International Progress Report

IPR-10-20

Äspö Hard Rock Laboratory

Status Report

September – December 2010

Svensk Kärnbränslehantering AB

April 2011

Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel

and Waste Management Co

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Äspö Hard Rock Laboratory

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Overview

The Äspö Hard Rock Laboratory (HRL) constitutes an important part of SKB's work to design and construct a geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site. In September 2010, the plans for SKB's research and development of technique during the period 2011–2016 were presented in SKB's RD&D-Programme 2010 /SKB 2010a/. The information given in the RD&D-Programme related to Äspö HRL is annually detailed in the Äspö HRL Planning Report and the information valid for 2010 is given in /SKB 2010b/. This Äspö HRL Status Report is a collection of the main achievements obtained during the period September to December 2010.

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, Transport Resistance at the Buffer-Rock Interface, Padamot, Fe-oxides in Fractures, Investigation of Sulphide Production Processes in Groundwater, 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, Cleaning and Sealing of Investigation Boreholes, Concrete and Clay, Low-pH Programme and Development of End Plugs for Deposition Tunnels. 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.

Mechanical- and system engineering

At Äspö HRL and the Canister Laboratory in Oskarshamn, technologies for the final disposal of spent nuclear fuel are being developed. Established as well as new technology will be used in the final repository. When it comes to mechanical- and system engineering, well known standard objects with secured function will be used to the fullest possible extent. With standard equipment as a basis needed adjustments, modifications and adaptations can be made for the intended function. Where no standard objects are available, new technical development will be necessary. Projects are on-going concerning equipment for backfilling, buffer emplacement, deposition machine, logistics study, multi purpose vehicle, transport system, drilling- and production system.

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 group Communication Oskarshamn 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 2010.

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 2011–2016 are presented in SKB's RD&D-Programme 2010 /SKB 2010a/. The planned activities related to Äspö HRL are detailed on a yearly basis in the Äspö HRL Planning Report /SKB 2010b/. This Status Report presents main achievements during the period September - December 2010. In the Annual Report more detailed information is given of new findings and results obtained during the whole year.

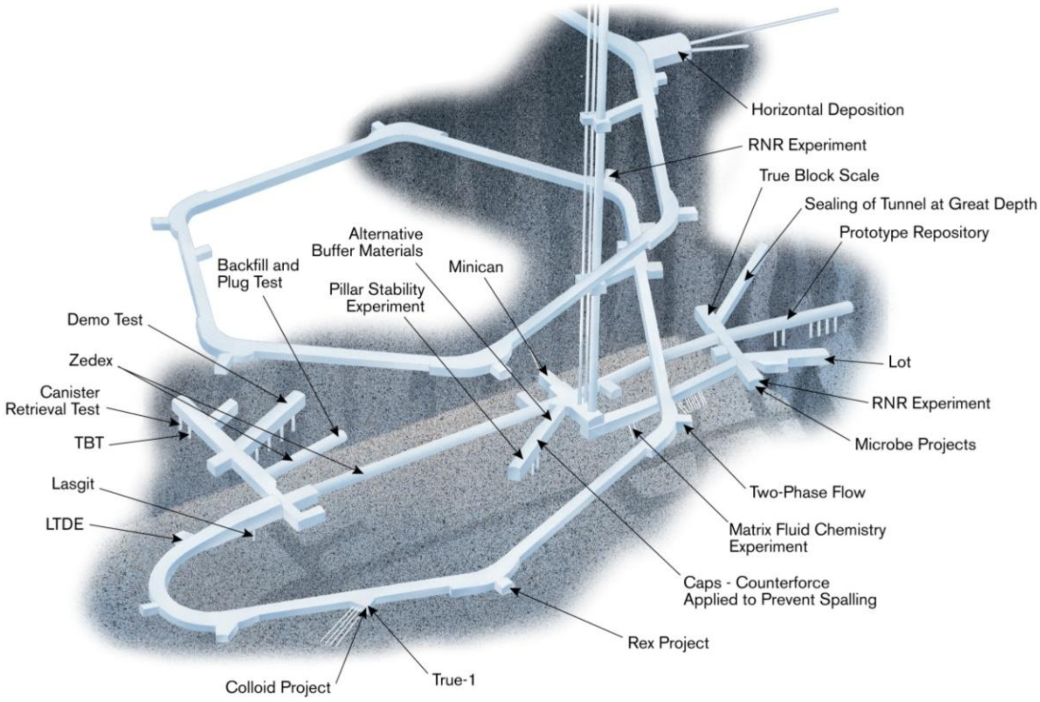


Figure 1-1 *Overview of the Äspö HRL and the allocation of the experimental sites from -220 m to -460 m level.*

2 Geoscience

2.1 General

Geoscientific research is a 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 objectives are to:

- Establish and develop geoscientific models of the Äspö HRL rock mass and its properties.
- Establish and develop the knowledge of applicable measurement methods.

The 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, geochemistry and rock mechanics, see section 2.2. The SDM will facilitate the understanding of the geological, hydrogeological, geochemical and rock mechanical conditions at the site and the evolution of the conditions during operation of Äspö HRL.

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

2.2 Äspö Site Descriptive Model

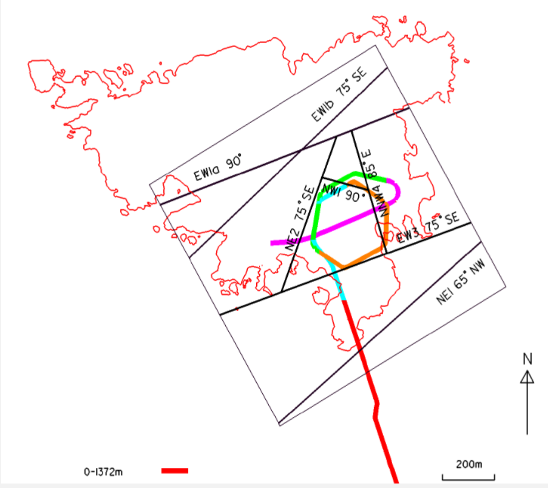


Illustration of deformation zones and tunnels in the Äspö Site Descriptive model.

The development of an Äspö Site Descriptive Model (SDM) will facilitate the understanding of the geological, hydrogeological and geochemical conditions at the site and the evolution of the conditions during operation of the facility.

The SDM also provides basic geoscientific data to support predictions and planning of experiments performed in Äspö HRL.

The aim is also to ensure high quality of experiments and measurements related to geosciences.

Achievements

During the last four-month period of 2010, reports on geological and hydrogeological single hole interpretations of five surface based boreholes and eight boreholes drilled from the tunnel have almost been finished. Lineament interpretation, based on ground surface magnetic measurements performed 1988 and topographic data, has been performed, see Figure 2-1. All water conductive fractures and water conductive deformation zones have been plotted in different sections along the tunnel.

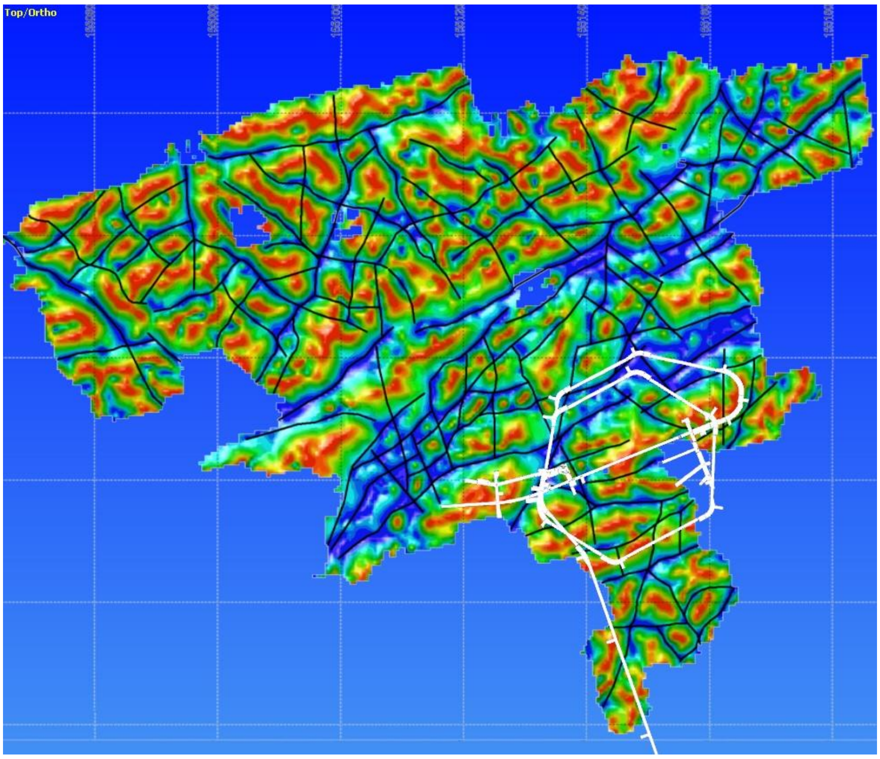


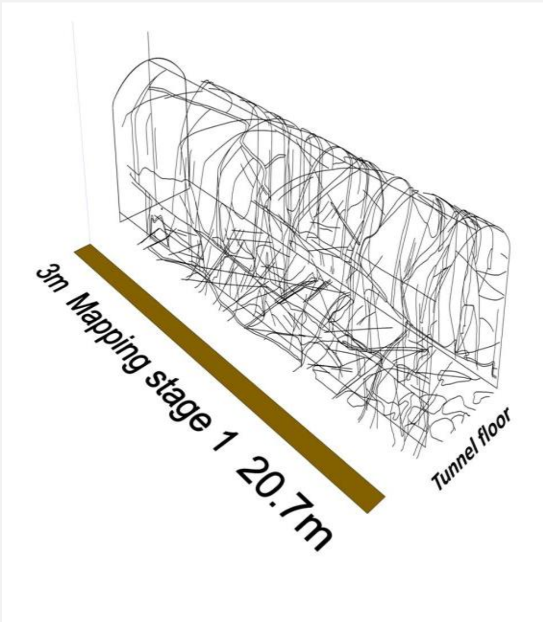
***Figure 2-1** Lineament interpretation based on ground surface magnetic measurements performed in 1988.*

Hydrogeochemical monitoring data has been analysed. Explorative analysis of the major components has been and is currently being done. Plots of Cl, Mg, $\delta^{18}O$ versus depth and time during and after the tunnel construction have been performed. Multivariate Mixing and Mass balance (M3) modelling has been used to determine end members and what reactions that needs to be modelled in PhreeqC.

2.3 Geology

Geological work at Äspö HRL is covering several 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.

2.3.1 Geological Mapping and Modelling



The TASA-tunnel, right wall, section 46-47 m. Boundary between the rock types Fine grained dioritoid (lower part) and Ävrö granodiorite (upper part) (left). A 3D-model of the TASS-tunnel, section 3-20.7 m. The irregular black lines in the model show fractures, rock boundaries etc. (right).

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 the last four months of 2010 have been:

- The report concerning the geological mapping of the TASS-tunnel has been adjusted after being reviewed. The report has now been sent on a linguistic review.
- The report concerning modelling of water bearing fractures at the -450 m level is now in print /Markström et al. 2010/.

- Work with Äspö SDM (Site Descriptive Model) continues, but lately at a slow pace due to other tasks.
- A method description (SKB MD 143.007) concerning the handling and sampling of drill cores has been released.
- The Äspö core storage has now been rebuilt, but occupies a smaller area since parts of the original area will be used for other purposes. A new digital camera has been mounted in the core logging room. The camera can be operated from the computer used for the core logging.
- The sorting and labelling of digitised photos from deposition holes and minor tunnels continues.
- The digitising and database entry of old geological mapping into the TMS
- (Tunnel Mapping System) continues. For example all the deposition holes from the TASK-tunnel have been completed.
- Core logging of the drill cores from the boreholes KO0014G01, KO0015G01, KO0017G01, KO0018G01 and KO0020G01 of the Brie project in the TASO-tunnel has been performed.
- Statistic analyses concerning CFF (Conductive Fracture Frequency) is still ongoing, but now over shorter tunnel sections.
- FPI (Full Perimeter Intersection) analyses concerning water bearing fractures is performed for the TASQ-tunnel. Cut-off for single fractures is set to about 2 m to allow for a combination of fractures that may fulfil the criteria for FPI.
- The TMS (Tunnel Mapping System) database has been copied to the Sicada database. New entries in the TMS database will have to be manually copied into the Sicada database.
- The finalising of the project "Sealing of Tunnel at Great Depth" has commenced.

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

The company 3GSM gives instructions about photogrammetry in the TASS-tunnel.

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, here referred to as RoCS-II.

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. Primarily photogrammetry and possibly laser scanning in combination with digital photography will be a part of that system. The resulting mapping system shall operate in a colour 3D environment where the xyz-coordinates are known.

Achievements

The main activities or achievements during the last four months of 2010 have been:

- The Austrian company 3G Software & Measurement (3GSM) has delivered the hardware and software for the photogrammetry part of RoCS. A course was held at Äspö HRL this fall about how to handle the hardware as well as the software.
- New battery powered LED-lamps/floodlights have been purchased by SKB to ensure good illumination during the field work in the tunnels.
- The company Ergo-data that also developed the software Boremap has been chosen to develop the mapping module in RoCS. A rather primitive test programme was first presented, but later a new and more developed test programme was delivered. The work is ongoing.

2.4 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

Geological and hydrogeological single hole interpretations have continued and a first draft report has been produced including the results from the boreholes KAS04, KAS06 and KAS08.

2.4.1 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. The system also includes surface hydrological and meteorological measurements.

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 has been ongoing, monitoring points were maintained and performing well, particularly the equipment installed in the tunnel. The restoration of the in-situ equipment in KAS02 failed. A total refurbishment is necessary in this borehole in order to make it operational but could not be carried out during 2010.

Additional points of groundwater pressure measurements were installed at approximately 40 locations along the tunnel with the specific aim to increase the near tunnel disturbance effect on pressure. These are planned to be included in the HMS database on-line system during next year.

The demobilisation of monitoring installations of the site investigation is ongoing. The monitoring is reported every four-month period through quality control documents and on an annual basis. In the annual report the measurement system and basic results are given.

2.5 Geochemistry

The major aims within geochemistry 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.

There is a need to develop method descriptions for the actual sampling procedures at field (underground, excavation of tunnel) for the hydrogeochemical work. In addition, instructions for procedures for quality assurance of hydro-chemical data to be included in the site characterisation database Sicada need to be established. The main task is to develop quality control and quality assurance procedures in the field of hydrochemistry and geochemistry.

Achievements

A PhD study has started with the aim to evaluate a new technique for sampling trace elements in deep groundwater. The project will be performed in Äspö HRL.

The hydrogeochemical monitoring has continued. Because of the early winter season and bad sea ice conditions, the sea point (PSM007097) and one soil tube point (SSM000240) had to be skipped in November. The monitoring points for core drilled boreholes, surface water, precipitation and soil tubes were maintained and were performing well.

Parts of the monitoring programme from the site of investigations at Oskarshamn have been transferred into the monitoring programme for Äspö. Spinner measurements have been performed in selected percussion boreholes in the area around Äspö.
The results will be used for preparation for installations of new sampling equipment in at least four percussion drilled boreholes (HLX01, HMJ01, HAV14 and HLX27) in January 2011. The sampling points will facilitate the understanding of the shallow water conditions and water mixing at Laxemar and Ävrö for Äspö SDM as well as the boundary conditions.

2.5.1 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 obtained from boreholes drilled from the ground surface and from the tunnel.

At the beginning of the 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.

Achievements

The monitoring campaign from autumn 2010 was put forward and will be completed in the beginning of 2011. Unfortunately KAS03 and KAS09 cannot be sampled because of the weather conditions.

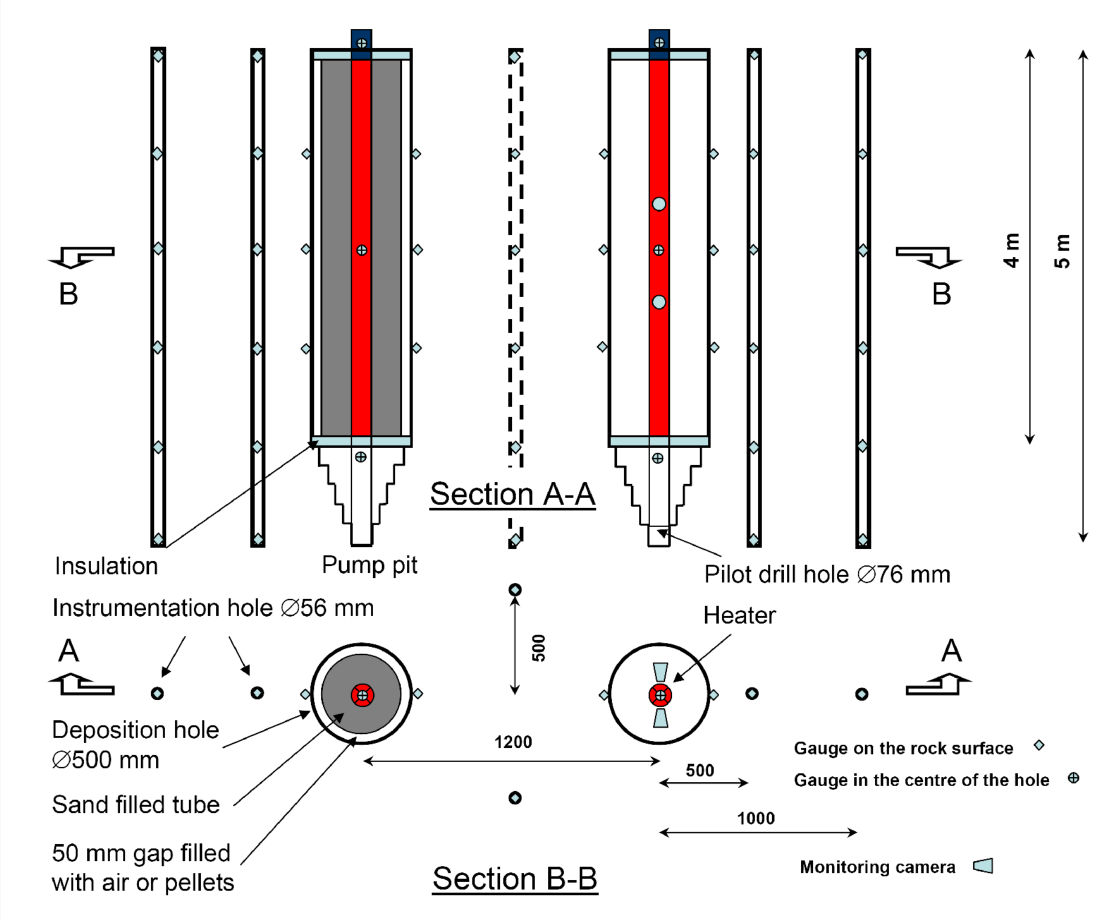
2.6 Rock Mechanics

Rock mechanic studies are performed with the aims to increase the understanding of the mechanical properties of the rock but also to recommend methods for measurements and analyses. This is 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.

The project called Caps (Counterforce Applied to Prevent Spalling) comprising field tests in Äspö HRL and numerical modelling is now finalised, see section below.

2.6.1 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 first heating test was initiated at the end of August 2008 and the final test was finished at the end of May 2009. The recorded data from the field experiment has been delivered to Sicada. The final report of the project was printed in July 2010 /Glamheden et al. 2010/.

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 conditions. The goals are to increase the scientific knowledge of the safety margins of the repository and to provide data for performance and safety assessment and thereby clearly present the role of the geosphere for the barrier functions: isolation, retardation and dilution.

Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are one of the main purposes of the Äspö HRL, see Figure 3-1. 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.

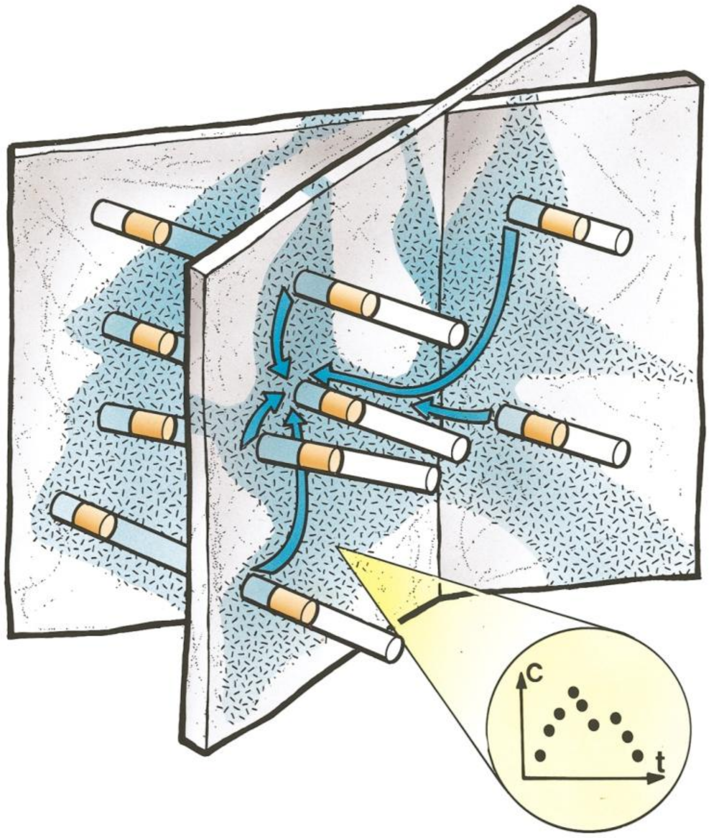
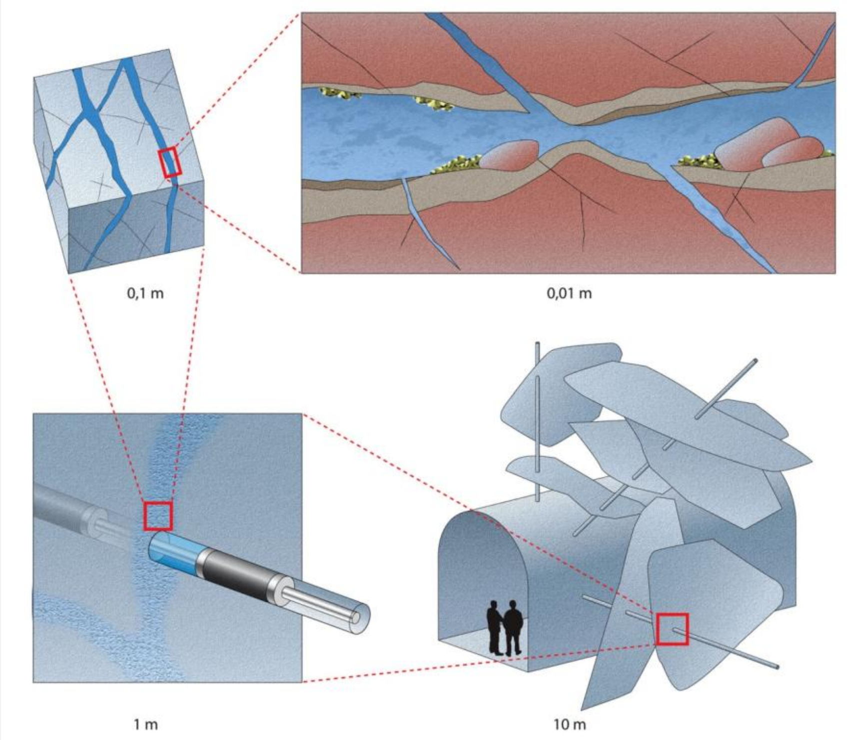


Figure 3-1 *An illustration of the TRUE-1 experiment performed at Äspö HRL, which gave an opportunity to test models for groundwater flow and transport of solutes.*

3.2 Tracer Retention Understanding Experiments



Schematic illustration of various scales of heterogeneity addressed by the TRUE experimental programme, ranging from block scale to micro scale. The micro scale illustration (upper right) shows a cross-section of a conductive fracture that includes a zone of enhanced porosity (light brown), fault gouge (dark brown), idiomorphic crystals (yellow) in a hydrothermally altered rim zone (red).

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. 2002/ 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.

After an interlude of site investigations and site modelling, finalisation of the principal components of the TRUE programme – TRUE-1 Continuation and TRUE Block Scale Continuation are near their conclusion.

In the aftermath, a project following up on the interpreted extensions of select TRUE Block Scale structures in the TASS tunnel has been initiated.

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 article entitled *Transport and retention from single to multiple fractures in crystalline rock at Äspö (Sweden):*

I. Evaluation of tracer test results and sensitivity analysis /Cvetkovic et al. 2010/
II. Fracture network flow simulations and generic retention model /Cvetkovic and Frampton 2010/

In addition, there is a stand-alone paper entitled "Significance of fracture rim zone heterogeneity for tracer transport in crystalline rock" /Cvetkovic 2010/.

A second step in the scientific reporting of the TRUE experiments is the production of a more high-profile paper directed to the general scientific public.

Achievements

A paper titled *"Would crystalline bedrock sufficiently contain radionuclide release from a high-level nuclear waste repository?"* was submitted to the journal Science. In the paper a model is presented for estimating the efficiency of a crystalline rock formation to contain radionuclides that relies on recent experimental and theoretical advances. The paper presents robust features of radioactive isotope retention over a wide range of spatial scales and sorption affinities, indicating consistency in the conceptualisation of field and laboratory scale transport experiments. The main implication is that field-scale transport of radioactive (metal) isotopes, serving as proxies for actinides in the crystalline bedrock, can be verified by combining independent information with a relatively simple conceptual model. The paper was rejected due to Science's stringent space limitations and the specialised nature of the paper. A second paper, submitted to Geophysical Research Letters, entitled *"Diffusion-controlled tracer retention in crystalline rock on a field scale",* is in press.

3.2.2 BS TASS – Follow-up of TRUE Block Scale structures in the TASS-tunnel

This project makes use of the possibility to investigate further selected relevant TRUE Block Scale structures in the TASS-tunnel, and associated pilot boreholes. This provides an opportunity to observe in the tunnel structures involved in the TRUE Block Scale tracer experiments, and to assess the heterogeneity in structure properties across a larger extent of the structure and allows assessment of heterogeneity at different scales of observation. Of particular interest is the validity of information collected in a pilot borehole for a tunnel, relative to information collected along the corresponding tunnel interface on the tunnel wall. Inferences made in the study have relevance to the detailed site characterisation to be carried out in conjunction with construction of a repository at Forsmark.

The objective is to carry out geometrical, structural-geological, mineralogical and hydraulic analysis of selected TRUE Block Scale structures, as observed in pilot boreholes for the TASS-tunnel and the TASS-tunnel itself, with the aim of describing the geological and hydraulic heterogeneity of the structures.

Achievements

The field work carried out in early December 2010 included remapping of intercepts with Structures #20 and in part #22, as observed in TRUE Block Scale and pilot boreholes in the TASS-tunnel, employing the descriptors employed in the site descriptive modelling carried out at Forsmark and Laxemar, see Figure 3-2. The structural, geological and mineralogical mapping has been made using one common photographic platform. Subsequently, detailed mapping of the Structure #20 and tentative mapping of Structure #22 was conducted in the tunnel. The mapping of Structure #20 in the tunnel was made in transects, similar to core mapping, along remnants of blast holes visible on the tunnel wall which also provide geometric reference. Interpolation of geometrical and structural characteristics is facilitated by the added information provided by the ordinary light and UV photography. Samples of the Structure #20 intercepts for fracture mineralogical analysis have been collected from the drillcores as well as from the tunnel. Assessment of hydraulic pressure information from existing boreholes has been made, and hydraulic test data have been compiled. Evaluation of the collected information is under way.

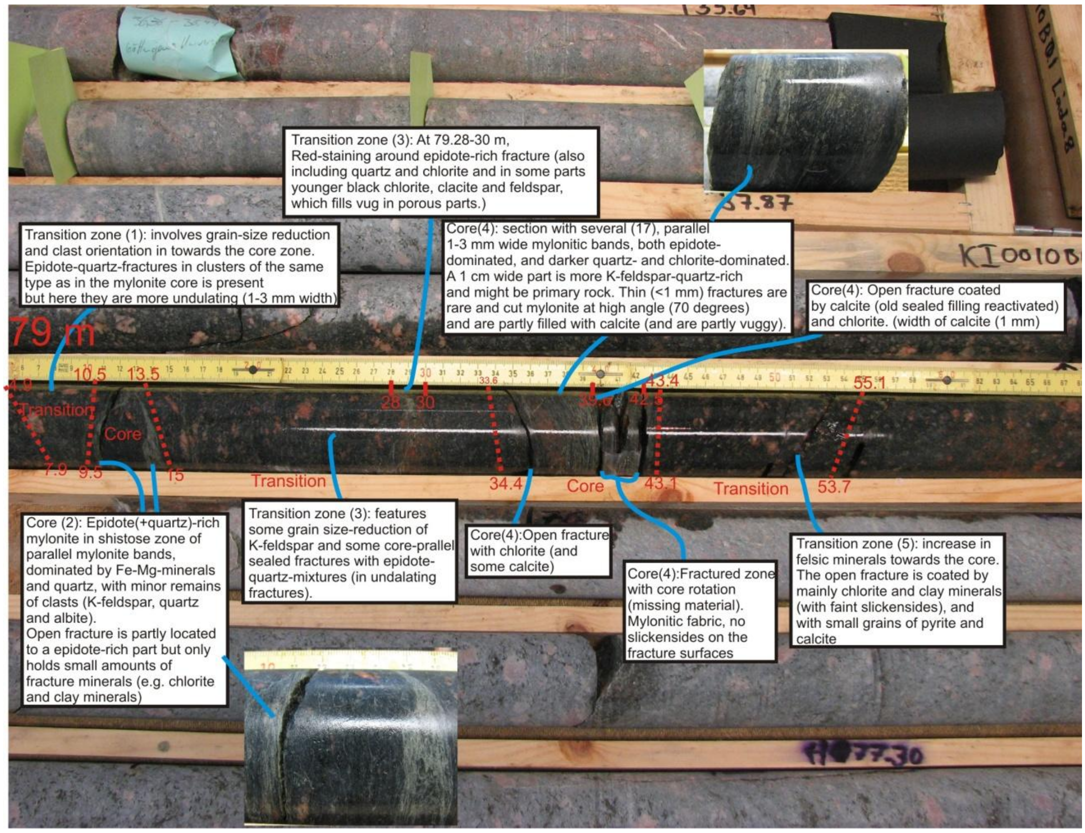


***Figure 3-2** Example of structural-geological description of intercept of TRUE Block Scale Structure #20 in pilot borehole KI0010B01, employing the general conceptual model for deformation zones used in the site descriptive modelling at Forsmark and Laxemar.*

3.2.3 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.

The complementary laboratory work on sorption properties of fracture rim zone and fault gouge material has been complemented with some additional analyses which will enable comparison between the current results and those obtained in the site investigations.

Achievements

During the period, the final report of the Fault Rock Zones Characterisation project /Winberg 2010/ has been completed. The report providing the results of the sorption and leaching experiments involving different tracers and rim zone and fault gouge materials /Byegård and Tullborg 2010/ has also been finalised.

3.2.4 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.

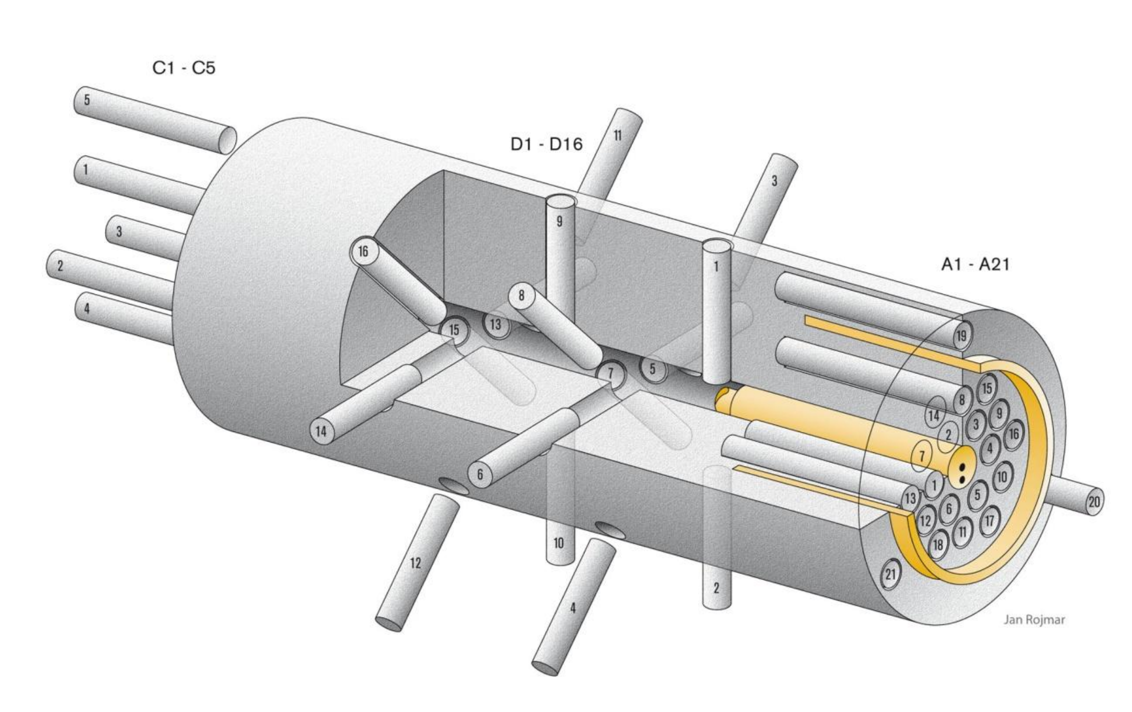
The general objectives of TRUE-1 Completion are:

- To perform epoxy injection and through the succeeding analyses improve the knowledge of the inner structure of Feature A and to improve the description and identification of the immobile zones that are involved in the noted retention.
- To perform complementary tests with relevance to the ongoing SKB site investigation programme, for instance in situ Kd-test and Swiw-test (single well injection withdrawal).
- To improve the knowledge of the immobile zones where the main part of the noted retention occurs. This is performed by mapping and mineralogical-chemical characterisation of the sorption sites for Cs.
- To update the conceptual micro-structural and retention models of Feature A.

Achievements

All field tests, experiments and analysis are completed earlier and only reporting remains in TRUE-1 Completion. However, the work within the project has lately been rather limited due to contributions of project members in other more prioritised SKB project. Accordingly, no new results or finalised reports were produced during the last four-month period.

3.3 Long Term Sorption Diffusion Experiment



Sample cores taken out from the over core: the fracture surface on the core stub (A1 – A18), the matrix rock surrounding the small diameter extension borehole (D1 – D16), control cores taken outside core stub (A19 – A21) and beyond the test section in the small diameter borehole (C1- C5).

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.

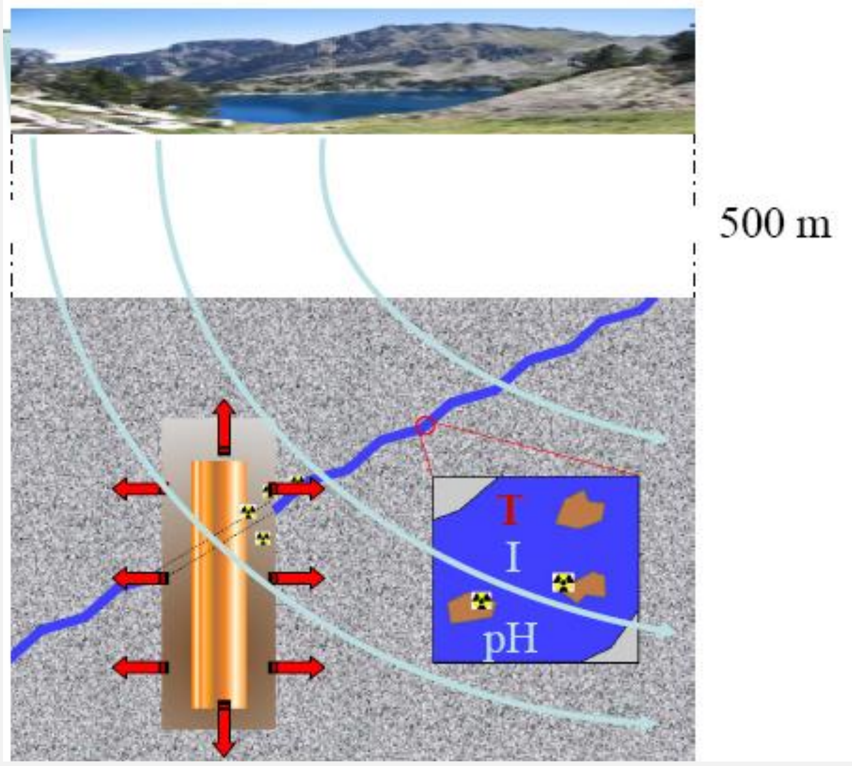
Achievements

The experimental parts of the project were completed in August and for the last months of the year all efforts were put on modelling, evaluation and reporting.

A general conclusion is that there is a good qualitative agreement of the results from the in-situ experiment to the behaviour of the tracers predicted from the laboratory programme and also to the general knowledge of the tracer behaviour.

For the very weakly-sorbing and non-sorbing tracers (e.g., ^{22}Na and ^{36}Cl) very low concentrations of the tracers are found in the first slices closest to the rock/water boundary. The concentrations decrease comparatively slowly by depth into inner part of the rock. The moderately sorbing tracers (e.g., ^{137}Cs, ^{63}Ni and ^{133}Ba) are present in quite high concentration in the first slices and, for the most cases, decrease to a level three to four order of magnitudes lower than the surface concentration already after 3-4 slices, that is 3 – 6 mm depth. For the very strongly sorbing tracer, e.g., ^{153}Gd, activities can only be measured in the first slices. The results can therefore be regarded as confirmation of a combined sorption/diffusion process taking place in the rock which is dependent on the sorption parameters (diffusivity and sorption).The project is finalised in 2010; only review, approval and printing of the main reports are foreseen for 2011. One report is compiled for the laboratory batch sorption tests and sorption/diffusion tests with intact rock pieces from the experimental site /Widestrand et al. 2010a/. The reports dealing with the evaluation, modelling and reporting of the in-situ experiment water phase and rock samples are in their final stages /Widestrand et al. 2010b; Nilsson et al. 2010/.

3.4 Colloid Transport Project



Colloid transport of montmorillonite colloids with or without radionuclides attached.

The main goal for the 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 predicted in modelling.

In the beginning of the lifetime of a deep bedrock repository, the groundwater will be quite saline and montmorillonite as well as natural colloids are not stable. Therefore colloid transport can be neglected during this time period.

In the scenario of intrusion of dilute glacial meltwater the conditions for colloid stability can drastically change. Bentonite erosion may give conditions for transport away from the barrier giving loss of material leading to a decrease in the barrier functionality. Also, in the scenario of a leaking canister, strongly sorbed radionuclides to montmorillonite colloids may be transported out from the barrier. Even if the conditions are such that bentonite erosion is favourable, it is not necessarily so that the transport out from the barrier is fast. Retention mechanisms as physical filtration and sorption may significantly reduce the mobility of the colloids.

Achievements

During 2010, experiments and modelling were finalised and will be summarised in a final report that is now under preparation and will be finalised in a first draft in March 2011. The final report will include the experimental and modelling work from both the Colloid Dipole project 2005-2008 and Colloid Transport project 2008-2010. Articles will also be submitted to scientific papers for publication.

One doctoral thesis by Sandra Garcia Garcia was published during 2010 with a number of experimental studies performed in the two projects with the title *"Generation, stability and migration of montmorillonite colloids in aqueous systems"*/Garcia Garcia 2010/. The thesis includes studies of colloid sorption to fracture filling minerals and transport of latex and montmorillonite colloids through fracture filling minerals from

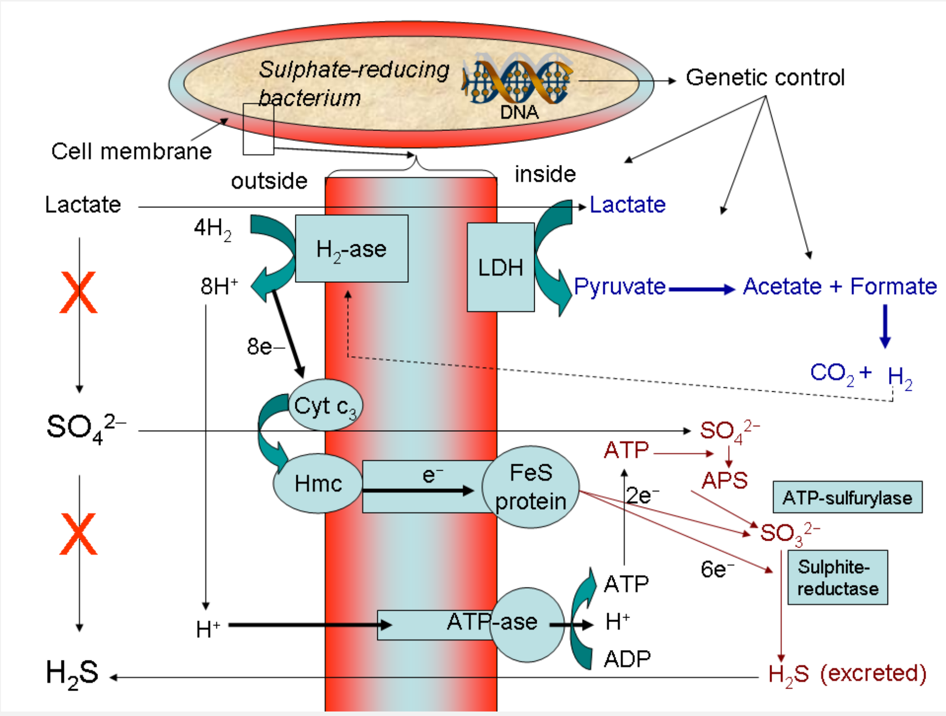
Äspö. The results are still not published but are finalised in a manuscript which is soon to be sent in to a scientific journal for publication. The colloid sorption to fracture minerals shows that attachment of colloids to the mineral surfaces is significant even in unfavourable conditions i.e. when both the colloids and the mineral surfaces are negatively charged. Minerals with the point of zero charge closer to the pH in which the experiments have been performed have a higher tendency to attract negatively charged colloids. Colloids with a less negative zeta-potential have a higher tendency to attach to the minerals. This is in accordance with the fact that the interaction is electrostatic. Transport experiments with latex and montmorillonite colloids in columns with the same minerals as used in the sorption experiments indicated that the retention in the system could be predicted by using the sorption data. Worth to notice was that the sorption experiments were performed in such a way that the colloids were stuck in the structure both by sorption and by physical hindrance in roughness on the mineral surfaces.

The stability of montmorillonite colloids in exposed γ-irradiation was shown to be more stable than their non irradiated counterparts. The effect has been further investigated, and one part of the explanation for the enhanced stability is the increasing Fe^{2+}/ Fe^{3+} ratio with irradiation giving a higher negative netto-charge increasing the colloid stability. Montmorillonite colloid transport experiments have been conducted in well characterised fractures in bore cores from Äspö. The colloids were not stable due to that the fracture surfaces were too fresh and Ca^{2+} induced aggregation and further sedimentation of the colloids. The ambition was to study actinide mobility in the presence of montmorillonite colloids, however, these experiments were not feasible due to the stability problems.

Modelling strategies for colloid transport and bentonite erosion in situ experiments to be performed at Grimsel in the CFM-project has been developed and the models are continuously being calibrated against experimental data.

3.5 Microbe Projects

The study of microbial processes in the laboratory gives valuable contributions to our knowledge about microbial processes in repository environments. However, the concepts suggested by laboratory studies need to be tested in a repository like environment. The reasons are several. Firstly, at repository depth, the hydrostatic pressure reaches close to 50 bars, a setting that is very difficult to reproduce in the microbiology laboratory. The high pressure will influence the 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 /Hallbeck and Pedersen 2008; Pedersen et al. 2008/. The university laboratory is best suited for pure cultures and therefore the effect from consortia of many participating species in natural ecosystems cannot easily be investigated there. The limitations of university laboratory investigations discussed above resulted in the construction and set-up of an underground laboratory in the Äspö HRL tunnel /Pedersen 2000/. The site was denoted the Microbe Laboratory and it was situated at the –450 m level in the F-tunnel.



Schematic illustration of the microbial sulphate reduction process on the scale of a single bacterium. Lactate will not react spontaneously with sulphate under the formation of sulphide. However, when sulphate reducing bacteria are present, lactate is oxidised by the bacteria, eventually to carbon dioxide and hydrogen. The hydrogen is then oxidised concomitant with the reduction of sulphur in sulphate to sulphide. This metabolic process is of great importance because sulphide is corrosive to copper canisters.

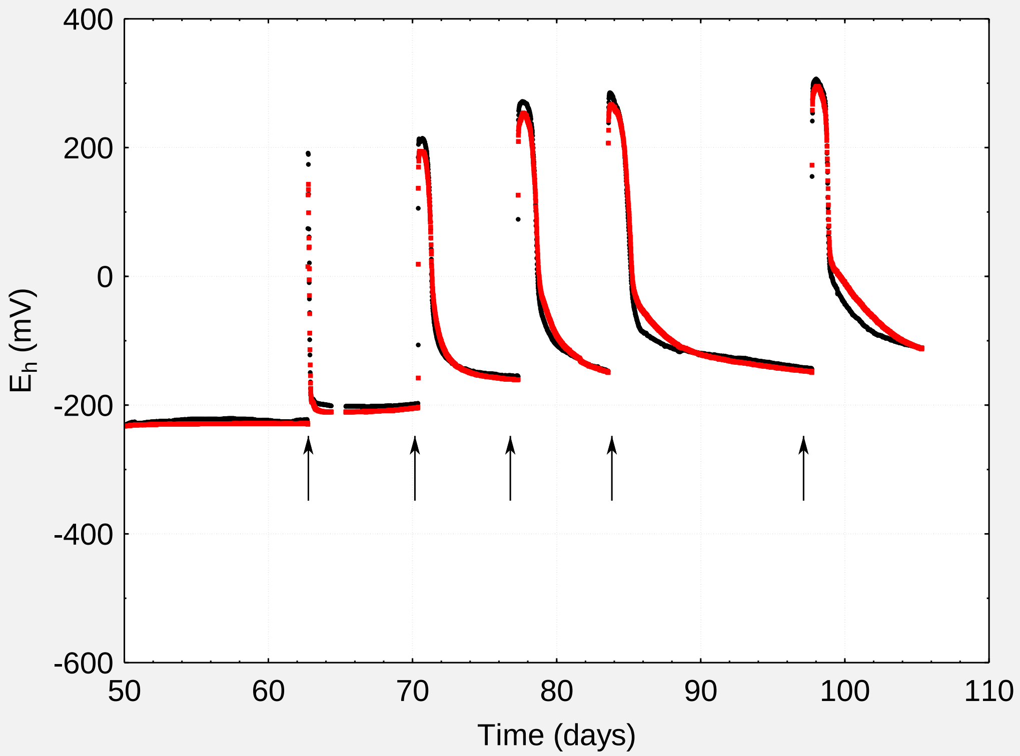
The Microbe Laboratory has been installed in the Äspö HRL for studies of microbial processes such as sulphate reduction to sulphide in groundwater under in situ conditions.

The Microbe site was situated on the -450 m level where a laboratory container with benches, an anaerobic gas box and an advanced climate control system was located. Three core drilled holes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures were connected to the Microbe Laboratory via tubing. The laboratory was equipped with six circulation systems, each could offer a total of 2,112 cm^2 of test surface in each circulation flow cell set up (four flow cells) for biofilm formation at in situ pressure, temperature and chemistry conditions. Alternatively, they could be equipped with a total of 450 g (per four flow cells) crushed rock material in the size fraction 3-4 mm. Three systems were metal free and three systems were made of stainless steel.

The major objectives were 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.

Three specific microbial process areas of importance for proper repository functions were selected to be studied at the Microbe Laboratory within separate projects. They were: Microbial effects on the chemical stability, including the redox potential of deep groundwater environments (Micored) and bio-mobilisation of radionuclides (Micomig). The Microbe projects have been executed in series for a total of 11 years since drilling of the Microbe boreholes during 1999 until the end of 2010. At present, there is no planned continuation.

3.5.1 Micored



The redox potential (mV) was analysed with two parallel electrodes (black and red) in a circulating system in the Microbe Laboratory that was spiked with 1 mM hydrogen gas. After 65 days of microbial growth, pulses of about 0.5 mM oxygen gas was introduced (arrows). The redox potential was strongly influenced by the oxygen for a short period of time, but was soon recovered by microbial processes.

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.

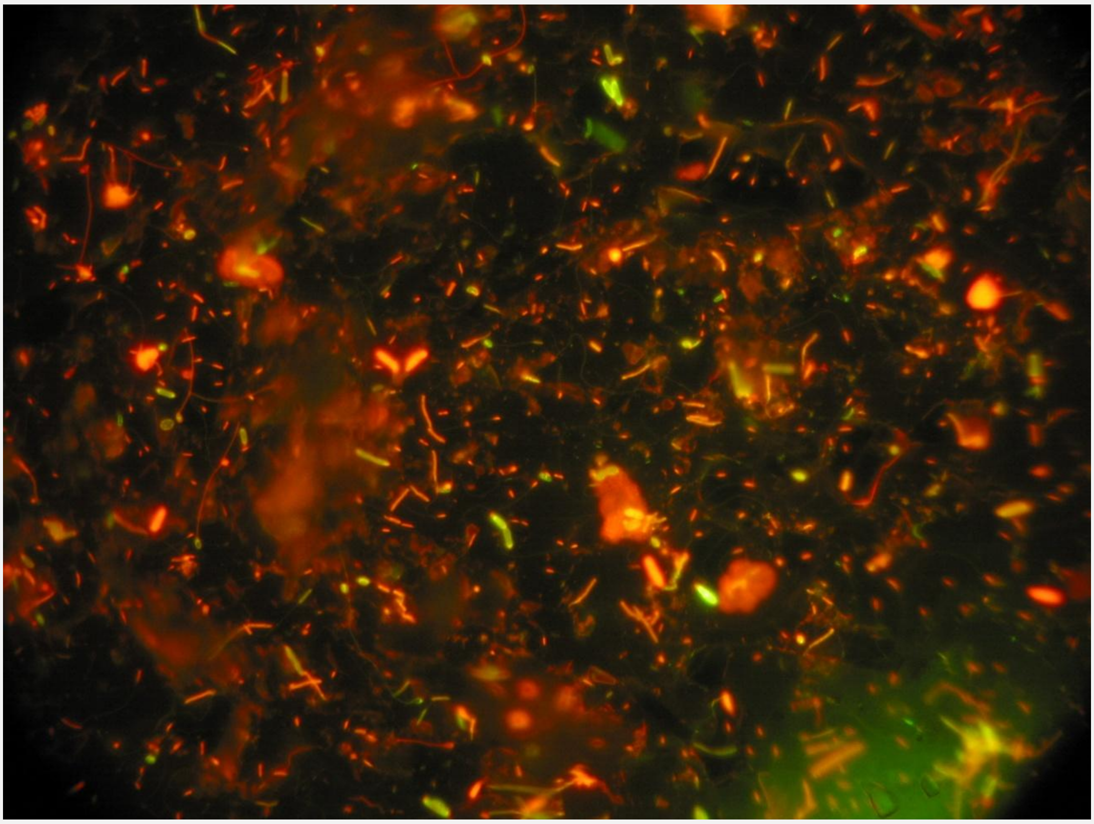
It was hypothesised that hydrogen from deep geological processes contributes to the redox stability of deep groundwater via microbial turnover of this gas. Hydrogen, and possibly also carbon monoxide and methane energy metabolisms will generate secondary metabolites such as ferrous iron, sulphide, acetate and complex organic carbon compounds. These species buffer towards a low redox potential and will help to reduce possibly introduced oxygen.

The major objectives were:
Clarify the contribution from microorganisms to stable and low redox potentials in near-and far-field 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

The experimental field-work was finalised in July 2010. Thereafter, laboratory analyses were performed for several months. During the last four months evaluation, compilation and delivery of data to Sicada have been performed. Modelling and publication of the results will follow during 2011.

3.5.2 Micomig



Microorganisms attach to surfaces in water systems. A polished granitic rock surface was exposed to flowing groundwater in one of the Microbe circulating systems and microorganisms attached and developed biofilms on the rock surface. The microorganisms are visible as orange long and short rods on the surface.

It is well known that 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. Research at the Microbe site indicated that these surfaces adsorb radionuclides.

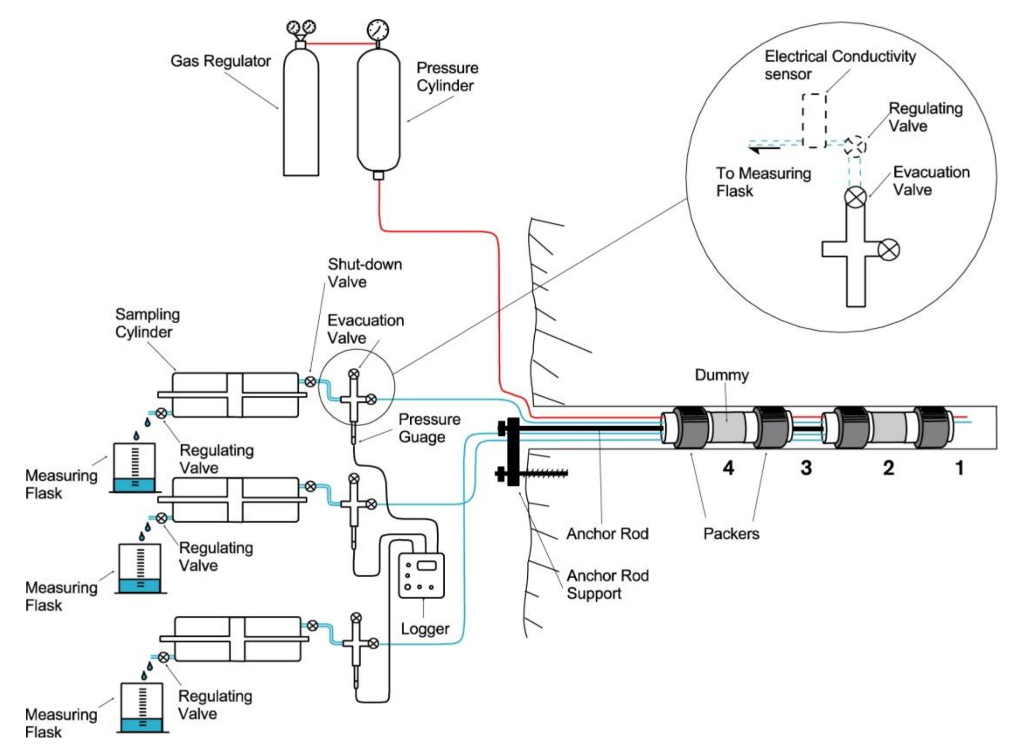
The major objectives were:

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

Achievements

The study of biofilms on rock surfaces in the Microbe Laboratory suggested that the rock surface could be isolated from the groundwater by such biofilms /Anderson et al. 2007/. This possible suppression of radionuclide adsorption by biofilms motivated further research. The analysis of fracture surfaces obtained during drilling at 1,362 m tunnel length in the Äspö tunnel showed that microbial biofilms form also on natural fracture surfaces, making effects from biofilms on radionuclides more likely. This work is now published on-line /Jägevall et al. 2010/.

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.

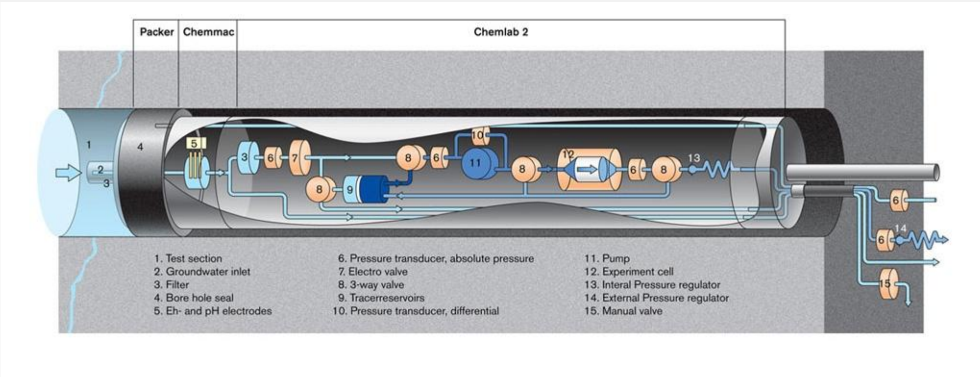
Achievements

No work has been performed within the project during 2010. The planning for 2011 is depending on other priorities, a final integrated report in the SKB technical series will be produced combining all unpublished data.

3.7 Radionuclide Retention Experiments

Most of the Radionuclide Retention Experiments that have been and are planned to be carried out, have 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 performed in two different unique borehole laboratories, Chemlab 1 and Chemlab 2. The Chemlab probes contain a number of valves, pumps, fraction collectors, etc., all to make it possible to perform a set of different experiments.

3.7.1 Spent Fuel Leaching



Principal drawing of Chemlab 2.

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 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

Due to priorities within SKB the project has been severely delayed and hence no longer considered relevant. The project was formally finalised during 2010 and no further work will be carried out.

3.7.2 Transport Resistance at the Buffer-Rock Interface

The expansion of bentonite into an artificial fracture.

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% while the diffusion resistance in the small cross section area of the fracture in the rock is estimated to 94%. The aim of the project is to perform studies to verify the magnitude of these resistances.

Achievements

Due to priorities within SKB the project has been severely delayed. Recently some simple scoping experiment were performed in a variable aperture slit that has been made by pressing two glass sheets with uneven surfaces together. A dye is allowed to diffuse upward in the slit. The progression of the diffusion is followed by taking pictures at regular intervals. A light box (Microlight) is placed behind the slit to ensure even and constant lightning conditions. A calibration slit is placed next to the variable aperture slit. The calibration slit is filled with dye of the same concentration as in the variable aperture slit chamber. The calibration slit has 0 mm aperture at the bottom and 1.00 mm at 100 mm height. By comparing the light transmission in the calibration slit with the same in the variable aperture slit (completely filled with dye) the variable aperture between the uneven glass sheets can be determined.

Figure 3-3 shows the equipment at the end of the introductory experiment. Visual inspection of the equipment during and after the introductory experiment showed that air bubbles had formed inside the variable aperture slit. This is due to leakage of air into the equipment.

The topography of the variable slit was determined by analysing a picture of the variable slit completely filled with dye and of the calibration slit using Matlab. A calibration curve for transmissivities versus colour intensity was generated. The topography of the variable slit used in the scoping experiment is showed in Figure 3-4.

A program was also written in Matlab to be able to follow the progress of the diffusion profile by time. The evaluation of the introductory experiment showed that the dye chamber needs to be enlarged.

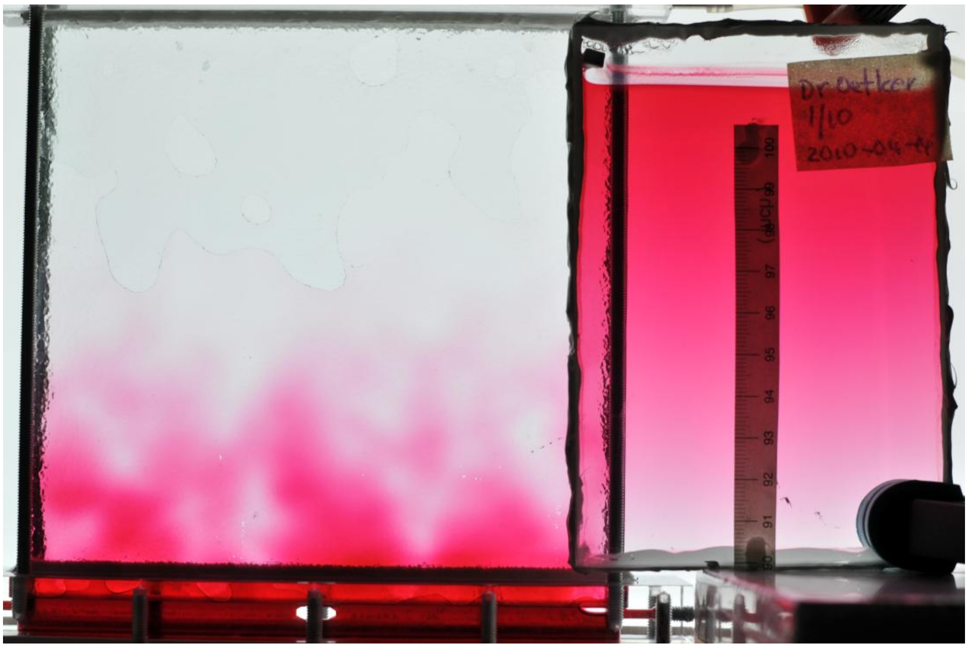


Figure 3-3 *Picture of the variable slit at the end of the experiment (after 60 days).*

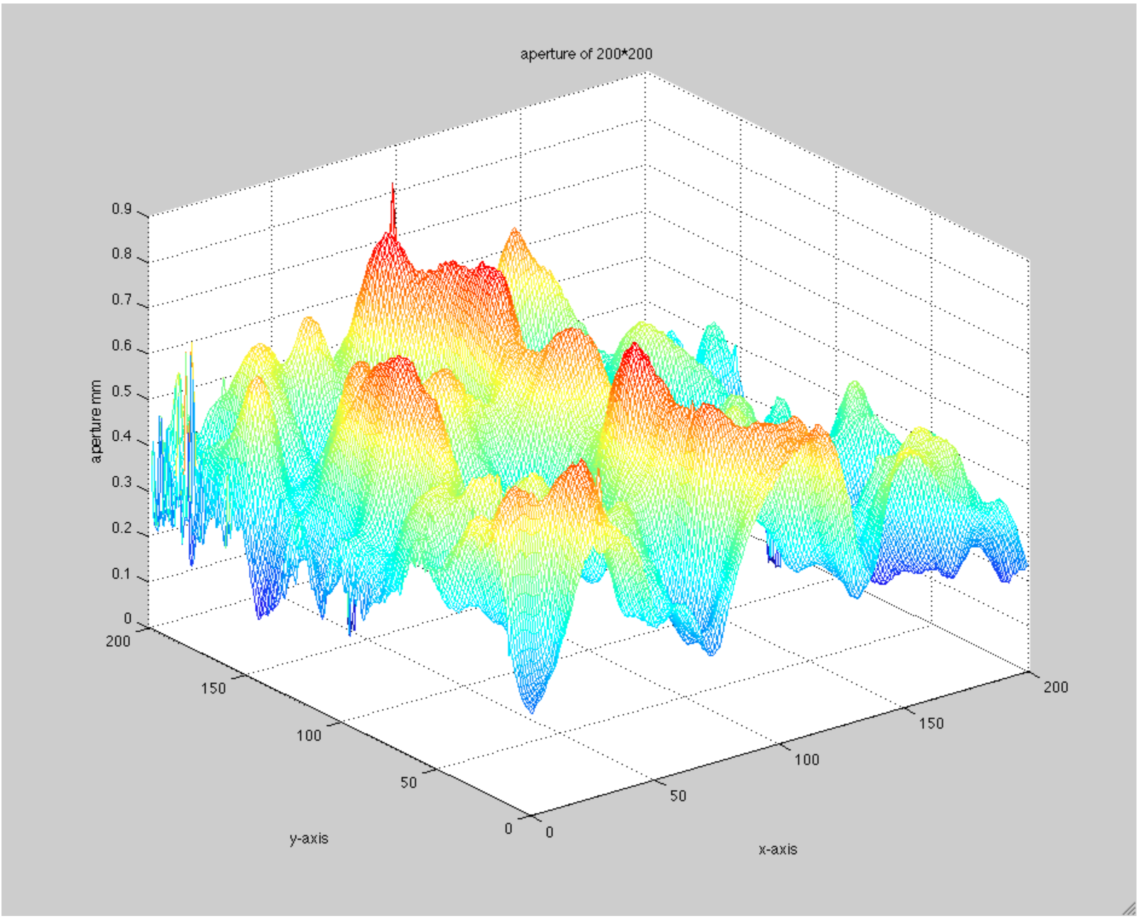
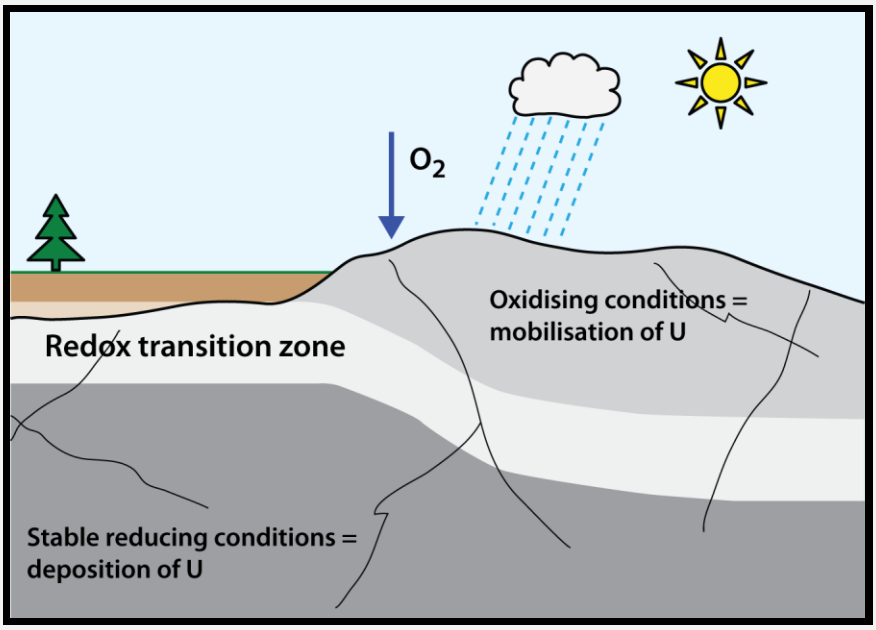


Figure 3-4 *Topography of the variable slit.*

3.8 Padamot



Oxygen entering the bedrock via recharge water will be consumed by organic and inorganic processes along the bedrock fractures. This transition can be detected by studies of uranium and uranium isotopes.

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:

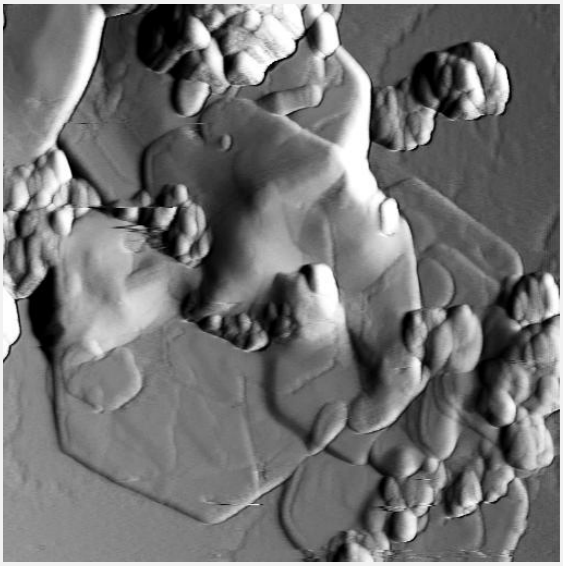
- Further developments of analytical techniques for uranium series analyses applied on fracture mineral samples and inter-laboratory comparisons.
- The use of these analyses for determination of the redox conditions during glacial and postglacial time.
- A summary of the experiences from the palaeohydrogeological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

There has been no real activity within the project during 2010. Nevertheless the methodology suggested within Padamot for detection of the redox fronts has been tested on the Greenland drillcores as part of the Greenland Analogue Project (GAP) project. The results indicate so far, on mineralogical and geochemical grounds that the redox front is situated well within the upper 100 meters of the bedrock also in these near ice cover conditions. Uranium series analyses are in the status of being processed.

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.

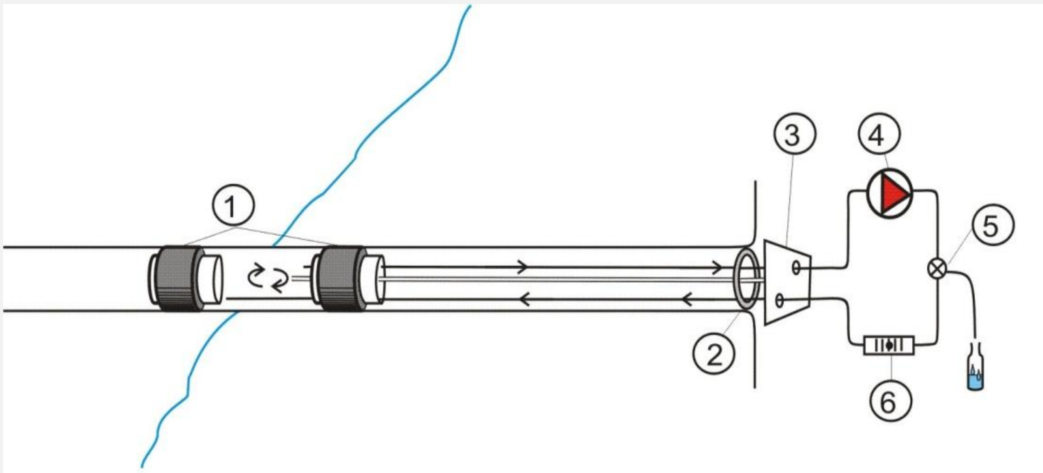
The basic idea of the project is to examine Fe-oxide fracture linings, in order to explore for suitable palaeo-indicators for their formation conditions, while at the same time learning about the behaviour of trace component uptake in general, both from the natural material as well as through testing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

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

Achievements

No work has been performed within the project during 2010. A final integrated technical report will be produced combining all unpublished data and all the published international progress reports.

3.10 Investigation of Sulphide Production Processes in Groundwater



A schematic picture illustrating circulation of groundwater in a packed-off borehole section. The circulation pump and flow meter are located outside the borehole. The distance between casing and investigated section is about 30 meters.

The aim of this project is to study the processes behind microbial sulphide production and the regulating factors for dissolved sulphide. This includes investigations on whether bacteria can use some carbon based components in equipment materials and additives as a source of energy in the process of reducing sulphate to sulphide. The overall aim is to be able to predict the expected variability of the sulphide concentration in a repository environment.

The conceptual idea is to follow the production of sulphide in an isolated borehole section. A suitable place for conducting the experiment is Äspö HRL, since the location underground facilitates sampling of dissolved gas, which is an important factor to study in connection to sulphide production.

A circulation system for study of sulphide production processes in a packed-off borehole section was assembled (see figure above).

The section water is circulated under maintained pressure using a circulation pump located outside the borehole. Tubing ending at the two ends of the section enables circulation / mixing of water before small volumes of water samples are collected and analysed as time-series.

The analytical programme includes sulphide and other chemical compounds, microorganisms and dissolved gases. In addition, analyses of stable isotopes in water and gases are performed in order to determine reaction pathways and origin of reactants and products.

The first stage of the experiment was completed in June 2010. This part of the investigation was aiming to evaluate the experimental concept and to follow the concentration of sulphide and parameters related to sulphide production over time.

Achievements

The experimental part of the project focused on the sampling and analysis of stable isotopes in order to gain information on the reaction pathways for bacterial production of sulphide. In this context, efforts were put on performing adequate sampling of dissolved gaseous compounds. Results from previous experiments were evaluated and suggest that each borehole section has its own specific concentration of sulphide and most likely also bacterial composition and that production and consumption of components related to sulphide production (such as acetate and hydrogen) are at a steady-state. For these reasons the project has recognised the importance of determining the natural flow of water and transport of dissolved components from fractures to the borehole sections in time periods between pumping.

Analysis data from the first experimental part was continuously evaluated in order to give important information for planning of the second part of the investigation. Preliminary results suggest that:

- The concentrations of sulphide and sulphate reducing bacteria increase with time (to a certain extent) when water in a packed-off section is circulated and small volumes of water are collected for analyses.
- Discharge of water from the section (increased water volume from the fractures) results in a decrease in sulphide concentration and sulphate reducing bacteria.
- Each packed-off section has its own specific sulphide concentration and possibly also composition of bacteria.
- The concentrations of acetate and other dissolved organic carbon constituents and dissolved gaseous compounds are more or less constant with time, which may indicate a steady-state situation with respect to production and consumption of components.

The second part of the experimental work was planned and initiated. The experiment was designed to collect and analyse stable isotopes (δ^2H, $\delta^{13}C$ and $\delta^{18}O$) in dissolved gaseous compounds (hydrogen, methane, carbon dioxide) and in carbonate, sulphide and sulphate. Stable isotopes will be analysed and used to determine reaction pathways, reactants and products.

3.11 Swiw-tests with Synthetic Groundwater

Preparation of the synthetic groundwater for the Swiw main tests.

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 project is to increase the understanding of the dominating retention processes by means of Swiw tests with synthetic groundwater. More specifically, the objective is to establish if fast or slow diffusion processes, i.e. diffusion from stagnant zones or matrix, dominates in the studied scale.

The basic idea is to perform Swiw tests with synthetic groundwater similar to the natural water at the site but with chloride, sodium and calcium replaced by nitrate, lithium and magnesium. Sorbing as well as non-sorbing tracers will 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 are 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.

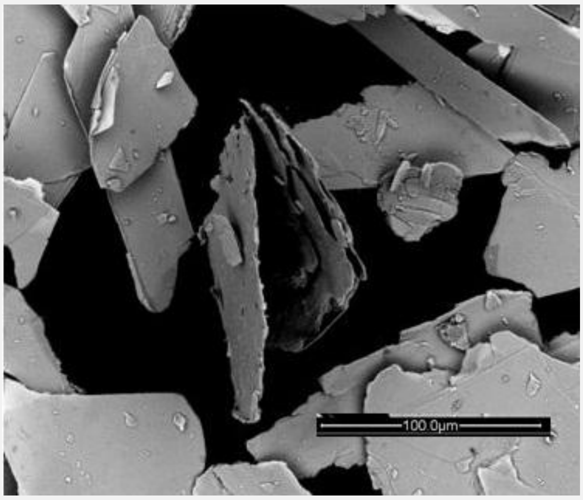
Achievements

Based on the results from the first two Swiw pre-tests, performed without waiting period and with a 48 hour waiting period, it was concluded that it would be beneficial and probably also possible to use a longer waiting period. Accordingly, a third Swiw pre-test with a 91 hour waiting period was carried out with a similar result as in the two first Swiw pre-tests. Based on the results from the three successful Swiw pre-tests it was decided that the Swiw main tests with synthetic groundwater should be carried out without a waiting period in the first test and with a long (about 96 hour) waiting period in the second test. It was also decided that a larger injection volume should be used in the main tests compared to the pre-tests.

Both the first and second main tests with synthetic groundwater were carried out during the period and all field tests within the project are thereby completed. The main tests were performed without any major complications considered to affect the end result. However, no final results in terms of breakthrough curves are presently available.

3.12 Äspö Model for Radionuclide Sorption

A (25x15 x1 cm) chunk of the biotite sample used in the experiments.



The 75-125 µm size fraction of biotite as observed with SEM (Scanning Electron Microscopy).

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

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 possible localised 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. The ambition is to include experimental data for specific surface area and sorption capacity for each of the mineral phases that constitutes granitic rock into the model.

Achievements

During the period September to December 2010, determinations of specific surface areas of selected particle size fractions of mineral specimens of magnetite, chlorite, K-feldspar and biotite have been continued using the BET-method. For selected samples also the porosity has been analysed, in terms of pore volume and pore size. For all mineral samples analysed, the obtained pore size from this preliminary assessment fell within the range 100-300 Å for most of the particle sizes analysed. As exemplified in Figure 3-5, there was in most cases no clear dependence of the pore size on the particle size. The specific pore volume, however, generally decreased with increasing particle size, see Figure 3-6. Moreover, there was a correlation between the analysed specific surface area and the specific pore volume, see Figure 3-7. Currently, the analytical results are further examined and verified.

The chemical compositions of the mineral samples used in the experiments have been determined. For chlorite and biotite, which are iron containing minerals with presence of both ferrous and ferric iron, the distribution between the oxidation states have been determined by Mössbauer analysis. This analysis revealed a considerable content of magnetite as an impurity in the chlorite sample that likely needs to be addressed before use of the sample in sorption experiments. The purities of all mineral specimens have also been addressed with XRD (X-ray powder diffraction). Analytical results are presently being evaluated.

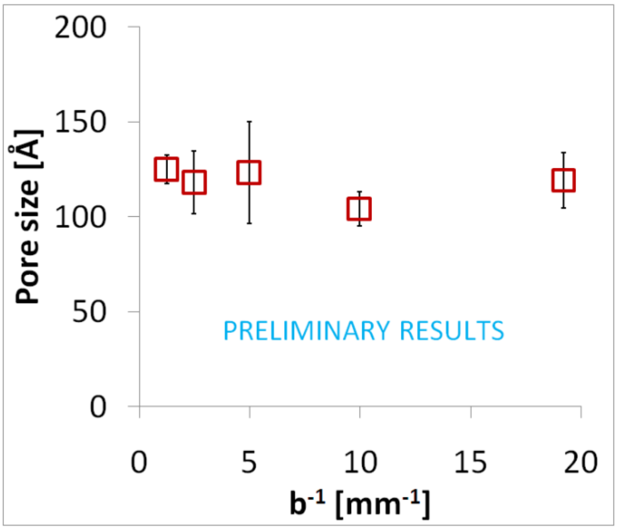


Figure 3-5 Pore size as function of the inverse of the representative particle size for biotite. Error bars indicate one standard deviation from triplicate analyses.

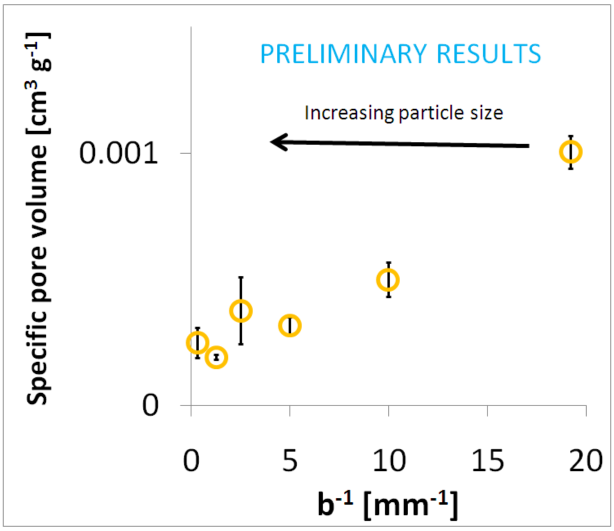


Figure 3-6 Specific pore volume vs. the inverse of the representative particle size for K-feldspar. Error bars indicate one standard deviation from triplicate analyses.

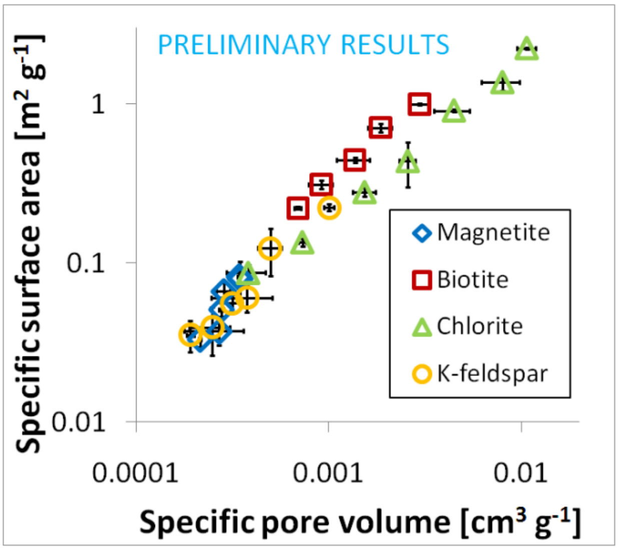


Figure 3-7 Specific surface area vs. specific pore volume as analysed by N_2 gas absorption for particles of various sizes of the minerals magnetite, biotite, chlorite, and K-feldspar. N.B. logarithmic scales.

During the last third of 2010, selected particle size fractions of the various mineral samples have been investigated with scanning electron microscopy, as a continuation of the previous preliminary examinations. These investigations aimed at identifying potential presence of adhering fine particles on the mineral surfaces and to get an idea of the surface roughness of the samples at different scales. They also aimed at establishing gross particle form and potential mineral contaminations. The particle form is expected to affect the dependence of specific surface area on the particle size and thus is needed for the detailed interpretation of previously obtained specific surface areas of biotite, chlorite, magnetite, K-feldspar, plagioclase, apatite, and hornblende specimens. Figure 3-8 shows results for labradorite as an example. Figure 3-8a shows the dominantly parallelepiped form of the particles, allowing one dimension of the particle to be larger than the cut-off sieve size used to delimit the particle size fraction (indicated as broken squares in the figure). Figure 3-8b shows that the particle, although having a gross form of a parallelepiped, is edgy with many geometric features. Further zooming shows that the actual surface is rough and that some fine particles adhere to the surface which is far from smooth, see Figure 3-8c. Finally, in Figure 3-8d the presence of surface roughness on the micrometer scale and the presence of fine particles of submicron size are shown.

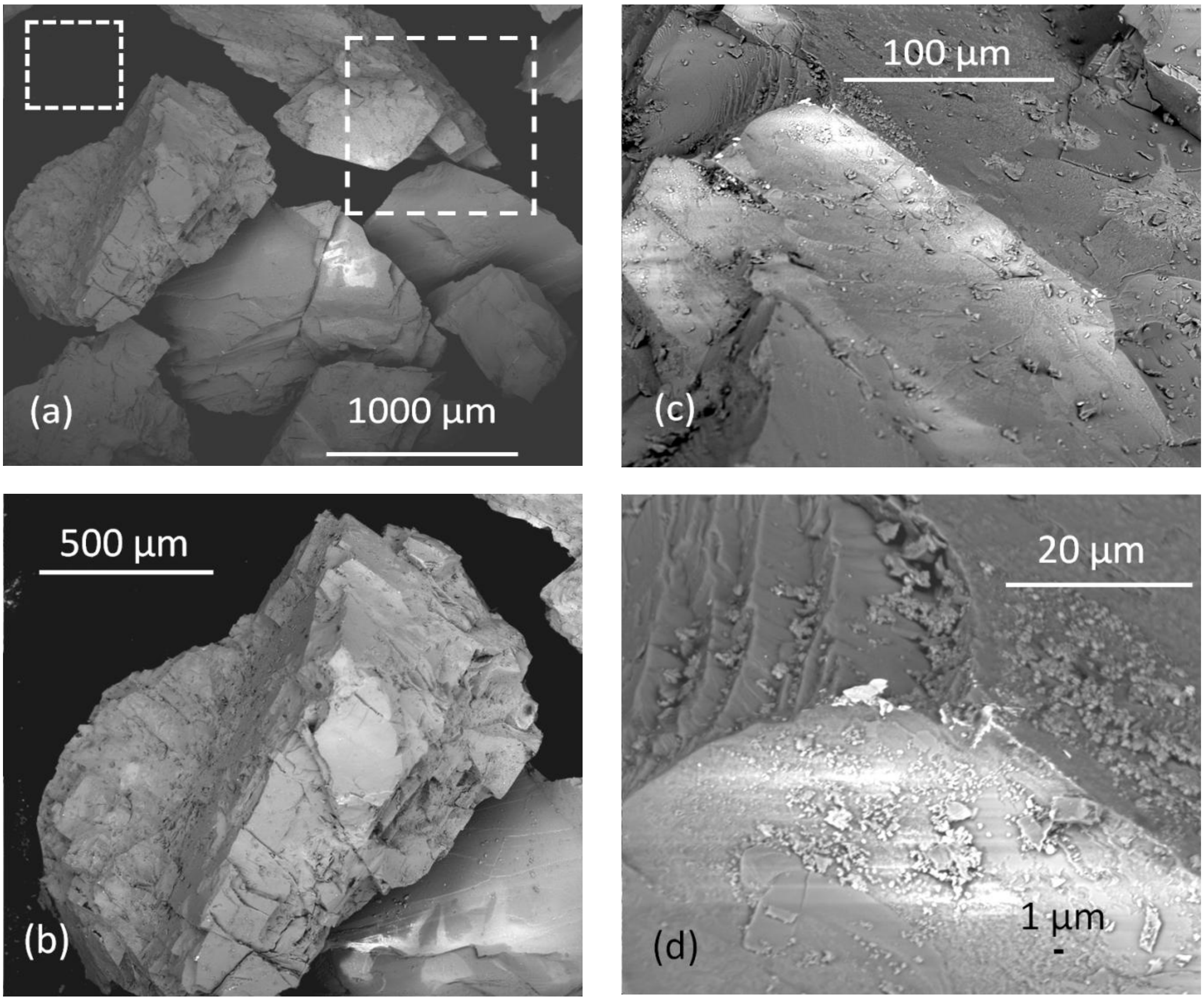
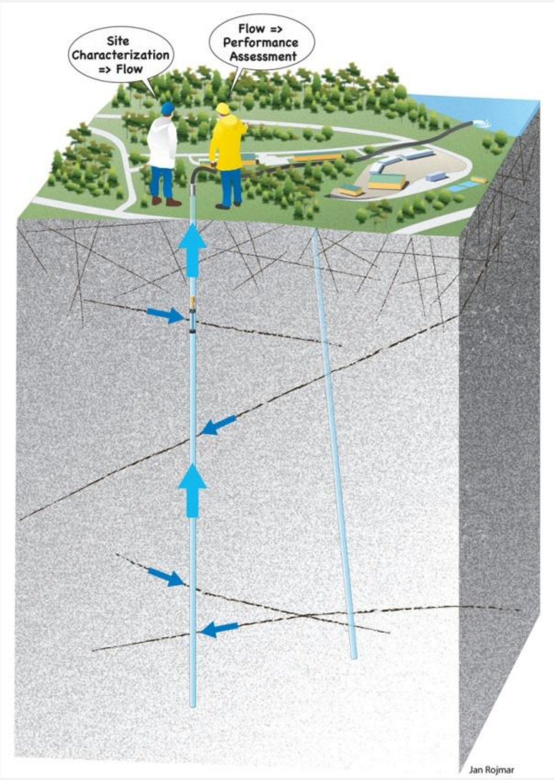


Figure 3-8 *Scanning electron microscopy images of labradorite from the size fraction 0.5-1.0 mm in different magnifications. The broken squares in (a) show the sieve sizes used to delimit the size fraction. N.B. Preliminary results.*

To gain further information on the particle size distribution within a particle fraction and the form of the particles, a few samples have been investigated with a particle analyser (PartAn 3001L and multi-imaging-software PartAn 3D). In this method, the particles are stroboscopically photographed while they fall. Comparisons of these data with information from SEM investigations are presently undertaken.

During the last third of 2010, one article /Dubois et al. 2010a/ has been accepted for publication in Radiochimica Acta and another /Dubois et al. 2010b/ has been printed in the proceedings of the 13th Water Rock Interaction conference.

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



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

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

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

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

Achievements

During the third four-month period of 2010, work has mainly been performed in Task 7 and Task 8. Task 7 is focusing on methods to quantify uncertainties in performance assessment (PA) type approaches based on site characterisation (CS) type information; along with being an opportunity to increase the understanding of the role of fracture zones as boundary conditions for the fracture network and how compartmentalisation influence the groundwater system. The possibilities to extract more information from interference tests will also be addressed.

Task 8 is a joint effort with the Task Force on Engineered Barriers, and will therefore be addressing the processes at the interface between the rock and the bentonite in deposition holes. The performed work in Task 8 includes planning, administration, task definitions, and scoping calculations. An updated task description has been sent out to the modellers during the fall.

A workshop on Task 7 and 8 was held in Lund in December. Updated results on both modelling tasks were presented. The modelling of Task 7 is near completion, and the remaining work contains reporting, submittal of papers and review. Preliminary results of the Brie (Buffer-rock interaction experiment), which is coupled to Task 8, were presented at the meeting.

In summary, the description and the status of the specific modelling sub-tasks within Task 7 and 8 are given in Table 3-1.

Table 3-1 Descriptions and status (within brackets) of the specific modelling sub-tasks in Task 7 and 8.

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 International technical documents).
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. (Final results presented at the 26^{th} Task Force meeting).
7C	Here focus is on deposition hole scale issues, resolving geomechanics, buffers and hydraulic views of fractures. (Updated results presented at Task 7 and 8 Workshop in December).
8	**Interaction between engineered and natural barriers**
8A	Initial scoping calculation (Results presented at the 26^{th} Task Force meeting)
8B	Scoping calculation (Updated results presented at Task 7 and 8 Workshop in December)

4 Engineered barriers

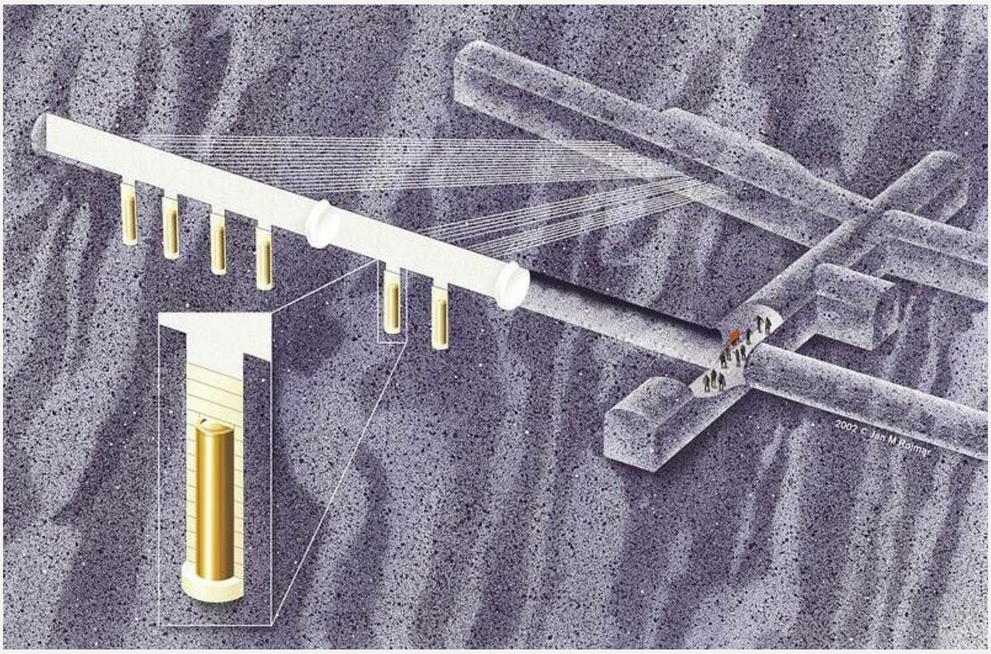
4.1 General

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 example in 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 *The lifting of the lower heather in the excavation of the Temperature Buffer Test.*

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. The surface between the rock and the outer plug was grouted in October 2004 and the drainage of the tunnel was closed at the beginning of November.

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. 23 covering the period up to May 2010 has been published in January /Goudarzi and Johannesson 2010/.

Acoustic Emission and Ultrasonic monitoring from the rock around deposition hole 5 and 6 is continuing. A report covering the measuring period October 2009 to March 2010 has been finalised and will be published.

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) was made at the end of 2009 in order to estimate the transmissivities of the rock around the Prototype Repository and the results from the tests will be published.

The third tracer dilution campaign during the Prototype Repository operation period was performed in January 2010. The purpose was to estimate the groundwater flows and hydraulic gradients in the vicinity of the boreholes and will function as a reference for comparison with results from modelling and prior assumptions. The report has been finalised /Harrström and Andersson 2010/.

The Prototype Repository is now subject for a new assignment for the members in the Task Force on Engineered Barrier Systems. The main goals of the assignment are a prediction of the state of the outer section of the Prototype Repository (mainly in the buffer in the deposition holes) and capturing the THM processes during operation. Since the outer section (which contains deposition holes 5 and 6) will be opened and retrieved during 2011, the modelling is focused to this section. Hole 6 is most heavily equipped with sensors (canister displacements, suction in rock), which makes it most suitable to begin with.

Three sub-assignments have been designed:

- Modelling of the water inflow in the repository before installation.
- Modelling of the thermal and hydraulic processes after installation (during the operational phase).
- Modelling of the THM-processes in the outer section (concentrating on hole 6) during the operational phase and predict the state at the excavation taking place during 2011.

The Retrieval of the Prototype Repository 2010-2013 is a co-operation project between SKB and Posiva Oy. The project plan comprises to plan and implement breaching of plug, backfilling and buffer of the outer section of the Prototype Repository. The breaching of the outer plug was initialized during November 2010. Opening of the outer section for the Prototype Repository is a substantial operation. No trial of this size has been made earlier with regard to removal of buffer and backfilling. Extensive examinations will be carried out.

A forecast of anticipated status prior to opening the Prototype Repository has been compiled and distributed as information to the Swedish Radiation Safety Authority (SSM).

Before breaching the plug, a number of reference measurements were performed:

- Estimation of the plug tightness and filter (geotextile) permeability.
- Measuring the corrosion rate of copper electrodes installed in deposition holes 1 and 5.
- Gas and microbiology sampling.
- Water sampling from the rock surrounding Prototype Repository.

Work with Activity plans for the extensive examination programme of backfill, buffer, sensors, canisters and bedrock has started.

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.

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 is 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 KBS-3 repository.

Schematic drawing of a test parcel.

Achievements

The three remaining heating tests have now been running for ten years (Table 4-1). The power has been close to 500 W in the two standard test parcels (T ~90°C) and close to 750 W in the adverse condition tests (T ~130°C). No significant problems are reported and a sufficient amount of sensors are still functioning.

General information on the project and the results from the A2 test in particular were presented at the bentonite workshop arranged by the Sapporo University, Japan in September. The report concerning the extra test parcel (A0) has been on expert review during the period and will be published in the near future.

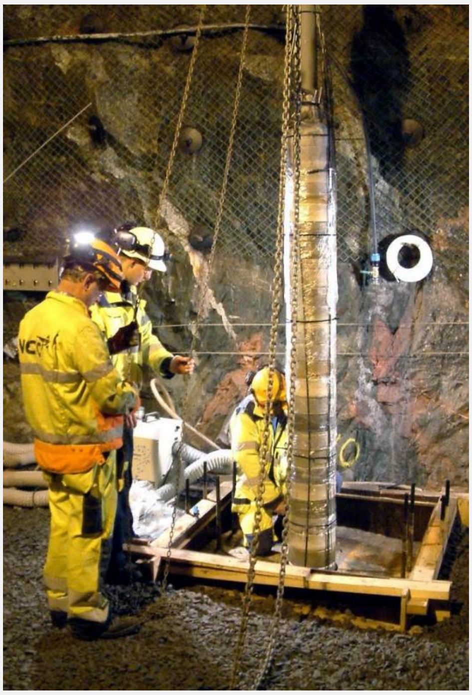
The heating of the three ongoing tests will continue during the next four month. At present, there is no plan for the uptake of the next test parcel. A project meeting is planned for in April.

Table 4-1. Buffer material test series.

Type	No.	max T	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	5	Reported
A	3	120-150	T	>>5	Ongoing
S	1	90	T	1	Reported
S	2	90	T	>5	Ongoing
S	3	90	T	>>5	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 test parcels. The photo illustrates the mixing of different compacted buffer blocks.

In the Alternative Buffer Material test, ABM, eleven buffer materials with different amount of swelling clay minerals, smectite counter ions and various accessory minerals are tested.

The test is performed in the rock at repository conditions except for the scale and the adverse conditions (the target temperature is set to 130°C). 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. Parallel to the field tests, laboratory analyses of the reference materials are going on.

The project is carried out using materials that are possible as future buffer candidate materials. The main objectives are to:

- Compare different buffer materials concerning mineral stability and physical properties, both in laboratory tests of the reference materials but also after exposure in field tests.
- Study the interaction between metallic iron and bentonite. This is possible since the central heaters are placed in tubes made of straight carbon steel.

Achievements

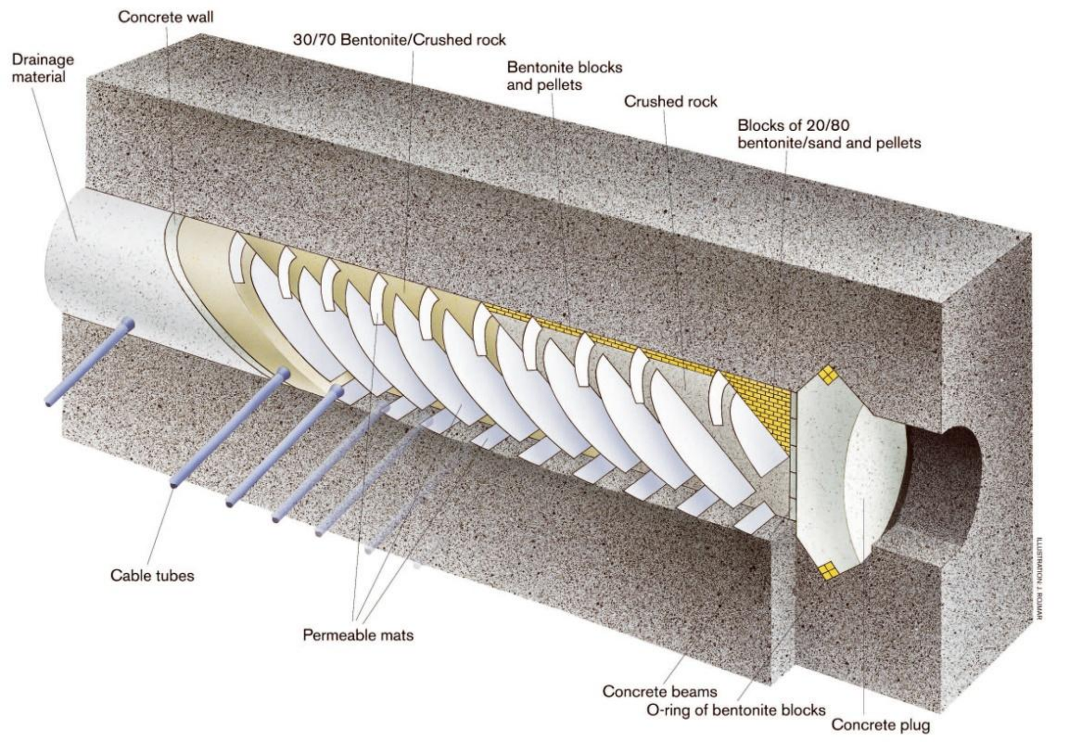
An investigation aiming to compare results from different laboratories regarding measurements of CEC (Cation Exchange Capacity) have been performed within the project. CEC gives important information about possible structural changes of clay minerals and geochemical changes in the buffer material. However, at the last project meeting, held in Lund (April 2010), the presentations regarding CEC measurements on the different ABM materials showed that there were rather large differences in CEC data between different laboratories also when the same materials were investigated. The laboratory investigation has been led by BGR, Germany, and five different laboratories have participated.

The analyses of the bentonite materials from parcel 1 (retrieved in May 2009) have continued. Some preliminary result from the laboratory analyses are:

- The degree of saturation was high in all positions of the test parcel (radial water content and density distribution has been determined in all blocks).
- Swelling pressure and hydraulic conductivity have been determined in some positions for the three materials of main interest for SKB. Compared to the reference material (MX-80), a slightly decrease in swelling pressure could be determined for the Deponit CAN and the Asha 505 material.
- The eleven installed bentonite materials origins from mines all over the word and had different smectite content, different overall cation content and also different distribution of interlayer cations. After 2.5 years in the test hole, determinations of CEC at several positions have shown that there has been an equalisation i.e. the cation distribution is almost the same for blocks positioned at the same level independent of material.
- X-ray Absorption Near Edge Structure (XANES) spectroscopy was performed at i811 at MAX-Lab, Lund. The clay blocks were sampled radial and preliminary results indicate higher FeII/FeIII 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 FeII-phase(s). These indicate that the FeII/FeIII ratio to some extent decrease with time.

Data from the field experiment (two test parcels are still installed) 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 and a draft will be ready in the beginning of 2011.

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.

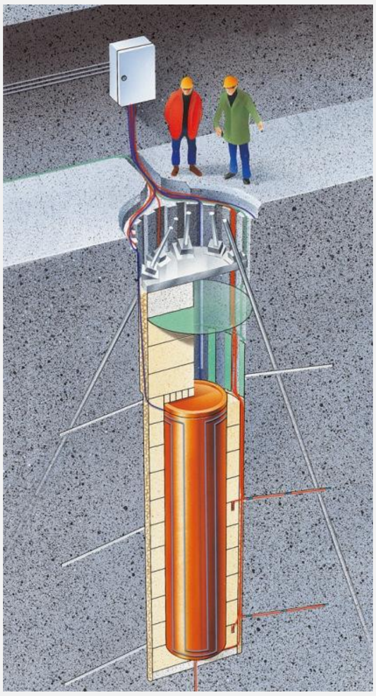
Achievements

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.

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

It has been decided to keep the project dormant for the coming years. The activities will be kept at a very low level, with continued data collection, maintenance of equipment, supervision of the test and reporting of measured water pressure, water flow and total pressure.

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

During the period the work concerning the buffer analysis article has proceeded and so has the work concerning the buffer analysis report. Also, the article manuscript "*Homogenization of engineered barriers, simulations verified against Canister Retrieval Test data*", to be published in the proceedings of *"Clays in Natural & Engineered Barriers for Radioactive Waste Confinement"*, Monday 29th of March to 1st of April 2010, Nantes (France), has been adjusted in the review process.

A report that describes the modelling of the Canister Retrieval Test in the Task Force on Engineered Barrier has been initiated.

4.7 Temperature Buffer Test

The French organisation Andra has carried out the Temperature Buffer Test (TBT) at Äspö HRL in co-operation with SKB. TBT aims at improving the understanding of the thermo-hydro-mechanical (THM) behaviour of clay buffers at temperatures around and above 100°C during the water saturation transient, in order to be able to model this behaviour. The test was installed during the spring of 2003, and was dismantled during the winter of 2009/2010.

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 was located in the same test area as the Canister Retrieval Test, which is in the main test area at the -420 m level. The experiment included two heaters in the axis of the deposition hole, one on top of the other, separated by a compacted bentonite block. The heaters were 3 m long and 610 mm in diameter and were constructed in carbon steel. Each one simulated 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 was applied in a slot between the buffer and rock, which was filled with sand and functioned as a filter.

Recorded data has been transferred by a link from Äspö to Andra's head office in Paris.

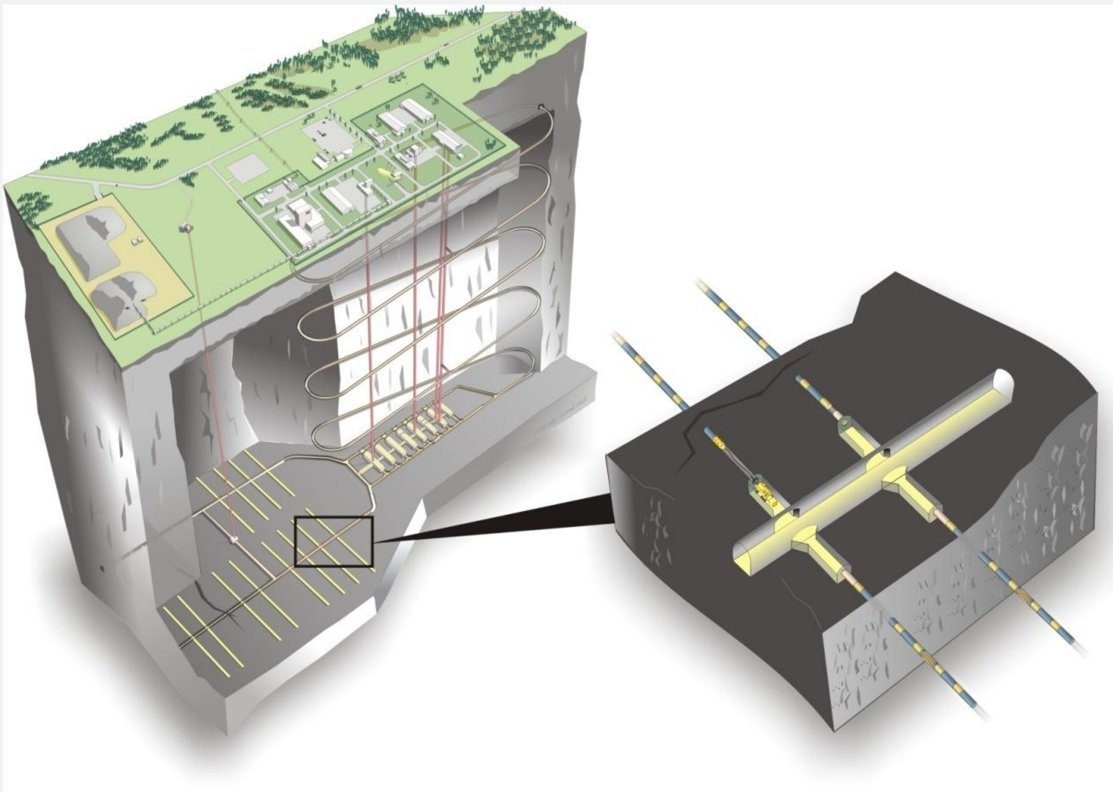
Achievements

The HM&C (Hydro-Mechanical and Chemical) characterisation programme has progressed and the THM modelling of the field test was resumed during the end of 2010 and will continue during 2011.

The following reports are now completed in draft form and ready for a review process:

- Temperature Buffer Test, Dismantling operation.
- Temperature Buffer Test, Measurements of water content and density of the excavated buffer material (report from the base characterisation programme).
- Temperature Buffer Test, Installation of buffer, heaters and instrument in the deposition hole (including appendices on the Heating system and As-built report).
- Temperature Buffer Test, Sensor data report No 13 (the last sensors data report including the reporting of the sensor function control).

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 is being 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. The current phase of the project; *"Complementary studies of horizontal emplacement KBS-3H"* is ongoing. 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

The compartment plug test continued during the last four month of 2010. The current test was initiated in January 2010 after the void behind the plug was filled with pellets. The original 30 day test has been prolonged with the aim to monitor long term behaviour. In the previous four-month period report it was stated that the pellets have sealed water bearing fractures and radically reduced the leakage into the rock. The recent data confirm this result and no reduction of the pellet sealing effect are indicated. Leakage through the plug has been stable at levels around 0.002 L/min, which is considerably less than the 0.1 L/min leakage acceptance criterion.

A high pressure test to break the plug was planned. The goal of the test was to collect data on the failure process of the compartment plug. The data could be useful for future design optimisation of the compartment plug as well as the new Drift End Compartment Plug. Before the test was initiated the pressure system in the compartment plug test malfunctioned. Due to this the pressure behind the plug was raised and deformed due to the high pressure. The compartment plug test is now terminated and the results compiled. The results will be presented in the report *"Summary of KBS-3H complementary studies phase 2008-2010"* (in preparation).

The project has been approved to continue with the next project phase during 2011 to 2014. During the first four month during 2011 the new project phase will be initiated, including detailed planning of new tests at Äspö HRL.

4.9 Large Scale Gas Injection Test

Panorama of the laboratory of the Large Scale Gas Injection Test (Lasgit) at -420 m level in Äspö HRL.

Current 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. During 2007 preliminary hydraulic and gas transport tests were performed. These were repeated in 2009, giving information on the maturation of the buffer in order to examine the temporal evolution of these properties. When the buffer is fully-hydrated a comprehensive series of gas injection tests will be undertaken to examine the mechanisms governing gas flow in bentonite.

Achievements

The last third of 2010 (September – December; Day 2038 – Day 2159) concentrated on the hydraulic constant head testing of an upper array filter in preparation for a gas test in 2011. Previous gas testing has been conducted in a canister filter on the lower array, namely filter FL903. The rationale for testing an upper filter is that this allows comparisons to be made for filter diameter, different stress and hydration state and position within the deposition hole.

The filter FL912 was selected as it has the largest contrast in filter diameter size compared with filter FL903. The hydraulic testing of this filter was started on day 2073, with pore pressure increased to 4.5 MPa. As seen in Figure 4-2 the increase in filter pressure of FU912 was mirrored by filter FU909. The system was quickly shut-off and the two filters were allowed to leak-off to background pressures. The rate of leakage was identical for both filters, even though they are different diameters. All data shows that the two filters were in direct communication. Short-circuiting by the calibration line or through the control board can be ruled out, suggesting that the communication is through the bentonite buffer. It should be noted that water pumped into the system was small, suggesting that the short-circuit is not through a large void.

It was decided to abandon filter FU912 and filter FU910 was selected instead. The diameter of filter FU910 (25 mm) is still smaller than FL903 (50 mm). Filter FU910 did not show any issues of communication with other filters. A hydraulic constant head test was successfully conducted in filter FU910 and was completed during December, see Figure 4-3. The form of the hydraulic data shows that filter FU910 has a lower hydraulic conductivity and lower specific storage compared to filter FL903.

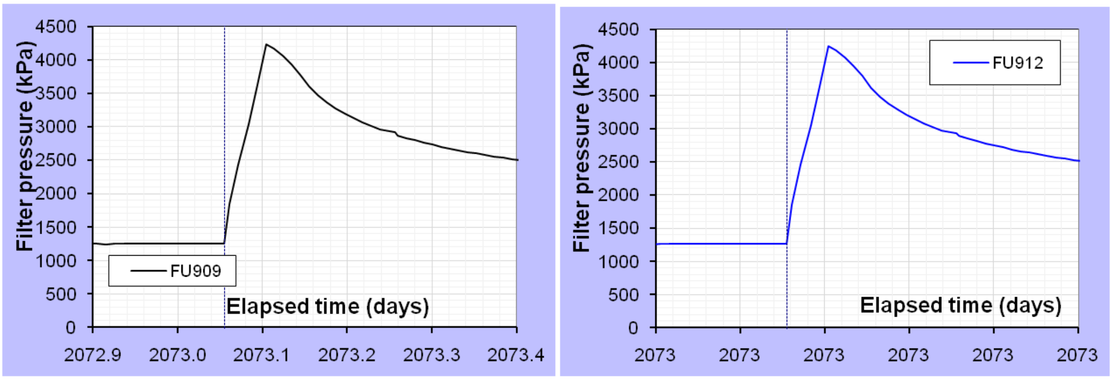


Figure 4-2 *Response for filter FU909 and FU912; the latter being pressurised.*

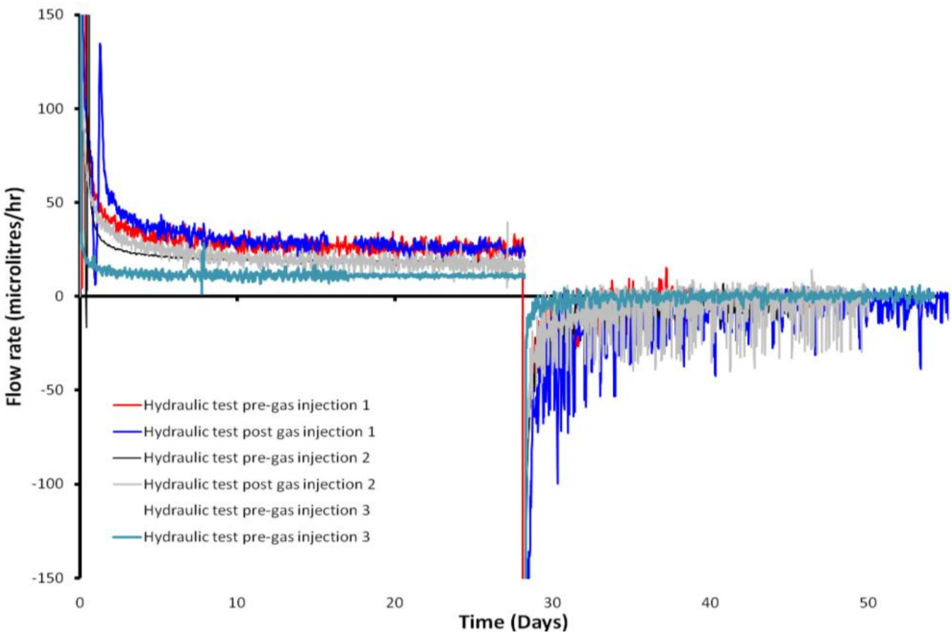


Figure 4-3 *The result for constant head tests conducted before and after the two gas injection tests conducted in filter FL903 and the hydraulic head test conducted before the gas test in filter FU910.*

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. In the sealing project at Äspö HRL a cement-based low-pH grout and a solution grout consisting of silica sol are used and evaluated. Newly developed understanding and design methods are taken into use and evaluated.

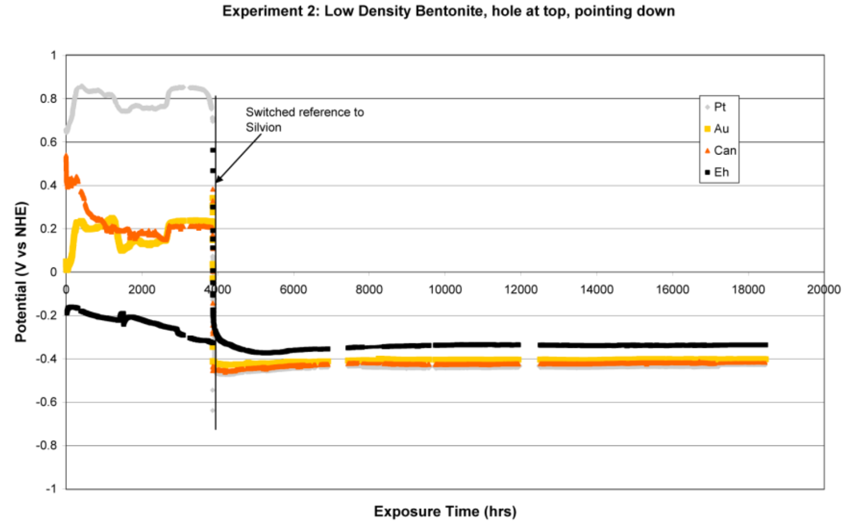
Another issue for the planned repository is the contour and status of the remaining rock after blasting. Drilling and blasting are given special attention and subsequent adjustments aim at successive improvements.

Achievements

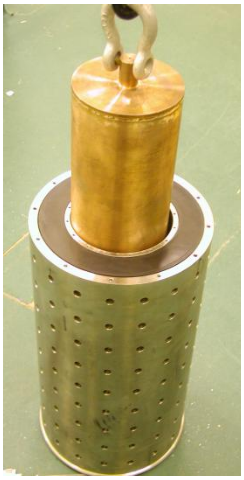
The inflow to the tunnel is being automatically monitored and a programme for mapping of inflows established. The monitoring and mapping is for the time being considered a priority task. Evaluation and reporting is almost completed and the project has provided ample data and further evaluation may be carried out in new projects.

All reporting will be completed during 2011.

4.11 In Situ Corrosion Testing of Miniature Canisters



Example of electrochemical potential data obtained from one miniature canister experiment.



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.

The boreholes have a diameter of 30 cm and a length of 5 m. All five canisters were installed in the beginning of 2007 in Äspö HRL.

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.

Achievements

During the reporting period, automated monitoring of the miniature canister experiments has continued. Data are being collected for the 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.

Data analysis has been performed and interpretation has been carried out where possible. The electrochemically measured corrosion rates for both iron and copper are higher than expected (using the LPR and AC impedance techniques), but it is not clear whether these are the results of experimental artefacts. The corrosion rates will be confirmed by dismantling one of the experiments and carefully analysing the material removed.

During the reporting period, chemical analyses together with microbial and gas analyses have been performed on all experiments. Results from the analyses are not yet obtained. Planning and preparation of equipment required for retrieval of experiment 3 have been conducted.

4.12 Cleaning and Sealing of Investigation Boreholes

Installation of a copper plug in a 200 mm borehole.

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 sub-projects:

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 earlier phases have indicated possible techniques for how borehole can be plugged. The work performed in Phase 4 has included characterisation of a number of investigation boreholes with respect to the frequency and nature of water-bearing and weak, fracture-rich zones, which provide difficulties in constructing borehole plugs.

Phase 4 has also comprised an attempt to model water flow along boreholes. This is done with the aim of estimating the risk of “short-circuiting” of plugged parts caused by hydraulic interaction of fractures that connect parts of the boreholes that are separated by tight plugs.

Plans for locating clay and concrete plugs, i.e. the two plug types intended to be used in practice, have been worked out for a number of reference boreholes at Forsmark, Laxemar and Äspö, and they form the basis of the technical/economical assessment that will be implemented.

Achievements

The project have indicated that a strategy implying very stringent principles for placement of clay and concrete plugs, according to hydraulic measurements and documentation of fracture frequencies in long holes, will lead to a very large number of plugs of different types. This would cause very long construction time and high cost. The principle to be followed is to identify those major, important fracture zones that should be hydraulically separated. The results from the conceptual modelling work will be presented in a final report.

The project times schedules have been delayed because of other SKB projects have been on a higher priority. Three reports have been sent for review and the results from the Phase 4 project will be presented in four different reports in 2011.

4.13 Concrete and Clay


Cylinders used for the experiments (left) and installation of cylinder in a selected hole (right).

Concrete and other cement based materials are important components in repositories for low- and intermediate level waste. Their mechanical and chemical properties make them suitable for the use both as a construction material in the repository as well as for the solidification of many different types of waste. Cement based materials are also known for their retention capabilities making them suitable as barrier materials to prevent the release of radionuclides

In the repository the cement will come in contact with the groundwater and the soluble compounds in the cement such as NaOH, KOH, $Ca(OH)_2$ and the CSH-gel will be dissolved. In the long term this will alter the chemical and physical properties of the cement but also the composition of the groundwater whose alkalinity will increase. In the repository, also the waste itself will react with compounds in the porewater and transform/decompose. For instance, the metals will corrode under anaerobic conditions forming solid or soluble corrosion products under the release of hydrogen gas whereas the organic waste can be expected to decompose into CO_2 and CH_4 as well as into other more complex molecules. Some of these are known to be very strong complexing agents that can enhance the transport of the radionuclides out of the repository.

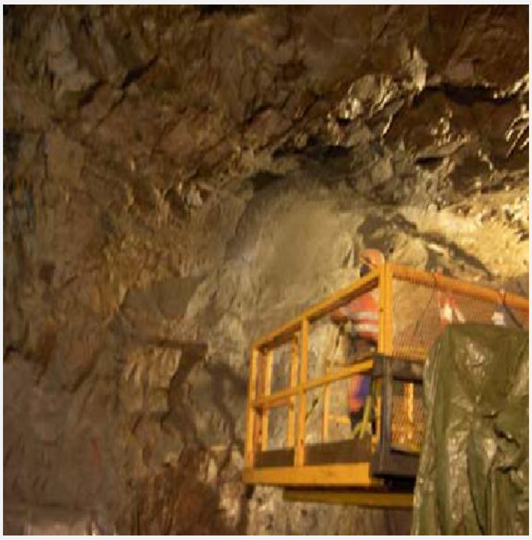
The aim of this project is to increase our understanding of the processes related to the degradation of low- and intermediate level waste in a cement matrix, the degradation of the cement itself through reactions with the groundwater and the interactions between the cement/ groundwater and adjacent materials such as bentonite and the surrounding host rock.

Achievements

During the former period the experiments in stage 1 of this project were prepared and deposited in the niche NASA0507A and during the last four month period of 2010 the planning of stage 2 of the project was initiated. This work included the planning of the drilling of investigation holes at the selected site (niche NASA2861A), as well as a preliminary selection of experiments for stage 2.

Depending on the results from the characterization programme, a choice of experiments for this site will be made. Once the experiments have been selected the site will be prepared and the concrete cylinders cast and deposited in the same manner as in stage 1. It is expected that stage 2 will be completed during spring 2011.

4.14 Low-pH Programme



Field test with low-pH shotcrete at Äspö HRL executed within the EC project ESDRED in 2006.

The purpose of this programme is to develop low-pH cementitious products that can be used in the final repository for spent nuclear fuel. These products would be used for sealing of fractures, grouting of rock bolts, rock support and concrete for plugs for the deposition tunnels.

SKB performed field test with low-pH grout for rock bolts at Äspö HRL in 2009. In total, 20 bolts have been installed. These bolts will be monitored and over-cored after 1, 2, 5 and 10 years for evaluation of the behaviour of the low-pH grout but also the corrosion of the rock bolts.

An international project for standardisation of pH measuring started mid 2008 as a joint project with the following participating organisations: SKB, Posiva, Nagra, Enresa, Numo and JAEA.

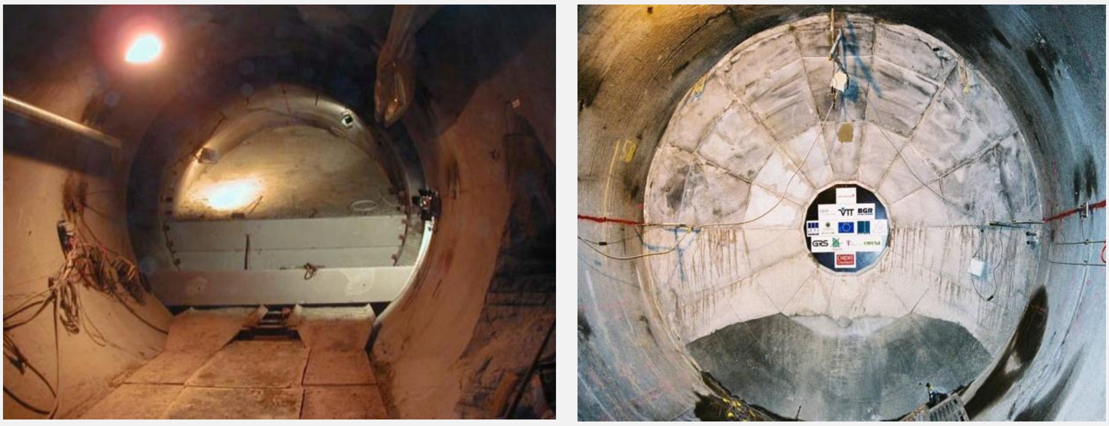
Achievements

The work during 2010 has mainly been focused on following up the activities from 2009 with the rock bolts and rock support. The design work of the plugs for the deposition tunnel has required additional investigations about material parameters of the low-pH concrete.

The main activity has been the preparation of an official report of the work performed during 2009. The report is expected to be ready in mid 2011.

The preparation for over-coring of the first set of rock bolts has been ongoing. The analysis of the results and reporting of this phase of the project has been ongoing up to the later part of 2010. The pH-project is expected to be finished during 2011.

4.15 Development of End Plugs for Deposition Tunnels



The plug installation for section I in the Prototype Repository

The development of end plugs for deposition tunnels has been an issue for SKB for several years. Two kinds of solutions have been investigated, vault plug and friction plug. To obtain as watertight a plug as possible, the choice for further development has been the vault plug. To improve the water-tightness, the concrete plug has in the reference design been complemented with a watertight seal and a filter, collecting water leaking from the backfilled deposition tunnel during the curing phase.

This principal solution is currently being evaluated and it is the analysed design that constitutes the reference design at this stage of development.

The detailed, as well as the principal solution, will be further developed before the construction of the final repository and deposition of encapsulated spent fuel commences.

Achievements

Different conceptual designs for the concrete plug have been evaluated and the choice for further design development will be a vault plug of low-pH concrete. The project is now in the final phase and the only remaining activity is to compile the complete results in a report in SKB series after which the project will be closed.

Documentation of the most appropriate plug-design, a number of design drawings and construction documents have been prepared. A sketch of the reference design is shown in Figure 4-4.

These results are now handed over to the new project *"System Design of Plug for deposition tunnels"*. This project will refine the design criteria and perform tests and modelling of the filter, bentonite sealing and drainage. In addition, the design will be adjusted to production-related conditions by further analysis of concrete behaviour and studies of the most appropriate way to make the rock excavation for a plug. The project will thereafter continue with a full-scale experimental installation in Äspö HRL at approximately -450 m depth (planned for 2012).

SKB has signed a Project Agreement with Posiva Oy for co-operation in the following development areas; requirements and methods for control, modelling of sealing, filter and drainage as well as rock excavation methods for plugs.

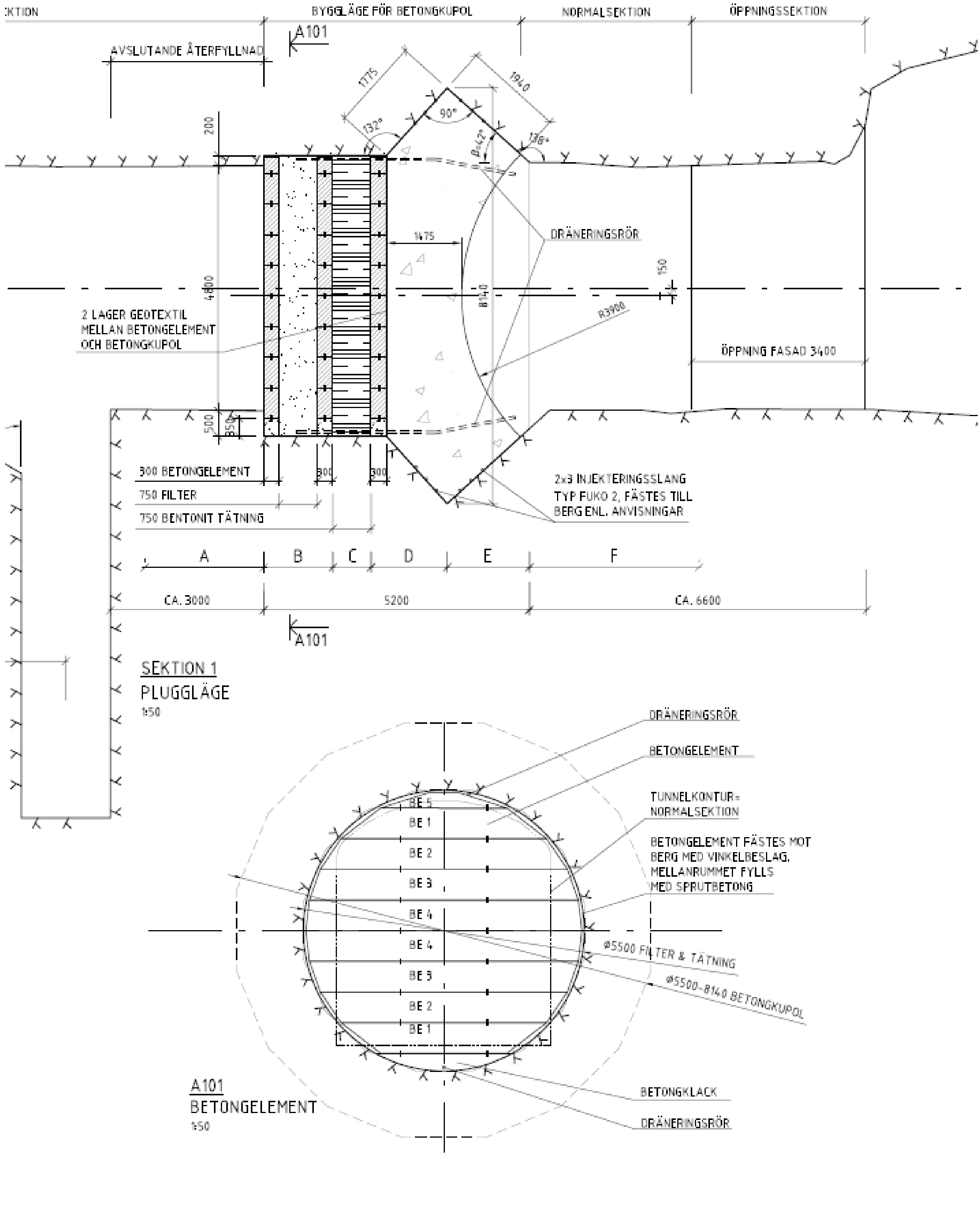
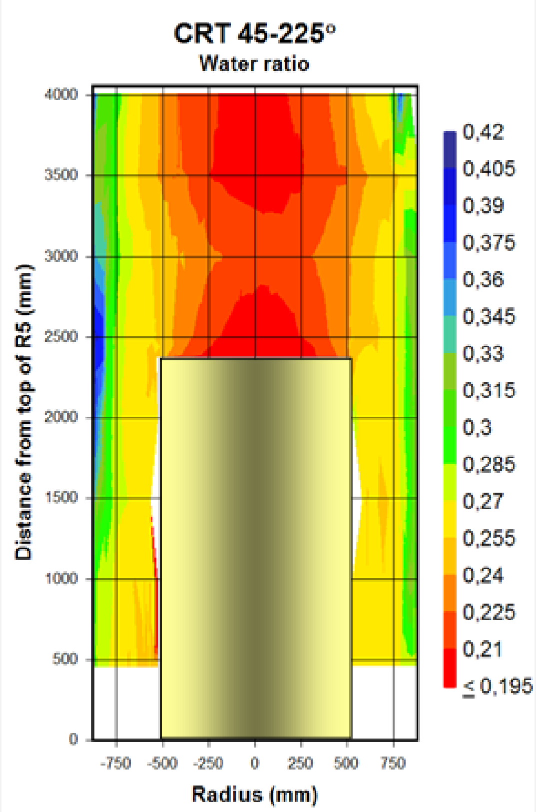


Figure 4-4 *A sketch of the reference design for end plugs for deposition tunnels.*

4.16 Task Force on Engineered Barrier Systems



The second phase of The Task Force on Engineered Barrier Systems (EBS) started in 2010 and is a natural continuation of the modelling work in the first phase.

The first phase included a number of THM (thermo-hydro-mechanical) tasks for modelling both well-defined laboratory tests and large scale field tests such as the two Canadian URL tests IT and BCE and the test CRT at Äspö HRL. In the first phase the Task Force was also enlarged to two groups, one treating the original THM issues and one group concentrating on Geochemical issues. The two Task Force groups have a common secretariat, but separate chairmen

The objectives of the Tasks are to: (a) verify the capability to model THMC 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), and (d) to evaluate available conceptual material models.

The second phase of the Task Force includes so far the following tasks:

THM:
- Sensitivity analysis
- Homogenisation
- Task 8 (common with TF Groundwater Flow)
- Prototype Repository

Geochemistry:
- salt diffusion in montmorillonite
- gypsum dissolution and sulphate diffusion in montmorillonite
- calcium/sodium exchange of montmorillonite in compacted state
- Core infiltration of MX-80 bentonite with artificial groundwater

Participating organizations in phase 2 are besides SKB at present are BMWi (Germany), CRIEPI (Japan), Nagra (Switzerland), Posiva (Finland), NWMO (Canada) and Rawra (Czech Republic). All together 10-15 modelling teams are foreseen to participate in phase 2.

Achievements

The 12th meeting of the Task Force on Engineered Barrier Systems was held in Prague in November.

Task Force THM

The task to model the Canister Retrieval Test 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. Five of the teams have modelled the entire test, while the other three have only modelled the central section. The reporting of the modelling results of SKB for phase 1 (CRT) have been delayed due to work with SR-Site but will be completed in the first half of 2011.

Four detailed suggestions of modelling tasks for the second phase of the Task Force were presented and discussed in the meeting in Prague in November. Some initial modelling results were also presented.

Sensitivity analyses - The analyses refer to a base case definition, which is proposed to be a deposition hole with KBS-3V geometry and MX-80 as buffer material. The base case will consist of well defined hydro-mechanical boundary conditions with relevant canister power and also include different stages of the repository life-time. The buffer, rock and canister properties will be defined and thermal, hydraulic and mechanical results requested in well defined positions. Then the influence of different conditions and parameter values will be investigated with sensitivity analyses by varying conditions, geometry and parameters etc. The objectives of the task are to investigate: (a) effects of value uncertainty on modelling results, (b) key parameters and (c) key processes.

Some preliminary results from examples of calculations were shown at the meeting in Prague. A structured proposal will be presented at the next meeting.

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 Ground Water Modelling 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 since 2009 and the work has started.

Task 8 is divided into 4 subtasks. Sub-task 8a is a generic scoping calculation exercise with a 2D axisymmetric geometry with a horizontal intersecting fracture. Sub-task 8b is also a scoping calculation, but in 3D with more site-specific data from the TASO-tunnel regarding geometry and fractures. In the distributed task definitions, this also includes some sensitivity analyses regarding material properties, boundary conditions and fracture location. When results from the characterisation of the TASO-tunnel are available, sub-task 8c will be a blind prediction of the inflow into the central borehole. Finally, sub-task 8d will be a blind prediction of the bentonite hydration.

An updated version of sub-task 8a and some sensitivity analyses regarding this task were shown. A mock-up test simulating the Brie experiment will be built and started at the beginning of next year.

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 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.

The first phase includes three different swelling and homogenisation tests with simple geometry; One-dimensional swelling, swelling and closure of an axisymmetric slot and swelling and closure of an axisymmetric hole.

Three test series with these geometries have been performed and the results were shown together with preliminary modelling results using the same material model that has been used for SR-Site calculations. The results show that the agreement is not very good and that there are convergence and element mesh problems, especially for series 3.

Prototype Repository - The main goals of the task are to: (a) predict the THM-state at excavation in the outer section of the Prototype Repository (focusing on the buffer) and (b) capture the THM-processes during operation.

The Task-Force teams were encouraged to develop their own solution strategy, which suits the numerical tools available, with the main goals in mind. A proposal of a sequential three-step solution strategy was presented at the meeting:

- **H-pre:** Modelling of the water inflow into the repository before installation to obtain representative rock conductivities and boundary conditions for the post installation models.
- **T/H/TH-post:** Modelling of the thermal and hydraulic processes in the repository after installation (during the operational phase) to obtain representative TH boundary conditions for the smaller THM models.
- **THM-post:** Modelling of the THM-processes in the outer section (concentrating on hole 6) to predict the state at the excavation and to capture the THM-processes during operation.

In addition, some information/conditions/issues related to the three subtasks (described above) were discussed. The inflow measurements into the empty tunnel and deposition holes were described as well as the water pressure measurements in the rock surrounding the empty tunnel. The drainage of the experiment was described. An existing thermal 3D-model was presented.

Task Force Geochemistry

During the November meeting in Prague, the following issues was presented/discussed:

- Calculations of salt diffusion in compacted montmorillonite (Benchmark 1) using the multi-porosity approach. The results were compared with results from earlier modelling using the ion equilibrium approach.
- Porewater calculations made on MX-80 and Rokle bentonite using Phreeqc. Data on Rokle bentonite is offered as a data set for benchmark calculations.
- Modelling of the core infiltration test performed on MX-80 bentonite at University of Bern (UniBern). The experiment has been modelled using both

Phreeqc and Crunchflow, utilising the multi porosity approach with DDL features. A hands-on demonstration of running the Crunchflow code was given.

- An extension of the ion equilibrium approach to pressure and water flow responses due to externally applied water pressure gradients were presented. It was shown that central concepts such as Darcy's law for water flow and the effective stress equation can be derived for compacted bentonite from considering only the water chemical potential. The theory was successfully applied to the UniBern core infiltration test and also to recently performed water flow experiments at Clay Technology showing non-linear flow and pressure response.
- Results from a second core infiltration test at UniBern, performed at ~140 °C.
- Molecular dynamic simulations of the montmorillonite/water system which illuminates the concepts colloidal coagulation due to ion-ion correlation effects in Ca-montmorillonite.

The multi-author report on activities in phase 1 is delayed but under production.

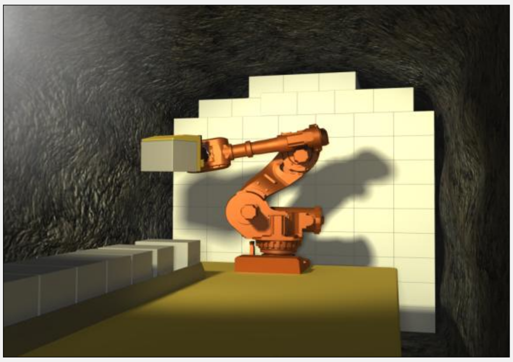
5 Mechanical- and system engineering

5.1 General

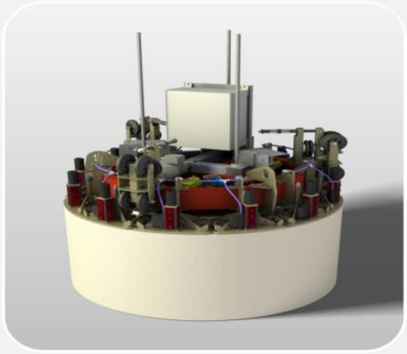
At Äspö HRL and the Canister Laboratory in Oskarshamn, technologies for the final disposal of spent nuclear fuel are being developed. Established as well as new technology will be used in the final repository. When it comes to mechanical- and system engineering, well known standard objects with secured function will be used to the fullest possible extent. With standard equipment as a basis, needed adjustments, modifications and adaptations can be made for the intended function. Where no standard objects are available, new technical development will be necessary. Projects are ongoing concerning equipment for backfilling and buffer emplacement, deposition machine, logistics study, multi purpose vehicle for heavy transports, transport system, drilling and mission control system.

Figure 5-1 *Illustration of the multi purpose vehicle for heavy load transports.*

5.2 Technical development at Äspö HRL



Backfilling equipment



Lifting tool for buffer emplacement

Deposition machine

Multi purpose vehicle

The technical systems, machines and vehicles to be developed are identified and listed in the project FUMIS. Preliminary plans for this development are drawn up.

A total of about 175 different objects, known today, are needed. The preliminary plans for these objects point out the start and finish time for development to have each object ready in time for operation. The plans also include time for development and tests of necessary prototypes. Also a model for cost calculation of modifying and development of objects is developed.

Several projects within mechanical- and system engineering are ongoing and the activities in some of the projects are described in the text below.

Multi purpose vehicle

SKB has a continuous need for performing heavy load transports in the ramp of the Äspö HRL. In order to perform these transports, a vehicle, called Multi Purpose Vehicle (MPV) has been ordered. The vehicle will also be used as a technical development platform for various systems and as a prototype for the future ramp vehicle for the final repository for spent fuel.

To perform tendering and ordering of the vehicle, a project was initialised during the spring and an advertisement was placed on the European homepage of Simap (Information system for European public procurement). The order was placed in the beginning of December 2010 with the Italian company Cometto, and the delivery is planned to take place in May 2011.

Equipment for backfilling

The project is performing design and testing of backfilling equipment. The simulation of a concept has shown that a robot should be able to place 200 tons of backfilling blocks per day, which is a requirement for the logistics in the deep repository. A rack mounted laser to check and measure the result of backfilling with the robot is being purchased.

Future work includes building and testing a prototype of the handling equipment, which will consist of a platform and an industrial robot with a vacuum tool. Testing will be performed both at the Bentonite Laboratory and at the -420 m level in the Äspö HRL.

Buffer emplacement

This project is investigating whether or not the buffer, in the shape of blocks and rings, can be placed in the deposition holes with the required degree of precision.

The tool uses vacuum to lift the bentonite rings and has been functioning well in the laboratory. Minor adjustments need to be made on the crane for final tests to be performed. The buffer rings used for testing were too porous and were easily breaking and vacuum could not be achieved on the damaged rings. The rings have now been repaired and can be used, however, damage may occur again and affect the tests.

During 2010 the steering gear of the emplacement tool was completed. A test programme is being drawn up, as well as a plan and instructions for the accomplishment of quantity and endurance tests. The test programme describes the hoists that are to be made both in design, number and sequence and how the tests are documented. Performance of the tests will start in 2011.

Deposition machine

The aim of the full-scale tests that are being carried out with completely automated operation is to collect data and evaluate the reliability and availability of the machine and the parts of the system, as well as the service requirements under continuous operation.

The tests have been initiated and product information on the deposition machine was developed. A remote connection has been installed and Navitec System are now using the remote connection for maintenance and fine tuning of the software. A UPS (uninterruptible power supply) has been installed for the screens in the driver cabin. The data collected from the first campaign of the full scale tests are to be analysed and a requirement specification for a test server (SCADA) will be produced. The SCADA will be acquired and the full scale tests will continue during the next few months.

Transport system for buffer and backfill material

A feasibility study aiming at finding a solution for the transportation of buffer and backfill material has been carried out during 2010. The study has included the transportation of material from the production premises to the equipment that places the buffer in the deposition hole and that installs the backfill and the pellets.
The feasibility study has determined a concept, which equipment to be used and a

preliminary analysis has been made regarding human factors. A report of the feasibility study has been produced. The main final objective of the project is to deliver an autonomous remotely operated transport system for material from the production premises to the deposition hole and the backfill of the deposition tunnels. The intention was to continue the work after the feasibility study in a new project, but for the moment the project has been put on ice.

Logistics study

The main objective with the logistic studies for the final repository for spent fuel is to be able to simulate all the activities at the repository during the operational phase, both rock excavation and the emplacement of buffer, canister, backfill and sealing of the deposition tunnel with a concrete plug. These logistic studies must be done in steps over a period of three to four years as needed information is not available at present.

A demonstration project was completed in June 2010. The purpose of the demonstration project was to find out if suitable software is available and if it is a practical way to carry out this type of simulations. The results of the demonstration project have been used for internal information and a decision for continued work with logistic studies. An evaluation report is on the verge of being finalised.

The aim of the logistic studies is to be a part of the decision making process for operation and control of all activities, and also to create information needed for detailed design of systems and equipment with respect to:

- Time needed for various activates.
- Bottlenecks and sensibility for disturbance.
- Layout and design of different parts of the facility.
- Design requirements for technical systems.
- Determine the need of different machines/vehicles and required capacity.
- Form a model for control, supervise and follow up of operation and production.
- Organisation structure for the final repository and need of staffing.
- Costs.

Since the Logistics study is depending on results from, amongst others, the project *"Transport system for buffer and backfill material"* and that project is on hold, there can be very little or no progress in the Logistics study until the Transport system project is generating results.

Mission control system, MCS

Within this project a prototype of a comprehensive automatic system, for the management and control of transport and production logistics for the final repository, will be developed. Preparatory work has been made during 2010 and formally the project was started in October 2010. The decision to develop a mission control system facilitates the use of automated vehicles in the final repository.

The scope of the first months of 2011 will be to define system properties and program structure. The mission control system and a related data base will be developed during 2011 and the test of the system will start in 2012.

Drilling Machine for Deposition Holes

For the drilling of the deposition holes for various projects, SKB has used a modified TMB machine. In total SKB has drilled 17 deposition holes at Äspö HRL /Andersson and Johansson 2002/.

A "state of the art" investigation of available technologies was performed during 2006 and the conclusion was that the push reaming technique would be the method that could meet the stringent requirements on the deposition holes and still have the high production rate required for the final repository. This technology has been tested in Finland for drilling of three deposition holes in the research tunnel at Olkiluoto /Autio 1997/. The same technology has also been used for the excavation of the two KBS-3H deposition tunnels at -220 m level in Äspö HRL. SKB are currently following Posiva's work on the subject. Posiva are expected to have a new drilling machine available for these purposes during 2011.

6 Äspö facility

6.1 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.

Äspö Hard Rock Laboratory has over the last four months entered a new interesting phase in its history, with the excavation of the outer section of the Prototype Repository that began as scheduled at the end of November. The operation of the already ongoing experiments in the Äspö HRL has continued and some have been completed with respect to field work. For those projects work to analyse, evaluate and report results from the experiments remains.

With regard to operation, maintenance and development of the facility, it has been an intense period both under and above ground. During the period restoration work has been performed underground to prepare the tunnels TASS and TASQ for coming experiments. The work to establish a geotechnical laboratory has also begun and the facilities for the chemistry laboratory are expanding to increase opportunities for researchers in Nova FoU to use Äspö HRL.

The Repository Technology unit is organised in four operative groups and one administrative staff function:

- *Geotechnical barriers and rock engineering (TDG),* responsible for the development, testing and demonstration of techniques for installation of buffer, backfill and plugs in deposition tunnels, backfilling of the final repository and plugging of investigation boreholes.
- *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.
- *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.

Earlier also the Public relations and visitors group, TDI, was a part of the Repository Technology unit. However the group was transferred to the reorganised Communications department within SKB in May 2010 and is now named Communication Oskarshamn. The group and its personnel are however still located at Äspö HRL and have a continuously close co-operation with the facility and the daily coordination of underground activities.

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 maintains the database and expertise on results obtained at the Äspö HRL.

6.2 Bentonite Laboratory

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

Achievements

A number of bed-tests have been performed in the Bentonite Laboratory with the purpose of better describing characteristics of the bed which will be installed in the deposition tunnels. The tests include stacking of blocks after a given pattern on a not compressed bed of pellet materials, with and without concurrent water inflow, see figure above. Bed stability during water inflow will also be tested. The results will be used to describe the prerequisites for block installation.

6.2.1 Impact of Water Inflow on Backfill

Migration of the water content in the three layers in test with an inflow rate of 0.1 L/min. Photo of upper surface with meandering water expelled from the steep channel.

The objective of the project is to investigate the impact of inflow from the rock on the constitution and properties of the pellet backfill in deposition tunnels. It is preceded by tests on different scales with similar intentions but without the present objective of identifying the detailed, actual process of water uptake of the pellet fill, and of determining realistic multi-point inflows corresponding to real rock structure. The project comprises the following sub-projects:

Sub-project 1 - It is focusing on the mechanisms that control migration and distribution of water entering pellet fills from inflow spots in the rock. The tests will be made on blasted rock slabs for identifying how water is taken up from “dry” and “wet” rock by pellet fills and flows along the rock/pellet contact.

Sub-project 2 - The first part includes determination of inflow into pellet fill in ”1/2-scale” tests using steel tunnels similar to earlier Baclo-experiments but with water inflow from coupled inflow spots simulating water-bearing fractures. The selection of the location of the spots is based on actual fracture mappings of water-bearing fractures in blasted tunnels at the Äspö HRL.

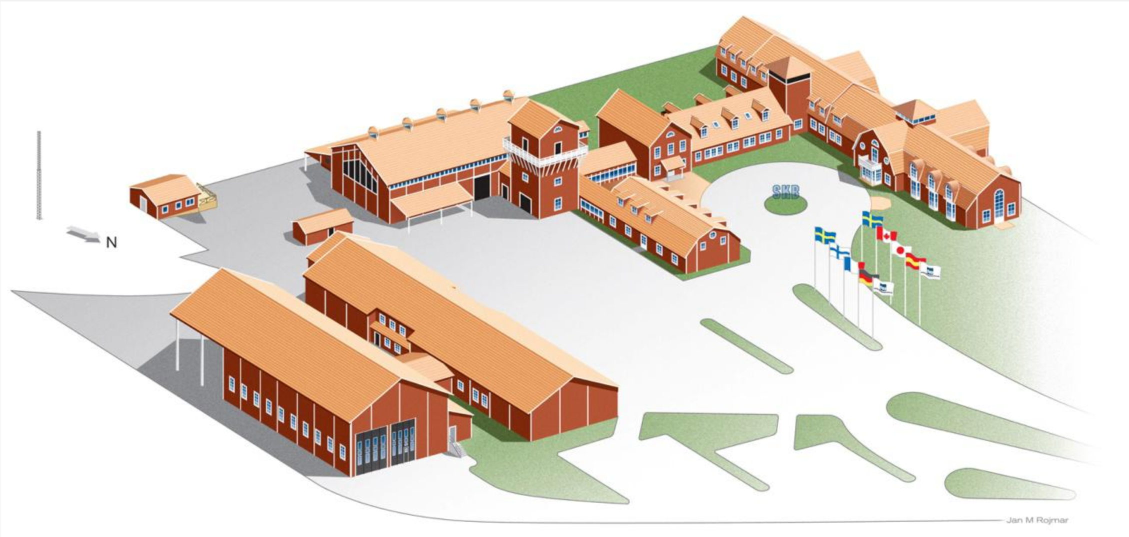
The second part includes a test series in which “wetted pellets” is placed in contact with “dry pellets” for simulating quick water saturation of parts of the tunnel backfill separated by less wet pellet fill into which water flows at a late stage. The major objective of the experiments in these tests is to find out what the critical inflow rate is in order to estimate what the backfilling rate is in meters per day without meeting significant problems with softening of placed backfill. A second purpose is to determine the conditions for creation of piping in partly water-saturated pellet fill.

Achievements

The project was planned to give information on how water entering a KBS-3V tunnel from water-bearing rock fractures enters the pellet backfill. A primary question was if transport of water from a fracture takes place along the contact between the pellet backfill and the rock or if it has the form of penetration into the interior of the pellet backfill in the normal direction. A second question was if the mechanisms of water transport through a pellet fill from an inflow spot can change in the course of permeation e.g. from relatively uniform migration to concentrated flow leading to channelling.

Both issues were investigated experimentally leading to conceptual models of water migration in fillings of smectite-rich pellets. The specific goal of the project was twofold. One goal was to evaluate the outcome of the continued tests with wetting and percolation of backfills of stacked blocks of compacted smectite surrounded by smectite-rich pellets. A report was finished during the last months of 2010 and is now on review. Another goal was to identify the process of wetting and percolation of pellet fill adjacent to natural granitic rock slabs, simulating the walls of blasted tunnels. A report is now on review and will be published during 2011.

6.3 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 months of 2010 and the underground facility has only been closed for planned stops. The recovery of the TASQ-tunnel has been completed and other activities can now be accommodated there. In the TASS-tunnel the roadway has been filled up and asphalted. The rock maintenance has been carried out as planned during the period.

The work with the sewer to OKG´s treatment plant and the new water plant started during the autumn. The work should be finished by the end of the year, but has been delayed. The treatment plant is now planned to be in operation in early February.

Redevelopment of the current warm storage to a geotechnical laboratory is in progress and is scheduled to be operational in early February. The reconstruction means that the locations for samples and analysis for the Äspö HRL will double, which makes it possible for other organisations linked to SKB to perform their tests and analysis.

The relocation of staff at the Äspö HRL was conducted in September. The relocation resulted in a lot of work with the redecoration and the purchase of new furniture. In addition, the planned move of the server room at the Äspö HRL has started with an inventory of the systems that shall be maintained locally.

6.4 Communication Oskarshamn

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

The main goal for the unit Communication Oskarshamn is to create public acceptance for SKB, which is done in co-operation with other departments at SKB.

The goal will be achieved by presenting information about SKB, the facilities and the RD&D work which is carried out at for example Äspö.

The unit is responsible for the visitor services at the central interim storage (Clab) and the Canister Laboratory and for taking care of and administrating all visitors to SKB´s facilities.

Furthermore, the unit has the responsibility for e.g. SKB´s exhibitions, for school information in Oskarshamn as well as in Östhammar and the magazine Lagerbladet.

Achievements

During the last four month of 2010, the three facilities in Oskarshamn were visited by 3,313 persons. The numbers of visitors to SKB’s main facilities are listed in Table 6-1. The visitors represented the general public, municipalities where SKB has performed site investigations, teachers, students, politicians and journalists. The total number of visitors to all SKB facilities including “Final repository information activities” in Oskarshamn and Forsmark was 4,977 persons during the same period 2010.

An organisational review of the department of EIA and public information has been carried out, and the public relation officers in Oskarshamn were transferred to the reorganised Communications Department within SKB in May 2010. The unit is located at Äspö HRL and have a continuously close co-operation with the facility and the daily coordination of underground activities. The visitor service is still a large and important part of the tasks carried out by the unit.

Table 6-1 Number of visitors to SKB facilities

SKB facility	Number of visitors September-December 2010
Central interim storage facility for spent nuclear fuel	761
Canister Laboratory	752
Äspö HRL	1,800
Final repository for radioactive operational waste (SFR)	1,564

During the period September-December, 2010, the following events and activities took place:

- There have been a number of VIP-visits during the year, during the third period special to be mentioned was, President Obama’s Blue Ribbon Commission on nuclear waste.
- 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 the public were invited to a geological walk through Oskarshamn. The Geological Day was arranged for students during one day (10th of September) and for the public during one day (11th of September). The events attracted about 100 participants in total.
- On the 24th of September a contribution to “EU’s Researchers’ Night” was held at Äspö. The theme was “machines in the final repository”. The event attracted about 60 persons.
- On the 27th of November the Äspö Running Competition was held in the Äspö-tunnel. 80 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 now and is much noticed by media.
- On the 4th 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. 50 people took the chance to visit Äspö and at the same time see the show.

7 Environmental research

7.1 General

Äspö Environmental Research Foundation was founded in 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).

7.2 Nova Research and Development (Nova FoU)

Äspö Hard Rock Laboratory is a world unique underground research laboratory which is now open for more general research. Nova FoU (www.novafou.se) is the organisation which implements this policy and facilitates external access for research and development projects to the SKB facilities in Oskarshamn (Figure 7-1).

Nova FoU is a joint research and development platform at Nova Centre for University Studies and R&D supported by SKB and the municipality of Oskarshamn. Nova FoU provides access to the Hard Rock Laboratory and the Bentonite Laboratory at Äspö and the Canister laboratory in Oskarshamn.

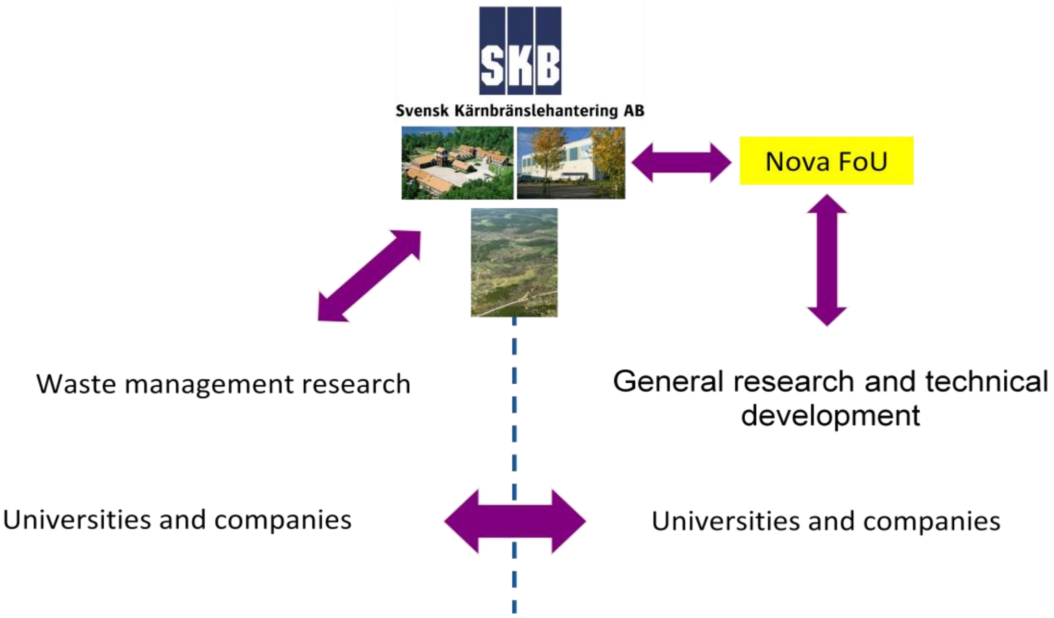


Figure 7-1 *Nova FoU provides access to the SKB facilities and data for universities and companies for general research and technical development. Nuclear waste management research is handled by SKB.*

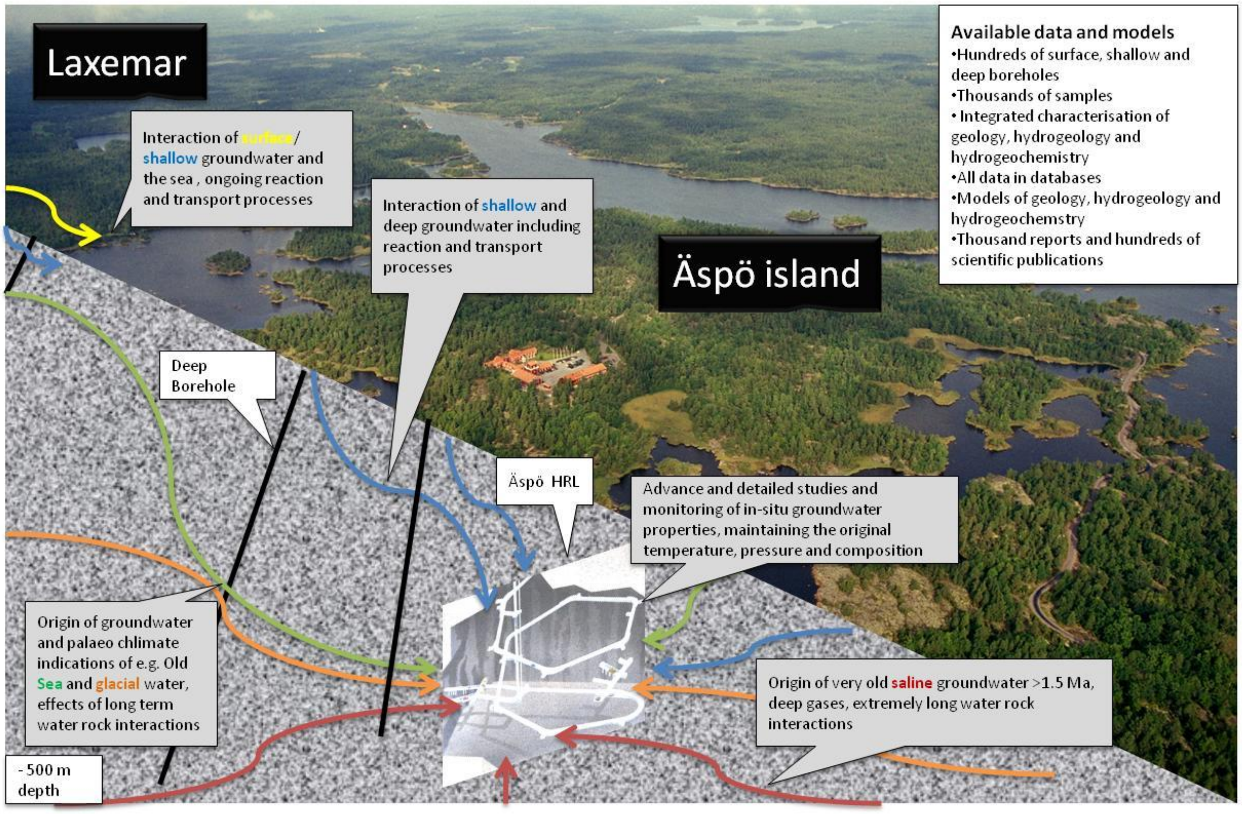


Figure 7-2 *The Äspö and Laxemar areas have been studied in terms of geology, hydrogeology, hydrogeochemistry and ecology. This information can be used for a number of purposes, for example to describe the water cycle and hydrogeochemical processes in 3D.*

The 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 7-2).

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.

Possible scientific and technical work at Äspö HRL are:

Scientific work

- How life is formed in underground conditions.
- Evolution of life where sunlight and oxygen are absent.
- How the deep parts of the hydrological cycle work.
- Interaction between deep and shallow groundwater systems.

- The nature of complex hydrogeochemistry.
- The character of water totally unaffected by man (deep brine).
- Development of fracture fillings over geological time.
- Environmental changes revealed by fracture minerals and groundwater.
- Generation of fracture networks in three dimensional spaces.

Technical development:

- Visualisation, simulation and animation of phenomena in natural science.
- New sampling, measuring and orientation devices for underground work.
- Material and technical development in corrosive and high pressure underground environment.

7.3 Status of the Nova FoU projects

The ongoing research and development projects within Nova FoU and the project owners are:

- Lanthanides in bedrock fractures (Linnaeus University)
- Fluorine in surface and ground waters (Linnaeus University)
- Modelling of groundwater chemistry (Linnaeus University)
- Geobiology of microbial mats in the Äspö tunnel (University of Göttingen)
- Coastal modelling (Royal Institute of Technology, KTH)
- 3D localisation system of persons, the Alfagate project (NeoSys AB)
- Integrated fire protection, the Safesite project (NeoSys AB)
- Utilisation of waste energy, the EoS project (Municipality of Oskarshamn)
- Detailed fracture mineral investigations (Linnaeus University)
- Expert group for the harbour remediation project in Oskarshamn (Municipality of Oskarshamn)
- Hydrochemical interaction between a tunnel and its surroundings – development of prediction models (Chalmers University of Technology)
- Trace elements in fracture minerals and groundwater (Linnaeus University)
- Corrosion protection of rock bolts (Swerea KIMAB AB)

The status of on-going and initiated projects is described below.

7.3.1 Lanthanoids in bedrock fractures

The aim of the project is to characterise and describe the variability in concentrations and fractionation patterns of lanthanoids in fracture minerals (primarily calcites) and groundwaters in Proterozoic bedrock.

The status of the project for the reporting period is that: (1) concentrations and fractionation patterns of lanthanoids in both calcites and groundwaters have been statistically analysed and interpreted, (2) the abundance and fractionation of lanthanoids in the groundwater have been compared with results of Multivariate Mixing and Mass balance (M3) modelling and (3) the relationship between lanthanoid concentrations and drilling-water % in groundwater samples have been studied.

The major results are as follows. There was no significant correlation between drilling-water content and lanthanoid concentrations (Figure 7-3), which is a good starting point for further statistical analyses and interpretation of the behaviour of the lanthanoids.

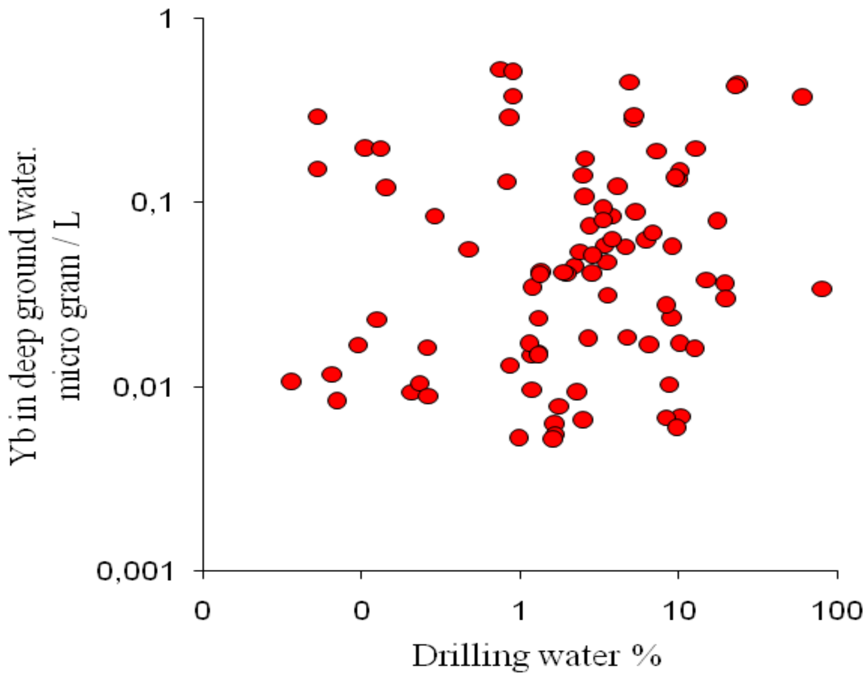


__Figure 7-3__ Scatterplot of drilling-water percentage and lanthanoid concentrations in groundwater.

The calcites show overall a strong relative enrichment of the light lanthanoids, which also is to be expected from partition coefficients obtained in previous laboratory experiments. The extent, to which the light lanthanoids are enriched, however, varies substantially. In some cases even the heavy lanthanoids are just as high as the light ones. It seems that a large part of the fractionation in the calcites can be explained by the fractionation of lanthanoids existing in the deep groundwaters (only current-day data exists) and partitioning into the calcites according to existing partition coefficients. This will increase the understanding of the interaction of lanthanoids (and indirectly actinides) in groundwater and fracture minerals in crystalline bedrock.

The spin-off effects from the project are so far mainly that the results can be used as a reference and starting point for other detailed lanthanoid and trace-metal investigations in other kind of deep-environmental materials such as other fracture minerals, bacteria and different types of groundwater.

7.3.2 Fluorine in surface and ground waters

The main aim of the project is to increase the understanding of the behaviour of fluorine in waters at different levels in the ground (from the surface down to 1,000 m or more) in the boreal environment. In more detail the project aim is to: (1) describe and explain the high fluorine concentrations in the water in the lower reaches of the Kärrsviks stream (Figure 7-4), (2) characterise and model fluorine abundance and transport in overburden and bedrock groundwaters in Laxemar, Forsmark and Äspö and (3) identify the sources of high fluorine concentrations occurring in many wells in the region (the county of Kalmar).

The major results are the findings and characterisation of a temporal and spatial fluoride pattern within the Kärrsviks stream and its catchment, confirming the hypothesis of indirect influence from fluorine-rich bedrock (Götemar intrusion) as a source for elevated fluoride concentrations in the surface waters of the catchment. The mechanism is weathering of glacial deposits, partially consisting of Götemar granite, and greisen fractures (which are strongly connected to the intrusion and, as well, rich in fluorite).

The spin-off effects from this project will be increased information and knowledge on fluorine abundance and transport in surface and groundwater in Laxemar and Äspö and elsewhere in the county of Kalmar, which has practical implications in terms of water supplies (concerning both private wells and public water resources). Many wells, both in the overburden and bedrock, in these areas contain fluorine concentrations, which are above the threshold values for drinking water, an issue that will be thoroughly discussed and highlighted within the project. In particular, the project will lead to a greater understanding of the mechanisms causing the well-water fluorine concentrations to increase in many areas, which is valuable information for the community. The findings may also lead to spin-off effects of economical value.

Figure 7-4 *The Kärrsviks stream has significantly elevated concentrations of fluoride, caused by the weathering of fluoride-rich minerals such as in Götemar granite (top left corner).*

7.3.3 Modelling of groundwater chemistry

The aim of the project is to increase the understanding of chemical reactions and transport in fractured Proterozoic bedrock. At the present time, a major task is to contribute to the updating of the Äspö Site Descriptive Model (Äspö SDM) by providing calculations and interpretations based on the M3 modelling. In addition, the potential artefacts caused by drilling water will be studied. The modelling will increase the understanding of the groundwater evolution during and after tunnel constructions in crystalline bedrock.

The status of the work during the reporting period is to focus on the exploration of the data from the Sicada database and to perform M3 modelling for the Äspö SDM project. The aim was to investigate the mixing proportions of the different waters types present in the boreholes at Äspö (i.e. KAS, HAS and the boreholes from the tunnel) and calculate the changes of the mixtures.

The main modelling is based on the following reference waters: old saline, glacial, marine (Littorina Sea) and meteoric water. Some additional modelling is planned for the end of this period in order to investigate the potential influence of the Baltic Sea water in the marine signature in some fractures. The main results of this ongoing project have been presented at the 13th international Water Rock Interaction symposium (http://wri13.cicese.mx/) which was held on the 20th of August.

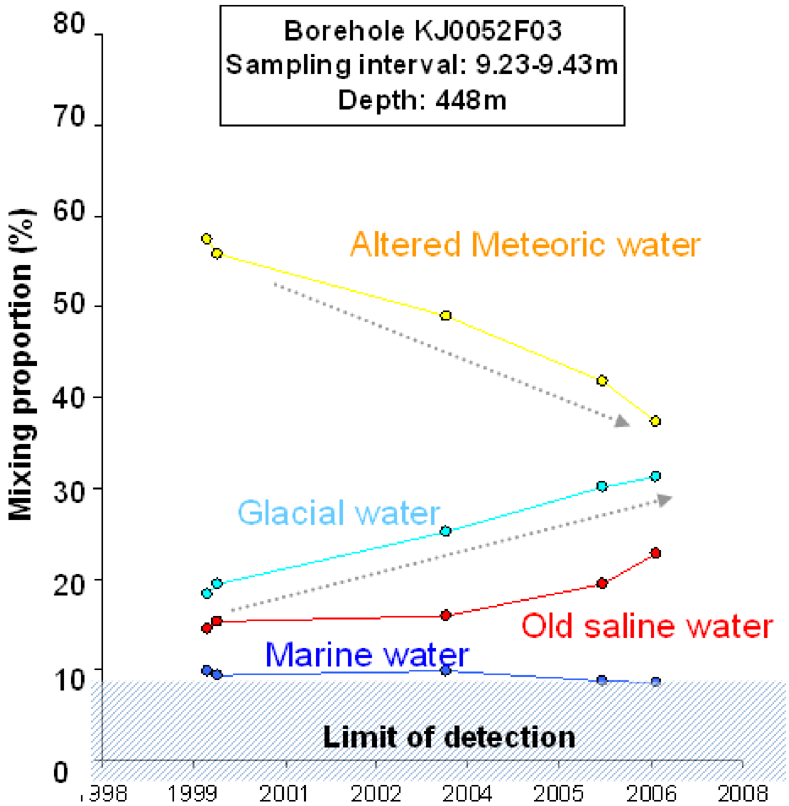


Figure 7-5 Changes of the mixing proportions with time in the borehole KJ0052F03 in the Äspö tunnel.

The major results for the Äspö SDM project are, see Figure 7-5:

- Meteoric and glacial reference waters dominate in the mixtures.
- Meteoric and glacial water proportions change moderately over time in most of the sampled fractures at Äspö.
- Old saline and marine reference water proportion are stable with time in most of the Äspö fractures.
- In some specific fractures, some changes in mixing proportion with time are noticed. These changes are connected with the increase of the salinity.
- Baltic Sea water influence is clearly identified from the increased Mg content in some of the samples.
- In addition to mixing, chemical reactions have altered the water composition.

7.3.4 Geobiology of microbial mats in the Äspö tunnel

The aim of the project is to study biomineralisation, biogeochemistry and biodiversity of chemolithotrophic microorganisms in the Äspö tunnel.

Three sets of flow reactors, each consisting of four units, were installed in 2006 and connected to aquifers of different chemical composition and age at sites in the TASA-tunnel (1327B, see Figure 7-6), the nisch NASA 2156B and the TASF-tunnel. These flow reactors enable a contamination-free study of the spatial and temporal development of microbial communities and associated mineral precipitates. Since the installation, the flow reactors are routinely sampled two or three times per year for monitoring physicochemical fluctuations, microbial communities, and microbial mat development. A part of the project will continue until the end of 2011. Long-term experiments are planned to continue for indefinite time.

Figure 7-6 *Flow reactor set (white boxes) installed in the TASA-tunnel (1327B) in 2006.*

In addition to high-resolution mineral, element and biomolecular studies of mineralising microbial mats, corresponding studies are performed on SKB drill cores to elucidate biosignatures of fossil deep biosphere communities in fracture minerals. These studies are performed using Time-of-Flight secondary ion imaging mass spectrometry (ToF-SIMS, in cooperation with SP, Borås) and Raman spectroscopy.

16S rDNA-DGGE analyses reveal that fluid-borne microorganisms (of aquifers down to 2156B) largely reproduce the pristine mat structures and compositions in the flow reactors compared to an open pond system. Sulphate-reducing bacteria similar to *Desulfolobus propionicus*, *Desulfobacterium autotrophicum* and *Desulfotalea psychrophila*, as well as the methanotrophs *Methylomonas sp*. and *Methylobacter sp*. have been shown to occur ubiquitously in all mat systems. Microbial mats dominated by the iron-oxidisers *Mariprofumdus sp.* and *Gallionella ferruginea*, are generally multilayered systems containing also bacteria similar to ammonia-oxidisers like *Nitrosomonas sp*., to the sulphur-oxidising *Thiocapsa sp*., and the lithoheterotrophic alpha-proteobacterium *Citricella thiooxidans.* The aquifer of the deepest section in the TASF-tunnel clearly differs from all other sites investigated with respect to community composition, biofilm structure and complexity.

Analysis of Trace and Rare Earth Element (TREE) accumulations within iron oxidising microbial mat communities in the dark and air-tight flow reactors in the TASA-tunnel (1327B, see Figure 7-7) and the nisch (NASA 2156B) revealed a massive (up to 10^6 fold) accumulation of most of the TREE within the mineralised microbial mats after two and nine months, respectively.

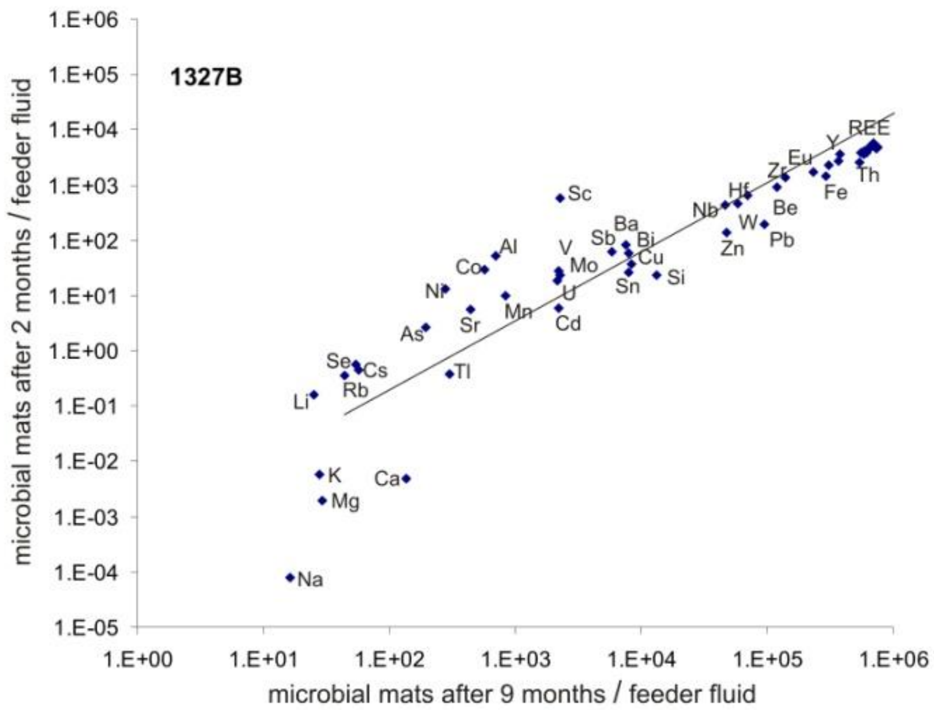


Figure 7-7 Trace and rare earth element accumulation within iron oxidising microbial mats in dark and air-tight flow reactor in the TASA-tunnel (1327B) after 2 and 9 months respectively (normalised on the supplying aquifer).

Time-of-flight secondary ion mass spectrometry (ToF-SIMS) was implemented as a new method for identifying organic biomarkers and spatially resolves their distribution directly on geobiological samples. ToF-SIMS imaging was successfully applied to microscopic cryosections of mineralised microbial mats to correlate specific lipid biomarkers (e.g. glycerophospholipids, archaeal tetraether lipids) with their source organisms.

An integrated geochemical approach to microbial biosignatures preserved in fracture minerals obtained from drill core KJ 0052F01 enabled the identification of several fracture mineral generations and a putative ancient biofilm that may have existed during a late glacial period, when the fracture was reactivated and water conducting.

Microbial mats accumulating TREE may potentially be used for the recovery of precious trace elements, and for water remediation purposes. These microbial communities or synthetic systems with similar properties may serve as an organic filter/buffer also for capturing radionuclides. Defining biosignatures of recent and ancient deep biospheres will be helpful for palaeo-environmental reconstructions, which may also support considerations about the long-term storage of nuclear waste.

7.3.5 Coastal modelling

The aim of the project is to study hydrogeological pathways and coastal dynamics with integrated transport and altering processes in water from land to the Sea.

A DarcyTools flow model for Forsmark has now been completed. Compared to earlier Forsmark models, new surface elevation data and also newly developed surface hydrology features have been included. This enables to obtain more complete flow patterns from soil infiltration to the Baltic Sea, including flow through the surface waters (lakes and streams), overburden and the bedrock in greater detail than has been done in the past. All flow is assumed to be laminar and driven by pressure/gravity. In its current form, the model assumes a uniform (average) aquifer depth. Additional complexity of the spatially variable overburden/soil depth in the catchment is now added by using the developed soil model from SKB. With this feature, the model will capture all major structural complexity, from complicated sub-catchments and surface water areas, to variable overburden and conducting fracture zones of the bedrock. Testing of the flow model is currently in progress in collaboration with experienced model developers.

Once the flow testing is completed, particle tracking will be implemented for computing the water transit times within the catchment, and evaluating the flow/transport partitioning between different sub-domains (surface and subsurface). Identification of the hydrological pathways and transit times will provide key quantities for understanding the basic hydrology and for investigations of reactive transport and geochemical analysis of the existing data, or for geochemical modelling.

7.3.6 3D localisation system of persons, the Alfagate project

The aim is to develop and apply RFID (Radio Frequency Identification) technology in tunnel environment. The technology is used to identify in 3D persons or objects in the tunnel environment. The project creates an open software structure which is not dependent of hardware and which will be integrated with other Äspö HRL systems.

The server software/driver Charon is used as the link between the hardware and the database within the Alfagate project. AlfaGate Admin is the software which handles the administrative parts of the system. The AlfaGate Tracker is the visualisation part of the system which shows the locations of the persons in the tunnel (Figure 7-8) and is used in the control room. A simpler version of the visualisation system is the AlfaGate viewer which is used in areas for the public. AlfaGate Pending is the gateway system controlling persons entering and leaving the tunnel.

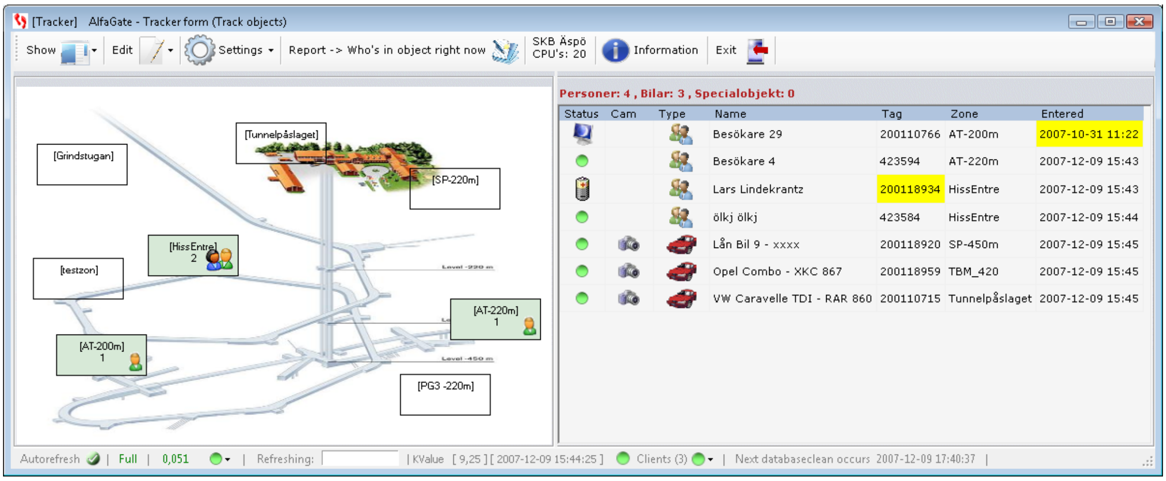


Figure 7-8 *AlfaGate Tracker is the visualisation system which shows the locations of the persons in the Äspö HRL.*

The status of the project is that it is in the development phase towards the commercial systems of TaggMaster, Aeroscout and Identec.

The major results are that the AlfaGate system is further developed towards the Identec's RFID HW and supports TagMasters RFID HW systems.

The spin-off effect from the project is that there is a great commercial interest for the system in Sweden and abroad. Additional local competences are needed in the company and cooperation agreements with local companies are discussed.

7.3.7 Integrated fire protection, the Safesite project

SKB requires a fire security system based on the best available technology. The aim of the Safesite project is to integrate the detection and verification of smoke or fire together with the entrance and logistic control of people and vehicles. True integration with the RFID system and other security systems are required.

The major results are that international companies such as Siemens and Niscaya have shown great interest and are included in the testing and verification of the system to be installed. From other companies and organisations it is a great interest to follow the development of the Safesite system.

7.3.8 Utilisation of low graded heat, the EoS project

The EoS (Eden of Sweden) project focuses on utilising the waste heat from different industrial process plants. EoS is aiming at demonstrating the latest technology for energy efficiency e.g. within housing, water cleaning, leisure facilities, green house production and as a research facility. The project is of national and international interest due to the huge amount of waste heat available globally and which can be utilised as a resource. The spin-off effect of this project is that it will create local competence in a field of potential global interest. A feasibility study is ongoing and will list about five possible research projects within the field of utilisation of low graded heat.

7.3.9 Detailed fracture mineral investigations

The aim of the project is to characterise and gain information from fracture minerals in bedrock fractures. Investigations of fracture minerals provide a useful tool to understand palaeohydrogeological conditions. Groundwater in crystalline rocks is mainly transported along fractures and different groundwaters subsequently flowing along fractures may precipitate a sequence of minerals on the fracture walls. Examination of these mineral coatings ideally yields a palaeohydrogeological record of formation temperatures, fluid compositions and potential origin. The project will lead to publications of several scientific papers on fracture minerals and their input to the understanding of past and present redox conditions in the bedrock, groundwater-mineral interactions, biological activity in bedrock fractures, stability of groundwater systems in Proterozoic rocks etc.

7.3.10 Expert group for the harbour remediation project in Oskarshamn

The aim of the expert group is to support and scientifically review the harbour remediation project in Oskarshamn. An expert group under the management of Nova FoU has been formed consisting of experts from the company Land, Water and Waste Management Group AB (LWWMG) and from the institution of Natural science at the Linnaeus University.

7.3.11 Hydrochemical interaction between a tunnel and its surroundings – development of prediction models

Investigations carried out show that groundwater recharge in rock increases during the building phase of underground constructions. The project aims to investigate the following related changes:

- Provide a deeper insight into and quantify chemical changes in surface water and groundwater caused by underground construction within a catchment area.
- Create an understanding of how the chemical change in the groundwater caused by underground construction can in turn affect reinforcements in the underground constructions, grouting measures and the functioning of the drainage system.
- To further develop numerical modelling tools to facilitate the use of data that can be gathered before the construction phase of an underground facility in order to assess, which hydrochemical conditions will prevail during the construction, and operational phases of the facility.

Research and development initiatives will also provide a basis for improving the content of environmental impact assessments in conjunction with underground projects. Furthermore the project aims to provide a basis for constructing safer tunnels with cost-effective maintenance.

The primary focus of the proposed project is to use acquired knowledge to create prediction models with the aim to predict hydrochemical changes in conjunction with underground construction, based on information gathered prior to the construction phase. The predictions provide a base for constructing safer tunnels with cost-effective maintenance.

7.3.12 Trace elements in fracture minerals and groundwater

The overall aim of the project is to characterise and describe the variability in concentrations of lanthanoids and other trace elements in fracture minerals and groundwaters in Proterozoic bedrock.

In more detail, the aims are to:

- Determine the distribution of lanthanoids and other trace elements in a variety of fracture minerals, including different generations of calcite, fluorite and pyrite.
- Determine the concentrations of lanthanoids and other trace elements in dissolved and colloidal form in the groundwater.

The solid-phase studies will focus on several generations of fracture minerals collected from bedrock cores stored in Oskarshamn (collected during the Site Investigation). The analyses will be carried out in the Department of Earth Sciences, University of Gothenburg. Shortly, the minerals are identified using SEM and optical microscopy, carefully picked by hand from grind material and mechanically cleaned from impurities of other mineralogical phases. Selected minerals are thereafter dissolved with appropriate acid for each mineral and the solutions subsequently analysed by ICP-MS (Agilent 7500a ICP-MS). The groundwater studies will focus on collecting lanthanoids and other trace elements with DGT samplers (passive samplers) in 4-5 selected boreholes in the Äspö tunnel.

7.3.13 Corrosion protection of rock bolts

Rock bolts made of carbon steel, galvanised steel, galvanised and epoxy coated carbon steel or stainless steel are rock reinforcement alternatives in tunnels. The corrosion-related lifetime for cast-in bolts is uncertain as is the corrosion protection capacity of the coatings now used, due to insufficient data. On openly exposed visible parts serious damage is frequently observed within short time whereas the state of parts in the rock is largely unknown. The purpose is to formulate requirements for corrosion protection of rock bolts and to provide a technical and economical basis for a rational selection of materials and coatings. A further aim is to gain increased knowledge of the corrosion effects of groundwater in contact with rock bolts. Quality control methods that are relevant for corrosion resistance of rock bolts and similar parts on real-life conditions will be developed. The efficiency of available corrosion protection will be experimentally documented.

8 International co-operation

8.1 General

Eight organisations from seven countries has in addition to SKB participated in the co-operation at Äspö HRL during 2010, see Table 8-1. 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 coordination of the experimental work arising from the international participation. Numo (Nuclear Waste Management Organisation of Japan) was represented as an observer at the IJC-meeting in May, 2009 and May 2010. Nagra left the central and active core of participants 2003 but are nevertheless supporting the Äspö activities and participates in specific projects.

Table 8-1 Prioritised activities for the international co-operation during 2010 according to Planning Report 2010 /SKB 2010b/.

Projects in the Äspö HRL during 2010	Andra	BMWi	CRIEPI	JAEA	NWMO	Posiva	Kaeri	Nagra	Rawra
Natural barriers									
Long Term Sorption Diffusion Experiment					X				
Colloid Transport Project		X			X				
Microbe Project		X							
Task Force on Modelling of Groundwater Flow and Transport of Solutes	X		X	X	X	X	X		
Engineered barriers									
Prototype Repository		X							
Alternative Buffer Materials	X	X				X		X	X
Long Term Test of Buffer Materials	X	X				X		X	
Temperature Buffer Test	X	X							
KBS-3 Method with Horizontal Emplacement						X			
Large Scale Gas Injection Test	X	X			X	X			
Task Force on Engineered Barrier Systems		X	X		X	X		X	X

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
Korea Atomic Energy Research Institute, Kaeri, Korea
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, Switzerland
Radioactive Waste Repository Authority, Rawra, Czech Republic

Several of the participating organisations take part in the two Äspö Task Forces on: (a) Modelling of Groundwater Flow and Transport of Solutes, which is a forum for co-operation in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock and (b) THMC modelling of Engineered Barrier Systems, which is a forum for code development on THMC processes taking place in a bentonite buffer and gas migration through a buffer.

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.

9 Documentation

During the period September – December 2010, the following reports have been published and distributed.

9.1 Äspö International Progress Reports

SKB, 2010. Äspö Hard Rock Laboratory. Status Report. January – April 2010. SKB IPR-10-15, Svensk Kärnbränslehantering AB.

Goudarzi R, Johannesson L-E, 2010. Äspö Hard Rock Laboratory. Prototype Repository. Sensors data report (period 20010917-2010-0601). Report No: 23. SKB IPR-10-18, Svensk Kärnbränslehantering AB.

Harrström J, Andersson P, 2010. Prototype Repository. Tracer dilution tests during operation phase, test campaign 3. SKB IPR-10-17, Svensk Kärnbränslehantering AB.

9.2 Technical Documents and International Technical Documents

No Technical Documents or International Technical Documents have been published during the period.

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Glamheden R, Fälth B, Jacobsson L, Harrström J, Berglund J, Bergkvist L, 2010. Counterforce applied to prevent spalling. SKB TR-10-37, Svensk Kärnbränslehantering AB.

Goudarzi R, Johannesson L-E, 2010. Äspö Hard Rock Laboratory. Prototype Repository. Sensors data report (period 20010917-20100601). Report No: 23. SKB IPR-10-18, Svensk Kärnbränslehantering AB.

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