (from day 1690 to 1742). The length of this stage was due to a request not to inject gas as this may have impacted another test underway within the Äspö HRL. The final gas injection stage was initiated on day 1742 (12^{th} of November) with a slow gas injection rate of 500 micro litres per hour, as shown in Figure 4-2. Similarly to previous pressure steps, gas flow into the clay rapidly increased following the start of gas injection. Pressure continued to rise until it reached a maximum of 5,872 kPa after 25 days of injection, this was followed by a spontaneous negative pressure transient very similar in form to those observed in small-scale laboratory tests /Harrington and Horseman 2003/.

Figure 4-3 shows gas flow into the bentonite buffer and the evolution of the injection pressure during this constant flow rate stage. As can be seen, prior to day 1766.5 gas flow into the clay was very small and constant showing no sign of any significant pressure dependency. However, at day 1766.5 gas flow spontaneously increased. At day 1767.3 the pressure in FL903 began to drop as the gas permeability of the buffer increased. As observed in laboratory experiments, the pressure in FL903 reduced and then increased as the system "under-shot" its ultimate level. By the end of the year, flow into the clay and the pressure in FL903 had appeared to asymptote. However this will be confirmed by continued injection in 2010.

Analysis of the total stress and porewater pressure sensors located within the deposition hole indicate that gas flow is both localised and a highly complex dynamic process with pathways opening and closing probably in response to localised changes in gas pressure. Significant changes have been observed in a number of porewater pressure and total stress sensors, giving insight into the direction and propagation of the gas, as well as the hydromechanical response of the buffer system. As with the previous gas test in 2007, propagation has been predominantly in a downward direction. However, the extended period of gas injection post-breakthrough has shown that gas continues to move around the system and has propagated to a number of locations within the deposition hole.

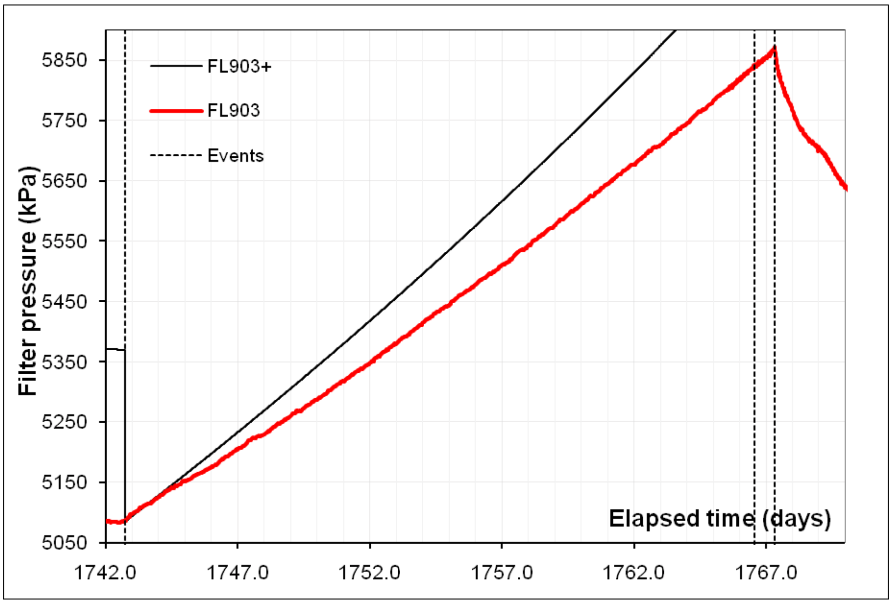


Figure 4-2. *Final stage of the gas injection test showing a slow increase in gas pressure from 5,080 kPa up to a maximum of 5,872 kPa. The two black event lines represent the start of gas flow into the clay at 5,833 kPa and the maximum gas pressure experienced (5,872 kPa).*

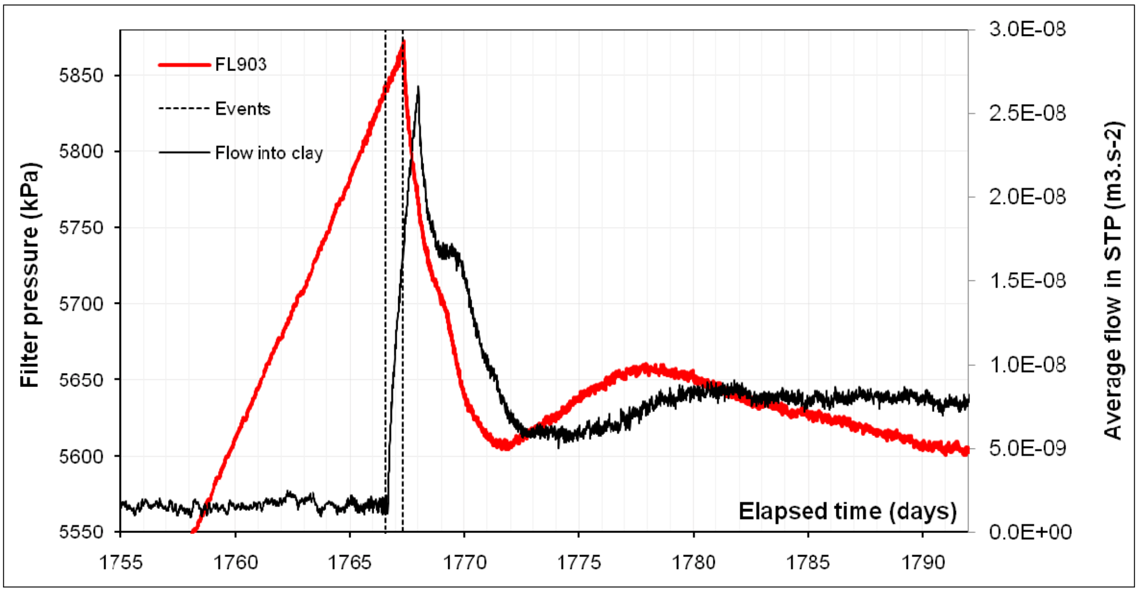
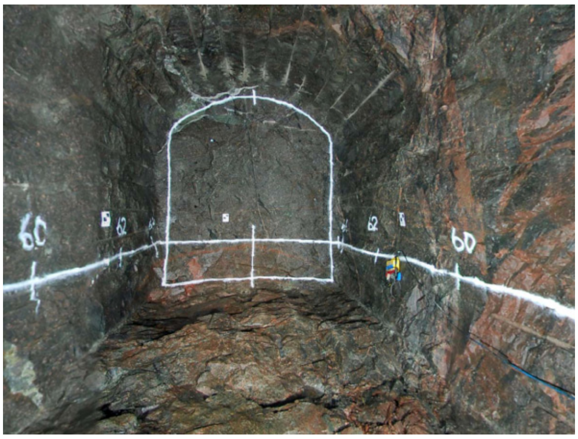


Figure 4-3. *The evolution of the injection gas pressure and the flow into the clay. The two black event lines represent the start of gas flow into the clay at 5,833 kPa and the maximum gas pressure experienced (5,872 kPa).*

4.10 Sealing of Tunnel at Great Depth



The Tass-tunnel in Äspö HRL

Although the repository facility will be located in rock mass of good quality with mostly relatively low fracturing, sealing by means of rock grouting will be necessary. Ordinary grouts based on cement cannot penetrate very fine fractures and due to long term safety reasons a sealing agent that produces a leachate with a pH below 11 is preferred.

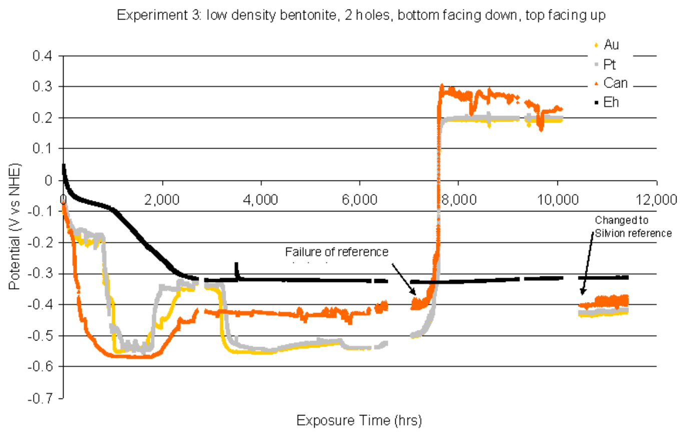
Silica sol, which consists of nano-sized particles of silica in water, has shown to be a promising grout, and in the sealing project at Äspö HRL, the use of silica sol is tested at great depth. Low-pH cementitious grouts will also be used and evaluated.

Another issue for the planned repository is the contour and status of the remaining rock after blasting. Drilling and blasting are given special attention and subsequent adjustments aim at successive improvements.

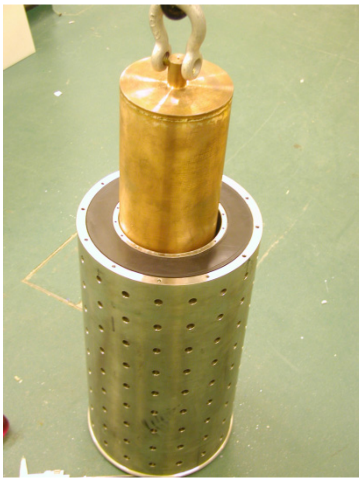
Achievements

The field works are completed and measurements of leakage into the tunnel are the only ongoing activity in field. Reports are now being written and are planned to be completed during 2010.

4.11 In Situ Corrosion Testing of Miniature Canisters



Example of electrochemical potential data obtained from one miniature canister.



Miniature canister with support cage.

The MiniCan project 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 have been set up in five boreholes with a diameter of 30 cm and a length of 5 m at Äspö HRL. All five canisters were installed in the beginning of 2007.

The canisters are mounted in support cages, four of which contain bentonite (three low density bentonite, one compact bentonite), and are exposed to natural reducing groundwater. Together with corrosion test coupons which are also in the boreholes, the canisters will be monitored for several years. The corrosion will take place under realistic oxygen-free conditions that are very difficult to reproduce and maintain for long periods of time in the laboratory.

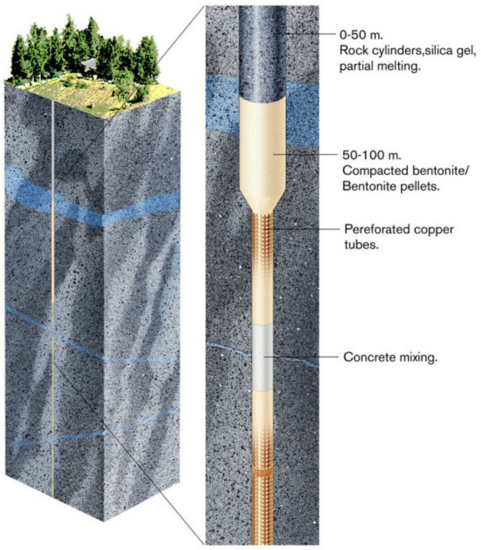
Data are transferred regularly to the UK for analysis through the internet link.

Achievements

During the last four month of 2009, monitoring of the miniature canister experiments has continued. Data are being collected for corrosion rate of copper and iron electrodes, and electrochemical potentials are being recorded for a range of electrodes, including Eh, gold, platinum, iron and copper. In addition, strain gauge data are being collected for two of the canisters. The planning for the removal of one of the canisters has started.

A report on the set up of the experiments and the results obtained up to May 2008 has been printed /Smart and Rance 2009/. Further progress reports are being prepared.

4.12 Cleaning and Sealing of Investigation Boreholes



The objective of the project is to work out a concept for rinsing, stabilising and plugging of deep boreholes drilled from the surface and repository level, such as they do not form significant transport paths for radionuclides from the repository to the biosphere. The project was initiated 2002 and Phase 1 to 3 have been finalised. The Phase 4 of the project comprises the following subprojects:

1. Characterisation and planning of borehole sealing
2. Quality assessment and detailed design
3. Sealing of two 300 mm underground boreholes
4. Interaction of clay and concrete plugs at 220 m depth

The specific goal is to collect available characterisation data of selected reference boreholes for working out generalised rock structure models and for planning sealing of boreholes.

A number of representative boreholes will be considered and those suitable for sealing will be divided into categories for which conceptual designs will be worked out. The project will select boreholes at Äspö, Laxemar and Forsmark for detailed design. The holes should represent typical rock conditions with respect to frequency, size and properties of permeable and unstable fracture zones.

Achievements

During the period, the main activity has been performed within the two new sub-projects “Sealing of two 300 mm underground boreholes at Äspö HRL” and “Interaction of clay and concrete plugs at 220 m depth”. In addition application of the Laxemar and Forsmark models has also been done for predicting long-term sealing efficiency of long boreholes.

Sealing of two 300 mm underground boreholes at Äspö HRL

The purpose of the activity is to permanently seal off two boreholes with 300 mm diameter and more than 15 m length. Plugs were placed following the principle that is basic to the entire project, i.e. to install tight clay plugs (Figure 4-4) where the rock is poor in fractures and to cast concrete where there are water-bearing zones. Two such zones were intersected and plugged with CBI concrete. The strong inflow required drainage through a central tube that served to guide the pre-compacted clay blocks to their specified positions. The tube was finally filled with clay pellets after placing an upper set of clay blocks and casting the upper concrete plug that was anchored in a recess in the holes. The design and construction of the borehole seals will be described in the final report of Phase 4 in early 2010.

Figure 4-4. Installation of clay blocks.

Interaction of clay and concrete plugs at 220 m depth

In 2004 two holes bored vertically from the floor of a room at 220 m depth in Äspö HRL (KA1621G01 and KA1621G02) were plugged. The holes were filled with sand in their lower parts over which plugs consisting of perforated copper tubes filled with compacted clay were installed and covered by CBI concrete up to the floor. The purpose of the tests is to investigate the chemical interaction of clay and concrete and the possible change in physical properties caused by such interaction. This required extraction of a rock column containing the plugged hole for taking samples of clay and contacting concrete which took place in December 2009. A detailed programme for sampling and analysis (Figure 4-5) has been worked out and will be followed. The description and outcome of the analyses will be described in the final report of Phase 4 in early 2010.

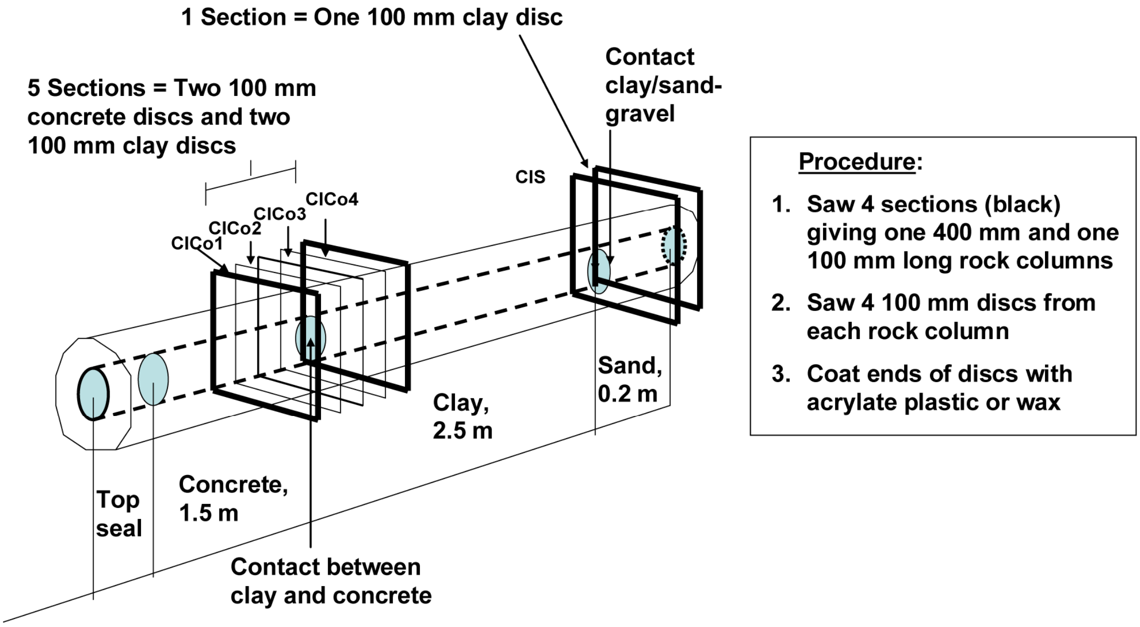


Figure 4-5. Principle of sampling and analysis.

Application of the Laxemar and Forsmark models for predicting long-term sealing efficiency of long boreholes

A first objective was to identify "reference holes" at Laxemar and Forsmark for applying physical rock models in order to determine the efficiency of borehole plugs. This was made for one of these holes, demonstrating the importance of strategically placed tight borehole plugs. If they fail short-circuiting can occur and lead to quick migration of radionuclides from the repository level to the biosphere (Figure 4-6). Preliminary assessments of the QC/QA of the integrated system of seals in deep boreholes and preliminary cost estimates have been worked out.

Special attention was paid to practical issues, primarily the preparation of boreholes and the impact of geometrical issues. In these respects the radius of curvature and variations in borehole diameter need consideration since they affect the placeability and sealing capacity of plugs. The description and outcome of the analyses will be described in the final report of Phase 4 in early 2010.

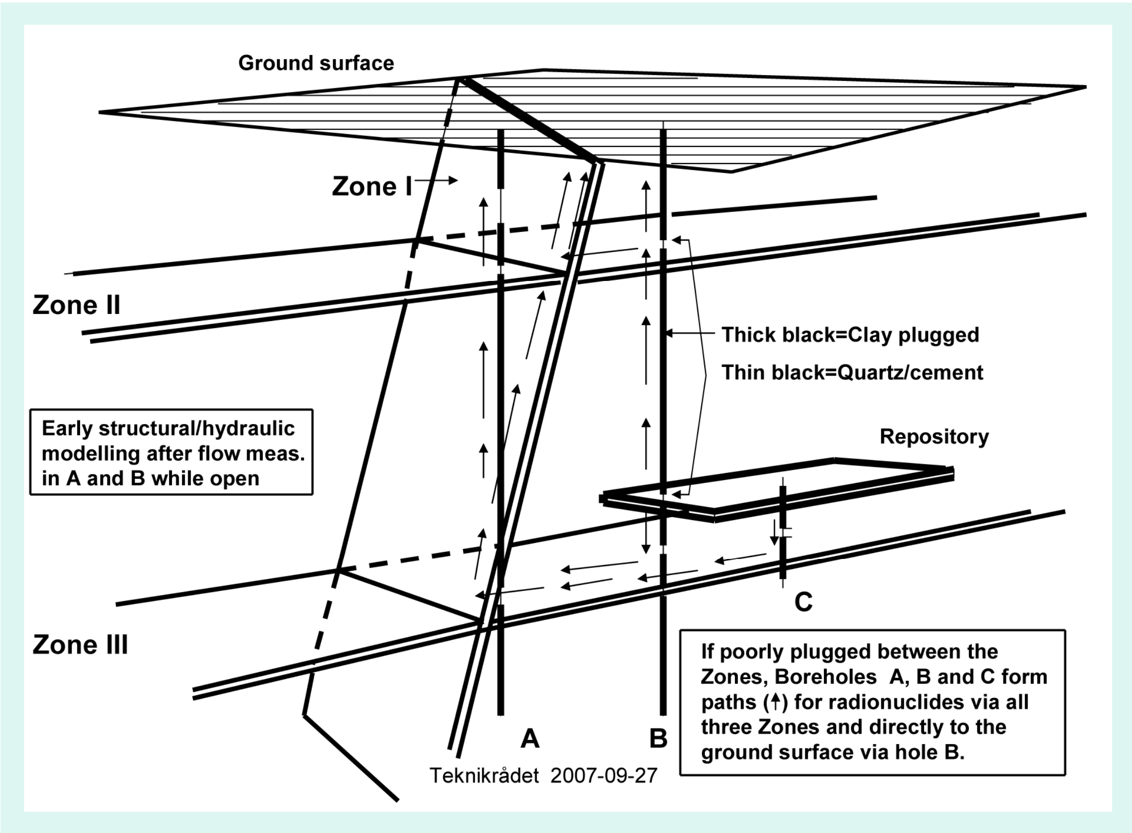
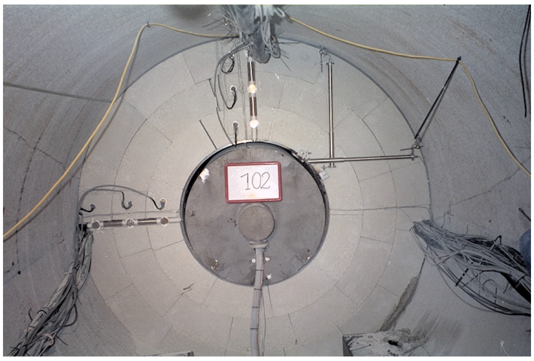


Figure 4-6. *Possible paths of migrating radionuclides by failing clay plugs.*

4.13 Task Force on Engineered Barrier Systems



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

Participating organisations besides SKB are at present Andra (France), BMWi (Germany), CRIEPI (Japan), Nagra (Switzerland), Posiva (Finland), NWMO (Canada) and RAWRA (Czech Republic). All together 12-14 modelling teams are participating in the work.

Since the Task Force does not include geochemistry, a decision has been taken by IJC to also start a parallel Task Force that deals with geochemical processes in engineered barriers. The two Task Forces have a common secretariat, but separate chairmen.

Achievements

A Task Force meeting was held in Pori in Finland in November where modelling results of both the THM/Gas group and the Geochemistry group were presented and discussed.

Task Force THM/Gas

The work with modelling of the Canister Retrieval Test (CRT) at Äspö HRL has continued during this four-month period. Altogether eight modelling teams are modelling this test. The task is divided into two parts where the first part is to model the thermo-hydro-mechanical behaviour of a central section of the test-hole with given boundary conditions. The second task is to model the entire test. Most teams have finished their calculations. Five of the teams have modelled the entire test, while the other three have only modelled the central section. Reports of these results are requested before the end of March 2010. Four suggestions of modelling tasks in the next phase were presented at the meeting and will be prepared during spring 2010:

Sensitivity analyses - This task implies sensitivity analyses with simple models. The purpose is to provide better understanding of the relationship between simulation variables and performance results regarding: (a) understanding of coupled processes active in the field, (b) identification of relevant key coupled processes, (c) identification of key parameters and (d) effects of parameter uncertainty on results.

Task 8: hydraulic interaction rock/Bentonite - This task focuses on the hydraulic interaction between the rock and the bentonite and is a joint task with the hydrogeology group. The main project goals are: (a) scientific understanding of the exchange of water across the bentonite-rock interface, (b) better predictions of the wetting of the bentonite buffer and (c) better characterisation methods of the canister boreholes. The task is related to and concerns modelling of a planned Äspö test in a project called Brie (Buffer-rock interaction experiment). Preparations for this task have been ongoing during 2009.

Homogenisation - This is a task related to erosion and subsequent homogenisation but can also refer to homogenisation in general. The general understanding of bentonite is that it has excellent swelling properties but the homogenisation is not complete due to friction, hysteresis effects and anisotropic stress distributions. The task is proposed to involve two phases. In the first phase a number of simple laboratory tests that have been made will be modelled and used for checking/calibrating the mechanical model. In the next phase one or two laboratory tests that simulate bentonite lost in a deposition hole will be performed and preceded by predictive modelling.

Prototype Repository - This task is to model one of the two outer deposition holes in the Prototype Repository in Äspö HRL. The motivations for this task are: (a) identical geometry with CRT but natural hydraulic interaction with the rock, (b) extensive instrumentation, (c) interaction buffer/backfill, (d) the test will be excavated just in time to be included in the next phase, (e) it is partly a true prediction and (f) it can be a joint task with the Task Force on Modelling of Groundwater and Solutes.

Task Force Geochemistry

At the Task Force meeting in Pori in November the following presentations were given: (a) The updated Crunchflow code, (b) Results from benchmarks 1 to 3, (c) Micro-structural interpretation of XRD, SAXS and chloride porosity measurements in bentonite, (d) Bentonite as thermodynamic mixture and (e) Correlation-corrected Poisson-Boltzmann theory.

Four suggestions of modelling main tasks in the next phase have been proposed and will be prepared during spring 2010:

Task 1 - Modelling of simple diffusion laboratory experiments. The work aims at testing presently available codes in order to compare capabilities and drawbacks.

Task 2 - Modelling of more complex laboratory experiments including mineralogical alteration and effects of the water saturation process. The work aims at testing presently available codes in order to compare capabilities and drawbacks.

Task 3 - Modelling of field experiments (e.g. Long Term Test of Buffer Material). This task aims at better explain the available field results by use of calculations, simple models and complex geochemical codes.

Task 4 - Predictive modelling of the mineralogical evolution in a repository.

Molecular dynamics (MD) have been used in order to study Donnan equilibrium between hydrated montmorillonite and an external saline solution, and reporting in the form of a scientific article is ongoing. Initial test have been made concerning friction in highly compacted bentonite.

5 Äspö Facility

5.1 General

The Äspö facility comprises the Äspö Hard Rock Laboratory and the Bentonite Laboratory, the later taken into operation in 2007. The Bentonite Laboratory complements the underground Hard Rock Laboratory and enables full-scale experiments under controlled conditions making it possible to vary experimental conditions and to simulate different environments.

In May 2009 part of the Äspö operation underwent an organisational change as the units *Äspö Hard Rock Laboratory* (TD) and *Repository Technology* (TU) within the Technology department were united. This change was done to focus the remaining development of the repository technology and performing of experiments and tests in a realistic repository environment at Äspö HRL. The new and larger unit inherited the name *Repository Technology.* Äspö HRL is the residence of the unit but the unit includes employees in both Äspö and Stockholm. The main responsibilities of the unit are to:

- Perform technical development commissioned by SKB's programmes for nuclear fuel and for low- and intermediate level waste
- Develop the KBS-3H concept
- Perform experiments in the Äspö HRL
- Secure a safe and cost effective operation of the Äspö HRL
- Prosecute comprehensive visitor services and information activities in the Oskarshamn area

The unit is organised in five operative groups and an administrative staff function:

- *Geotechnical engineering and rock engineering (TDG),* responsible for the development, testing and demonstration of techniques for installation of buffer, backfill and plugs. The development, testing and demonstration of techniques for backfilling the final repository and plugging of investigation boreholes are also part of the responsibilities within the group.
- *Mechanical- and system engineering (TDM),* responsible for the development, testing and demonstration of equipment, machines and vehicles needed in the final repository.
- *Project and experimental service (TDP),* responsible for the co-ordination of projects undertaken at the Äspö HRL, providing services (administration, design, installations, measurements, monitoring systems etc.) to the experiments.
- *Public relations and visitor services* (TDI), responsible for presenting information about SKB and its facilities with main focus on the Äspö HRL.

- *Facility operation (TDD),* responsible for the operation and maintenance of the Äspö HRL offices, workshops and underground facilities and for development, operation and maintenance of supervision systems.

- *Administration, quality and planning (TDA*), responsible for planning, reporting, QA, budgeting, environmental co-ordination and administration. The staffing of the Äspö reception and the SKB switchboard are also included in the function.

Each major research and development task carried out in Äspö HRL is organised as a project led by a Project Manager reporting to the client organisation. Each Project Manager is assisted by an on-site co-ordinator with responsibility for co-ordination and execution of project tasks at the Äspö HRL. The staff at the site office provides technical and administrative service to the projects and maintain the database and expertise on results obtained at the Äspö HRL

5.2 Bentonite Laboratory

Preparation of Test 4 in the half-scale steel tunnel.

Before building a final repository, where the operating conditions include deposition of one canister per day, further studies of the behaviour of the buffer and backfill under different installation conditions are required.

SKB has built a Bentonite Laboratory at Äspö, designed for studies of buffer and backfill materials. The laboratory, a hall with dimensions 15×30 m, includes two stations where the emplacement of buffer material at full scale can be tested under different conditions.

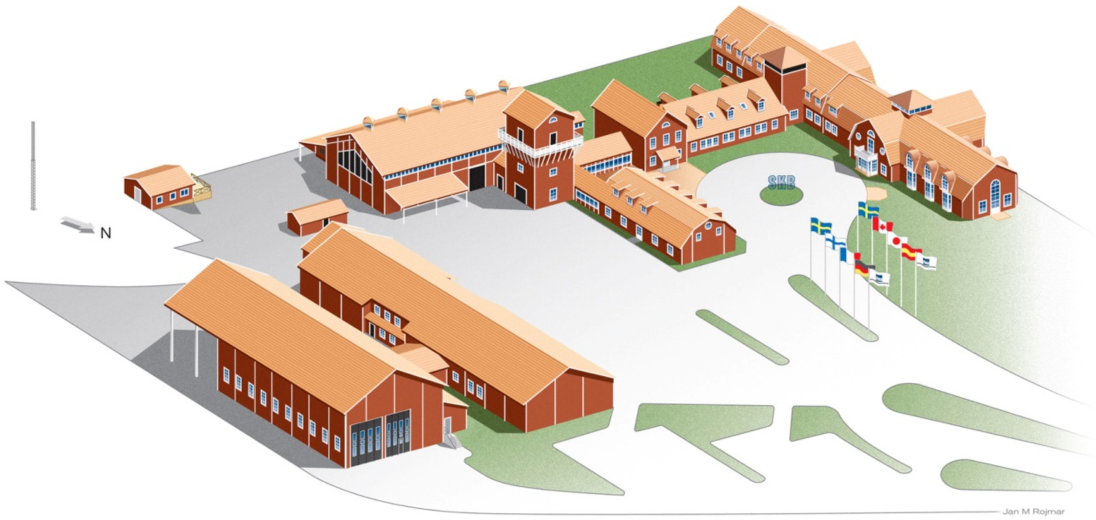
The hall is used for testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

Achievements

Tests concerning impact of water inflow on backfill have continued during the last four-month period of 2009. In Test 3 the same type of fracture mode used in tests 1 and 2 were used to isolate the rearmost 2m chamber by supplying it with water to 0.0025 L/min over a period of 120 hours. At the end of this initial period, the water was delivered to the rear of the chamber at a rate of 0.2 L/min through two separate bays each delivering 0.1 L/min. The behaviour of this test was very different than what has been observed previously in the extensive testing in the half-scale tunnel. Preparing for the test four has started and will be implemented in the end of December. Test 4 will be similar to Test 3 with a dry and a wet section but the set will be about one meter longer.

In parallel to the dismantling operation in the Temperature Buffer Test, the density and water content of the extracted core samples have been analysed at the Bentonite Laboratory. The evaluation of the results from these analyses is ongoing. The eight rock/pellet tests and the four half-scale tests will be reported in the beginning of 2010 when all the tests are finished.

5.3 Facility Operation



The main goal for the operation is to provide a safe and environmentally sound facility for everybody working or visiting Äspö.

This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power, ventilation, alarm and communications have a high degree of availability.

Achievements

The operation of the facility has been stable during the last four-month period, though the work-load has been high.

In the autumn, responsibility for the premises was divided between the machine-group and the facility operation group. The machine group is responsible for the heated building at the tunnel entrance and for the building for the disposal machine. Machines and equipment have been moved. At the tunnel entrance, a roof has been built over the containers that are used for storage, and the area has been tidied.

After the main rock inspection, reinforcement with rock-bolts has been carried out and some rock-surfaces have been netted. Reinforcement work with shotcrete will be carried out at the beginning of 2010.

In order to ensure that the facility's surveillance system works in the event of a power cut, the last stage of the extension of the UPS-system in the tunnel has been completed.

The steering documents *Health and safety plan* and *Entrance and surveillance* have been updated. In addition, a new work-platform, which complies with the current regulations, has been delivered to Äspö.

5.4 Public Relations and Visitor Services

SKB operates three facilities in the Oskarshamn municipality: Äspö facility, Central interim storage facility for spent nuclear fuel (Clab) and the Canister Laboratory.

Site investigations have been performed during 2002-2009 in the municipalities Oskarshamn and Östhammar. In June 2009 SKB decided to select Forsmark as the site for the final repository for Sweden's spent nuclear fuel.

The main goal for the Public Relations and Visitor Services group is to create public acceptance for SKB, which is done in co-operation with other departments at SKB. The goal will be achieved by presenting information about SKB activities and the Äspö facility. Furthermore the team is responsible for visitor services at Clab and the Canister Laboratory.

In addition to the main goal, the information group takes care of and organises visits for an expanding amount of foreign guests every year. The visits from other countries mostly have the nature of technical visits.

As from autumn 2008 the team also has the responsibility for the production of SKB's exhibitions; stationary, temporary and on tour.

The information group has a special booking team at Äspö which books and administrates all visitors. The booking team also is at OKG's service according to agreement.

Achievements

SKB facilities have been visited by 6,412 persons during September-December 2009 and in total 21,157 persons during the whole year. The numbers of visitors to SKB's main facilities are listed in Table 5-1. There have been a number of VIP-visits during the period, e.g. the chairman of the Swedish Paper Workers Union and the group leader for the Social Democrats. Äspö HRL has also been visited by a new member of SKB's board of directors and by the new principal for the Linnaeus University. There have been several international visitors, e.g. delegations from Russia and Japan. It is expected that the number of international visits will increase. Preparations for dealing with this have been intensified during the last four-month period and are an important part of SKB's strategy for visits.

Several events have been carried out during the period:

- The national event "The Geology Day" takes place every year all over Sweden to give people the opportunity to learn more about geology. One of the participating organisations is SKB and in September people were invited to geological and cultural excursions at Stensjö village. Focus was on the issue why the bedrock is important to a final repository and about 90 people participated.
- On the 25th of September a contribution to "EU's Researchers' Night" was held at Äspö, with research on groundwater in focus. The event attracted about 60 persons and another 171 persons listened to the lectures online.
- On the 28th of November the Äspö Running Competition was held in the Äspö-tunnel. Seventy participants, men and women, ran all the way up to the surface from -450 metres depth. This event has been a tradition for eleven years and is much noticed by media.
- An event called "The Environmental Day" was held at Äspö on the 1st of December. The theme of the day was the eutrophication of the Baltic Sea. The event was held in cooperation with Äspö Environmental Research Foundation and attracted about 60 participants.
- On the 5th of December an event was held at Äspö as a contribution to "Oskarshamn in Light". The event consisted of a light and music show down in the laboratory and 75 people took the chance to at the same time visit Äspö.

On account of an inquiry from SKB's technical staff and the Swedish Ministry of the Environment, an exhibition took place at IAEA General Conference in Vienna in September. Personnel from the Public Relations and Visitor Services group and the technical staff prepared the exhibition and also represented SKB in Vienna. The exhibition contained information about SKB's facilities, site investigations, history and planned future facilities. Information about the new European technical platform, where SKB is one of the active participants, was also given. Many participants of the General Conference took a great interest in the exhibition.

Table 5-1. Number of visitors to SKB's main facilities

SKB facility	Number of visitors September-December 2009
Central interim storage facility for spent nuclear fuel	728
Canister Laboratory	683
Äspö HRL	2,330
Final repository for radioactive operational waste (SFR)	2,531

6 Environmental research

6.1 General

Äspö Environmental Research Foundation was founded 1996 on the initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its resources available for national and international environmental research. The activities have since 2003 been concentrated to the Äspö Research School. When the activities in the school was concluded as planned in 2008, the remaining and new research activities were transferred within the frame of a new co-operation, Nova Research and development (Nova FoU).

6.2 Nova Research and Development (Nova FoU)

SKB wants to broaden the use of knowledge and data gathered within the SKB research programme. Nova FoU (www.novafou.se) is the organisation which implements this policy and facilitates external access for research and development projects to SKB facilities in Oskarshamn. Nova FoU is a joint research and development platform at Nova Centre for University Studies in Oskarshamn.

Nova FoU provides access to the following SKB facilities:

- Äspö Hard Rock Laboratory
- Bentonite Laboratory at Äspö
- Canister Laboratory in Oskarshamn
- Site Investigation Oskarshamn (Laxemar)

Nova FoU can co-finance the projects by valuing the access to the SKB facilities, knowledge and data. The aim with the research and development projects through Nova FoU is to create long term spin-offs and business effects beneficial to the region. Nova FoU supports new and innovative research, for example environmental studies, where the extensive SKB data set from geological, hydrogeological, hydrogeochemical and ecological investigations and modelling can be used (Figure 6-1).

The research and education programme is the most matured activity within Nova FoU and the activities within the Geochemistry Research Group are described in more detail in Section 6.2.1.

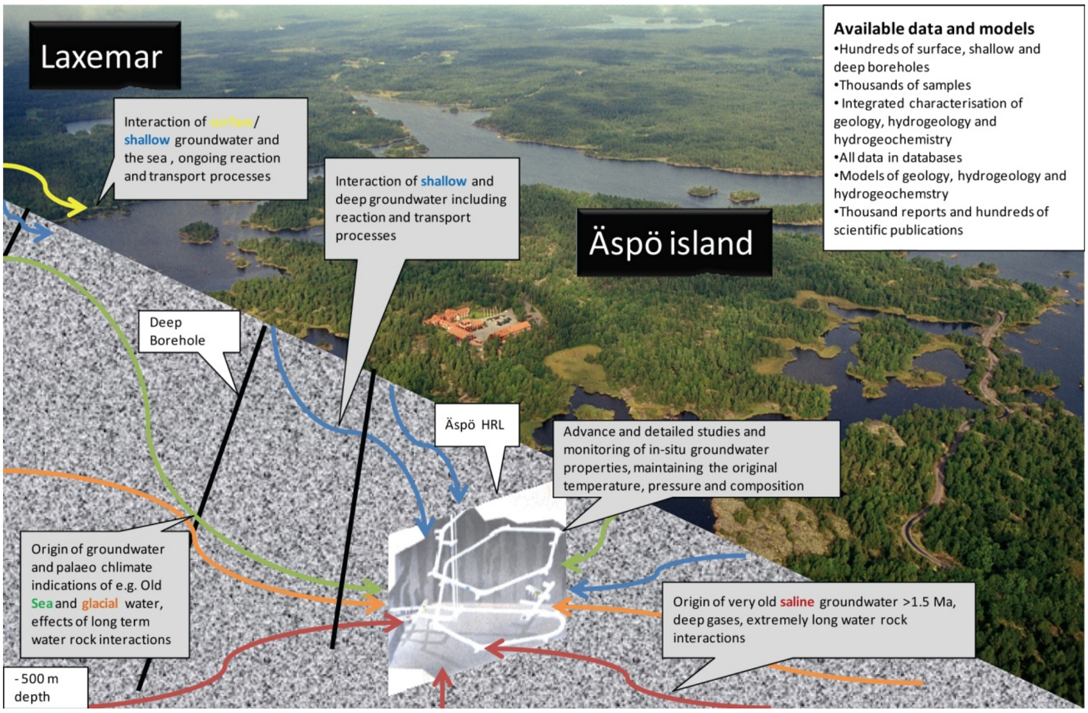


Figure 6-1. *The Äspö and Laxemar areas have been studied in terms of geology, hydrogeology, hydrogeochemistry and ecology. This information can be used for a number of purposes, for example to describe the water cycle and hydrogeochemical processes in 3D.*

The data can be used e.g. for assessing the consequences of natural resource management and pollution risks. The data and models can be used to estimate exposure both at individual and population levels. Development of monitoring and analytical systems can be performed relating to the management of various renewable natural resources in, for instance, agriculture, fisheries, forests and groundwater. Studies which give a better knowledge concerning pollution problems coupled to toxicological and epidemiological issues are possible. Technology, innovations and spin-off effects at pre-market stages are of special interest.

Other possible studies are:

- Groundwater origin, mixtures and evolution
- Interaction between large depths, surface and sea
- Model and technology development
- Tunnel and borehole experiments

6.2.1 Geochemistry Research Group

Surface water sampling point at Laxemar catchments area

The Geochemistry Research Group at Äspö HRL is a project within the research platform Nova FoU. The group consists of a professor, a post doc and three Ph.D. students.

Focus is on research of chemical elements in soil, water, bedrock fractures and biota, and includes detailed studies of how elements are distributed in streams and groundwaters at various depths. The research includes field monitoring, laboratory work and modelling.

Achievements

During the last four-month period one scientific paper was published in Applied Geochemistry /Augustsson et al. 2009/ and progress was made within several projects:

- Fracture minerals, including pyrite and calcite, were collected from fractures in bedrock cores collected during the site investigations in Oskarshamn (Figure 6-2). Microscopy and ICP-MS analyses were carried out in the geological laboratories of the Gothenburg University. The results have as yet not been interpreted in detail and additional analyses, including isotopic determination, will be carried out before the results are interpreted published.
- The sources and pathways of fluoride in the unusually fluoride-rich Kärrsviksån catchment were investigated further. Correlations were made between fluoride levels in the surface waters and overburden groundwater, and a detailed mapping of fluoride distribution and origin in the bedrock varieties and fracture fillings were carried out. A detailed field study located around bedrock fractures extending from the Götemar granite to the Kärrsviksån stream was undertaken. The waters collected in this field campaign were analysed for fluoride and a few other variables in the chemical laboratory at Äspö. The results have as yet not been interpreted in-depth and thus not published.
- The impact of drilling water content and chemistry on the hydrochemistry of waters sampled in deep boreholes in the bedrock was investigated with PHREEQC and M3. The preliminary results point to the possibility of defining how these drilling artefacts will influence major anion and cation chemistry. Further modelling will be carried out before the results are published.

- The levels and distribution of lanthanides in overburden groundwater from the site investigations were analysed by means of univariate and bivariate statistical methods. The concentrations of lanthanides in several of the groundwater tubes show a decreasing trend over time. While it is possible that such trends are natural, there is a risk that they are caused by disturbances initiated during the installation of the soil tubes. A similar decreasing trend in concentrations over time occurs, for example, for aluminium, while all major cations and anions as well as pH and organic carbon show rather stable levels over time in all tubes. A hypothesis is that the high initial concentrations of lanthanides and aluminium are caused by initial high concentrations of colloids. This hypothesis shall be further tested before utilisation and publication of the data.

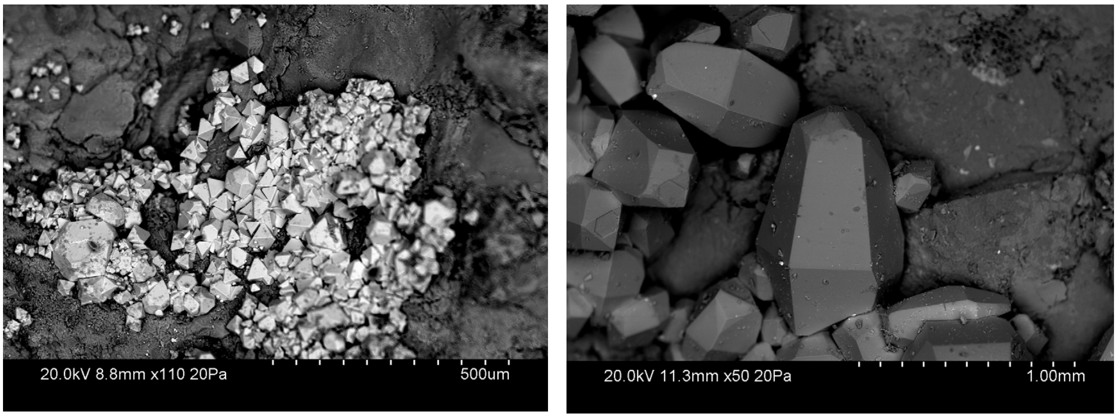


Figure 6-2. *SEM-picture of pyrite in borehole KLX10 at -357 m (left) and SEM-pictures of calcite in borehole KLX10 at -698 m (right).*

7 International co-operation

7.1 General

In addition to SKB, eight organisations from seven countries participate in the co-operation at Äspö HRL during 2009, see Table 7-1. Six of them; Andra, BMWi, CRIEPI, JAEA, NWMO 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.

Table 7-1. International participation in the Äspö HRL projects during 2009.

Projects in the Äspö HRL during 2009	Andra	BMWi	CRIEPI	JAEA	NWMO	Posiva	Nagra	RAWRA
Natural barriers								
Long Term Sorption Diffusion Experiment					X			
Colloid Transport Project (Part of Colloid Formation and Migration CFM)		X			X			
Microbe Project		X						
Task Force on Modelling of Groundwater Flow and Transport of Solutes			X	X	X	X		
Engineered barriers								
Prototype Repository		X				X		
Alternative Buffer Materials	X	X				X	X	X
Long Term Test of Buffer Materials					X	X	X	
Temperature Buffer Test	X							
KBS-3 Method with Horizontal Emplacement						X		
Large Scale Gas Injection Test	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
Nuclear Waste Management Organisation, NWMO, Canada
Posiva Oy, Finland
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, Switzerland
Radioactive Waste Repository Authority, Rawra, Czech Republic

As can be seen in Table 7-1 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 (Section 3.12) and solute transport in fractured rock and (b) THMC modelling of Engineered Barrier Systems, which is a forum for code development on THMC processes taking place in a bentonite buffer and gas migration through a buffer (Section 4.13). The proposal of a joint Task 8 of the two Task Force projects, related to modelling hydraulic interaction of rock and bentonite has been further discussed.

SKB also takes part in work within the IAEA framework. Äspö HRL is part of the IAEA Network of Centres of Excellence for training in and demonstration of waste disposal technologies in underground research facilities.

8 Documentation

During the period September – December 2009, the following reports have been published and distributed.

8.1 Äspö International Progress Reports

Hakami E, Weixing W, 2005. TRUE-1 Continuation project. Fault rock zones characterisation. Characterisation and quantification of resin-impregnated fault rock pore space using image analysis. SKB IPR-05-40, Svensk Kärnbränslehantering AB.

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8.2 Technical Documents and International Technical Documents

Four Technical Documents and one International Technical Documents have been published during the period September – December 2009.

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