International Progress Report

IPR-10-16

Äspö Hard Rock Laboratory

Status Report

May – August 2010

Svensk Kärnbränslehantering AB

February 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. The plans for SKB's research and development of technique during the period 2008–2013 are presented in SKB's RD&D-Programme 2007 /SKB 2007/. The information given in the RD&D-Programme related to Äspö HRL is annually detailed in the Äspö HRL Planning Report /SKB 2010/.

This Äspö HRL Status Report is a collection of the main achievements obtained during the period May to August 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, Radionuclide Retention Experiments, 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 ongoing concerning equipment for backfilling, buffer emplacement, ramp vehicle, deposition machine, logistics study, multi purpose vehicle, transport system, drilling machine for deposition holes 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. Nine organisations from eight 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 2008–2013 are presented in SKB's RD&D-Programme 2007 /SKB 2007/. The planned activities related to Äspö HRL are detailed on a yearly basis in the Äspö HRL Planning Report /SKB 2010/. This Status Report presents main achievements during the period May to August 2010. In the Annual Report more detailed information is given of new findings and results obtained during the whole year.

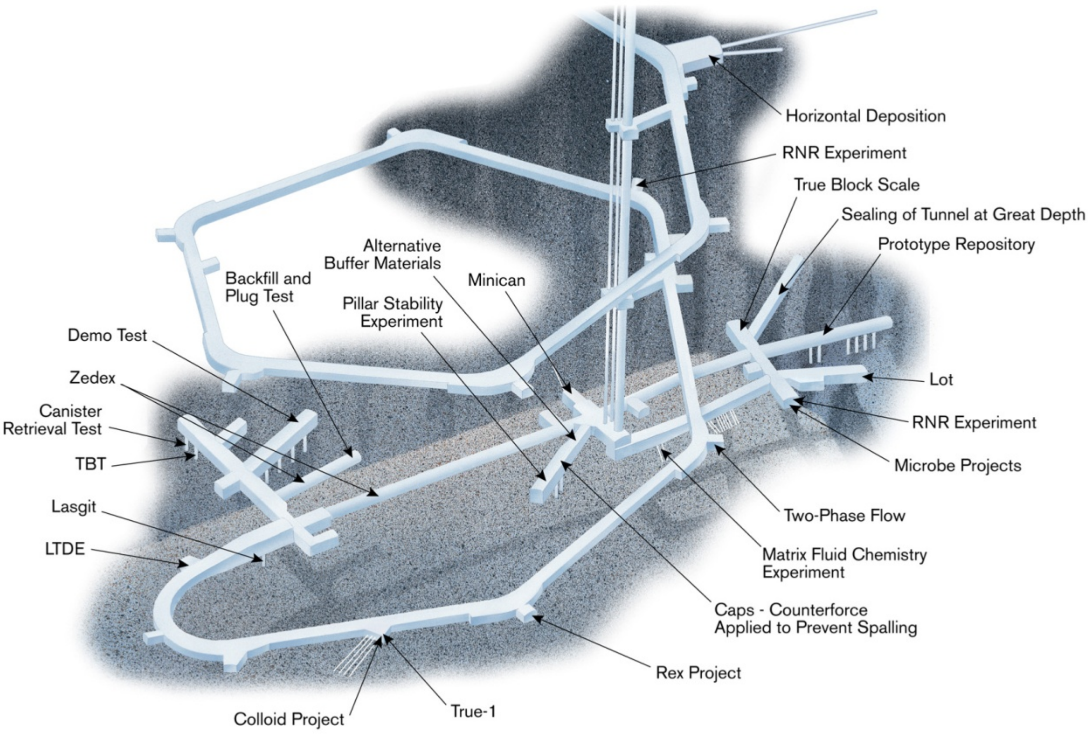


Figure 1-1. *Overview of the Äspö HRL and the allocation of the experimental sites from -220 m to -460 m level.*

2 Geoscience

2.1 General

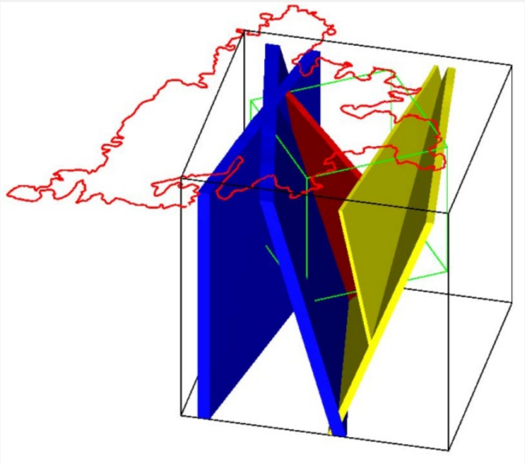
Geoscientific research is a part of the activities at Äspö HRL and is conducted in the fields of geology, hydrogeology, geochemistry and rock mechanics. The studies include laboratory and field experiments, as well as modelling work. The objectives are to:

- 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



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 second four-month period of 2010, the work with the Äspö SDM continues. Hydrogeological single-hole interpretation was introduced to be undertaken integrated with the geological single-hole interpretation with the objective to arrive at an integrated geological and hydrogeological interpretation. This entails establishing a methodology and then the execution of it for a limited number of boreholes. This activity was initiated in the first four-month period and is ongoing. Single-hole interpretations of about 13 boreholes have been interpreted.

Digital borehole images (Bips) were taken of borehole KC0045F in order to support the single-hole interpretation and the further modelling of hydrogeological structures. Bips images proved to be of low to moderate quality but hopefully still useful for the orientation of the fractures in the core.

In situ pH measurements have been performed in the tunnel in several boreholes to assist the hydrogeochemical modelling for Äspö SDM.

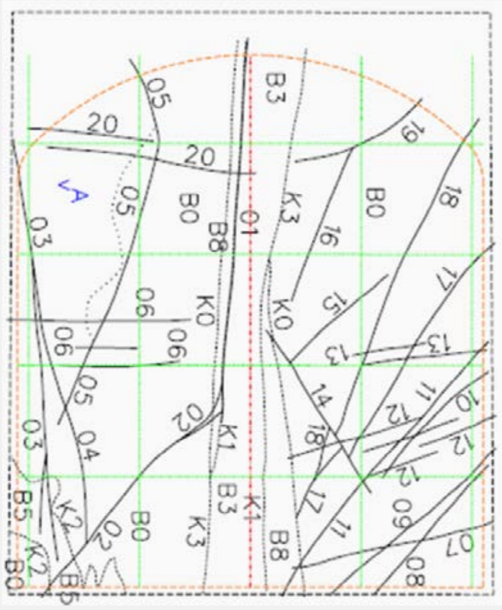
2.3 Geology

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.

Achievements

Geological single-hole interpretation has been performed on boreholes from the surface; KAS02, KAS04, KAS06, KAS07 and KAS08 as well as from the tunnel; KA1755A, KA2050A, KA2162B, KA2511A, KA2563A, KA2598A, KA3376B01 and KC0045F. Evaluation of the GeoMod model from 2003 as well as preliminary modelling for the planned new tunnel which will be excavated in Äspö HRL has been performed. New lineament interpretation of old detailed magnetic and resistivity measurements on the surface performed in 1989 together with lineament interpretation of topography data has been performed. Delivery of coordinated interpretation is planned in the third four-month period. Work with preliminary conceptual understanding of deformation zones at Äspö HRL has been initiated. Updating of the rock nomenclature in the Äspö tunnel has been performed. Recoding of the rock nomenclature in the tunnel mapping system (TMS) is ongoing as well as work with fracture frequency variations in the tunnel which will be an important part for the single-tunnel interpretation (STI).

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.). Geological map of the tunnel face (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 May to August have been:

- The report concerning the geology of the Tass-tunnel has been reviewed and is now waiting for adjustments.
- The report concerning water bearing structures at the -450 m level has been adjusted after the second review and is now in print.
- Work with Äspö SDM continues, see Section 2.2. Geological single-hole interpretations of 13 boreholes have been done, 5 from the surface and 8 from the tunnel. Interpretation of lineaments over Äspö, based on ground magnetic, topographical and resistivity data is still ongoing. Some reconnaissance of previous interpreted deformation zones at the Äspö HRL has been done. A review of the old models and a compilation of various existing models have been delivered to the Äspö extension.
- The orientations of fractures and deformation zones in the Äspö HRL have been plotted in stereo and rose diagrams. The plots show fractures plus deformation zones, only fractures or deformation zones, only water bearing or dry fractures/zones. The diagrams represent the total tunnel system or the tunnel system divided into sections. The work is now completed.
- The drawing summarising the geological mapping of all the Äspö-tunnels is still being up-dated to include the mapping of new tunnels and the colours used in the new rock type nomenclature.

- During the work with summarising the geological mapping of all the Äspö tunnels some errors were discovered in the TMS (Tunnel Mapping System). These errors have now been corrected and resulted in a check up on rock types and change of rock type names in parts of the Tasa-tunnel.
- The work regarding copying the TMS (Tunnel Mapping System) database to the Sicada database is still ongoing.
- Updating of the instruction how to handle and sample drill cores is still ongoing.
- Statistic analyses concerning CFF (Conductive Fracture Frequency) are ongoing.
- The core storage at Äspö HRL has been emptied and the core boxes have been transported to the storage facilities in the town of Oskarshamn. The Äspö core storage will be rebuild since parts of it will be used for other purposes.
- Core samples that have been returned after analyses and tests have been put back into their core boxes when possible.
- The planning of the extension of the Äspö HRL underground facilities is ongoing.

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

Demonstration of photogrammetry by Adam Technology in Posiva's establishment Onkalo (September 2009, Olkiluoto, Finland).

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. Laser scanning in combination with digital photography and/or photogrammetry 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

An offer to develop SKB's geological mapping system, based on the principles of the Boremap-core logging system and photogrammetry, has been received and is still being evaluated.

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

New functionality for the database Sicada has been undertaken for rational interpretation of interference and response tests. Some problems occurred due to missing monitoring data in Sicada which still are not resolved. Old reports have been reviewed and data and parameters in the reports have to some extent been delivered to Sicada. Work with a new functionality in Sicada to incorporate and combine geology and hydrogeology tables is ongoing.

In addition, work is ongoing or planned in the following areas:

- Statistic analyses of conductive fracture frequency together with implementation of rose- and stereo diagrams of water conductive fractures.
- Implementation of old Posiva Flow Log (PFL) data. This work will continue in the third four-month period.
- Hydrogeological single-hole interpretation integrated with geological single-hole interpretation. This work was not performed in this way during the site investigation and the new working process will be adopted. A lot of data is still available in reports only and are not available in Sicada, for example water strike (inflow during drilling and flow logs).
- During the third four-month period work with flow modelling using Darcy Tools with GeoMod from 2003 as a basis will be initiated.

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.

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. A rehabilitation of measurements in the borehole KAS02 is ongoing with the intent to make it operational sometime during the last four-month period of 2010.

After the discontinuation of the monitoring system for the site investigations at Oskarshamn a limited number of monitoring objects were transferred to Äspö HRL as of January 1st 2010. Äspö HRL is charged with the task to demobilise of all remaining monitoring installations of the site investigations and this work 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. The monitoring for the year 2009 is reported in Wass and Nyberg /2010/.

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

The monitoring programme for cored boreholes, percussion boreholes, surface water in Laxemar and Äspö area has been finalised. The results from the sulphide programme in phase one have been evaluated and summarised in a preliminary report.

The evolution of the groundwater chemistry during the construction phase of the tunnel has been evaluated. The evolution of the groundwater chemistry will still be evaluated during the third four-month period as an input for the geochemistry report. A review of the different water types has been undertaken in order to understand how the Äspö water differs from for example the water in Laxemar. Mixing modelling with the M3 code will in the third four-month period be combined with value-depth diagrams of groundwater chemistry in order to get an optimal classification of the groundwater chemistry.

Geochemical modelling will start up during the third four-month period. The groundwater chemistry data from Äspö are missing important pH data obtained from the field (surface and underground boreholes). However, some pH measurements from the pre-investigation phase are available. The hydrochemical group with members from the modelling team from Äspö HRL and from SFR Forsmark had a meeting in June 2010.

A presentation on the "Temporal evolution of groundwater chemistry in fractured bedrock at depth between 400 and 700 m was presented at the conference "Water-Rock Interaction 13" in Guanajuato, Mexico, 2010 and an extended abstract was published during the second four-month period /Mathurin et al. 2010/.

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 performed in autumn 2009 is now reported and quality assured in the database Sicada. During this four-month period measurements of pH were made in the groundwater in selected boreholes in the tunnel and the data will be used in Äspö SDM modelling, see Section 2.2.

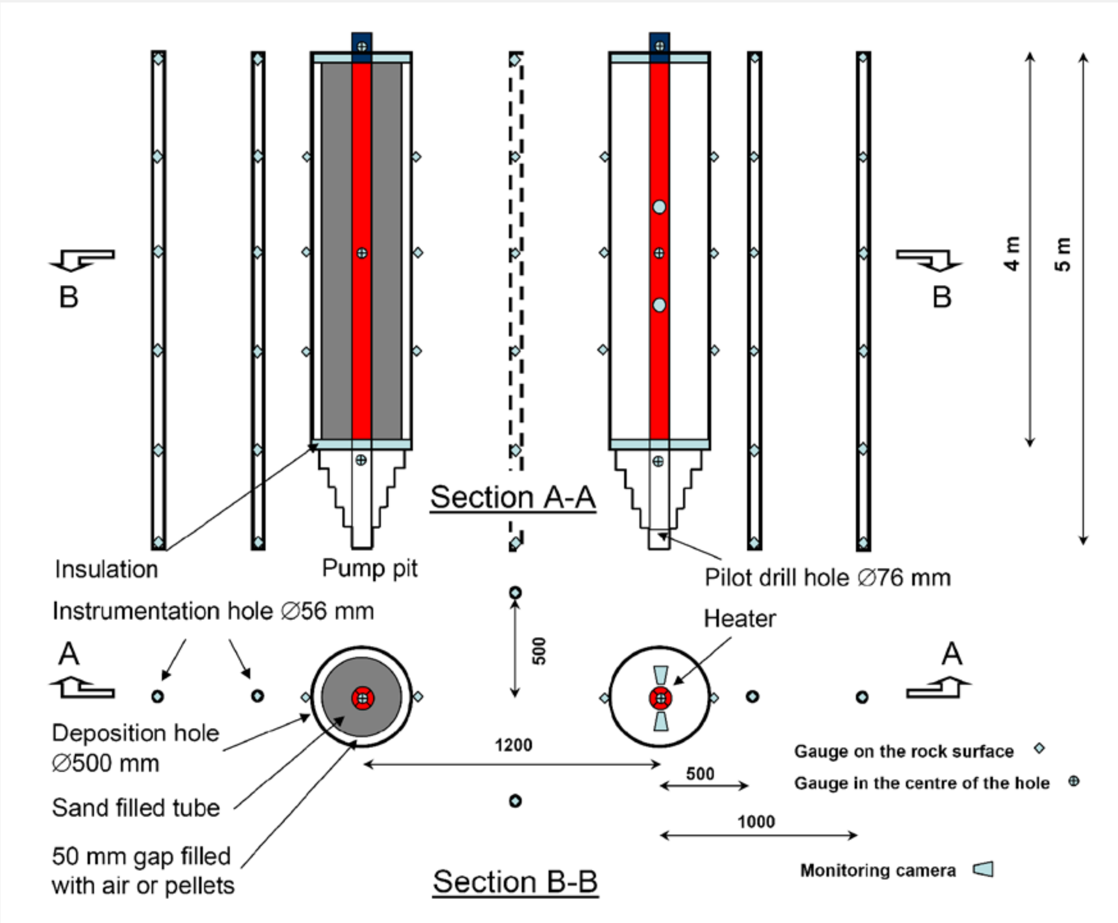
2.6 Rock Mechanics

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.

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

2.6.1 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 field experiment is finished and reported. The final report of the field experiment is ready for printing and the recorded data has been delivered to Sicada. The project evaluation report is under preparation.

3 Natural barriers

3.1 General

Experiments at the Äspö HRL are performed at conditions that are expected to prevail at repository depth. The experiments are related to the rock, its properties and in situ environmental conditions. 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.

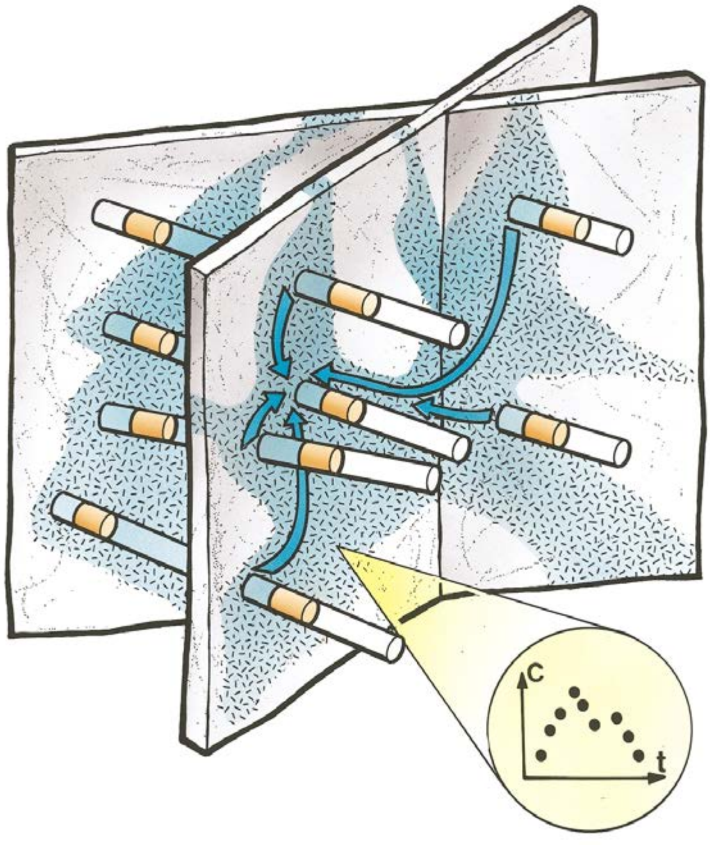
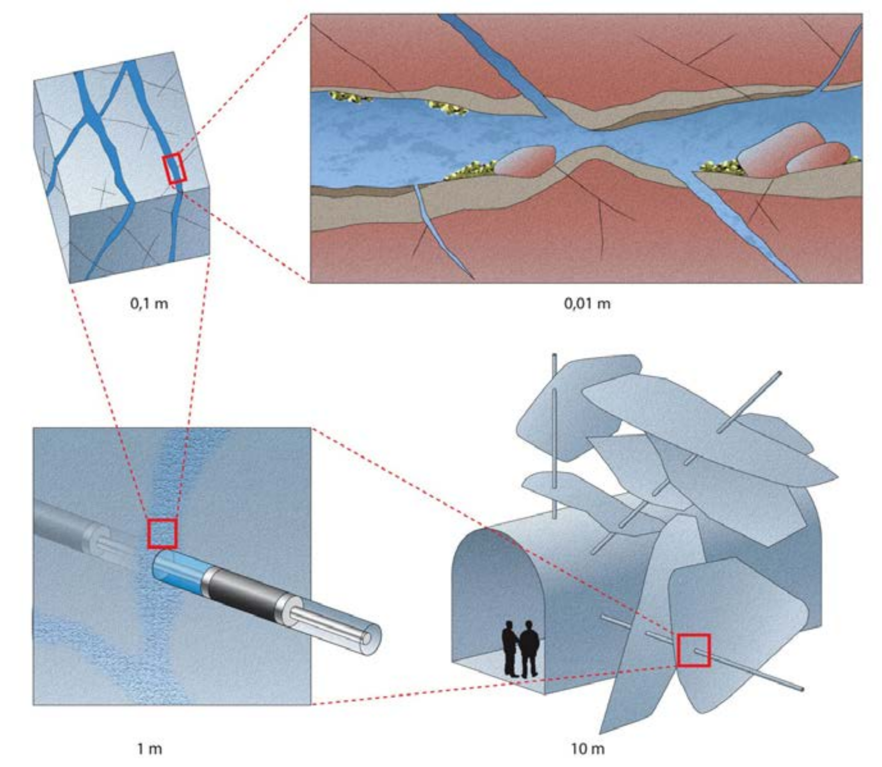


Figure 3-1. *An illustration of the TRUE-1 experiment performed at Äspö HRL, which gave an opportunity to test models for groundwater flow and transport of solutes.*

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. 2003/ have come to their respective conclusion. Complementary field work and modelling have been performed as part of two separate, but closely coordinated, continuation projects.

The TRUE Block Scale Continuation (BS2) project, which was a continuation of TRUE Block Scale (BS1), aimed at obtaining additional understanding of the TRUE Block Scale site /Andersson et al. 2007/.

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

In the TRUE-1 Continuation and Completion projects the objectives are to obtain insight in the internal structure of the investigated feature and to study fixation of sorbing radioactive tracers. Prior to the resin injection in Feature A, complementary hydraulic and tracer tests are performed to better understand Feature A and its relation to the surrounding fracture network. In addition, a dress rehearsal of in situ resin injection is realised through a characterisation project focused on fault rock zones.

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

3.2.1 TRUE Block Scale Continuation

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

The planned series of articles covering the TRUE Block Scale experiments have been transformed into one two-part 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. The tentative title of this paper, aimed at the journal Science is "*Would crystalline rock effectively contain radionuclides released from a high-level nuclear waste repository*?" A second paper, submitted to Geophysical Research Letters, entitled *Diffusion-controlled tracer retention in crystalline rock on a field scale, is in press*.

Achievements

During the period the draft version of the scientific article directed to the journal Science has been subject to internal review within the project group. Following an update of the manuscript and supplement, the article will be submitted to the editors.

3.2.2 TRUE-1 Continuation

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

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 achievements primarily lies in reporting. A draft final report of the Fault Rock Zones Characterisation project has been produced and will be subject to independent expert review. Furthermore a draft progress report on the complementary sorption and leaching experiments on rim zone and fault gouge material has been devised and are currently subject to internal review.

3.2.3 TRUE-1 Completion

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

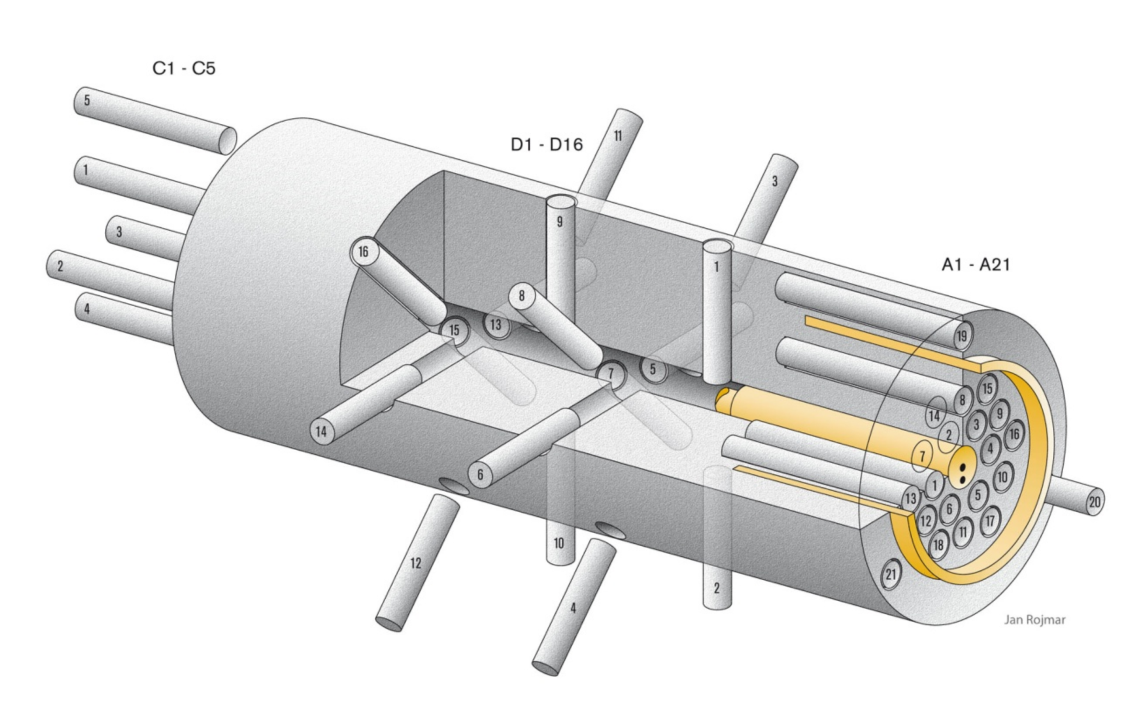
The general objectives of TRUE-1 Completion are:

- 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- 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

The last period was used for reporting of previously performed tests and experiments. The two reports covering epoxy injection with overcoring and tracer tests were sent for review during the period. The report of analyses of core material is soon expected to be ready for review.

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.

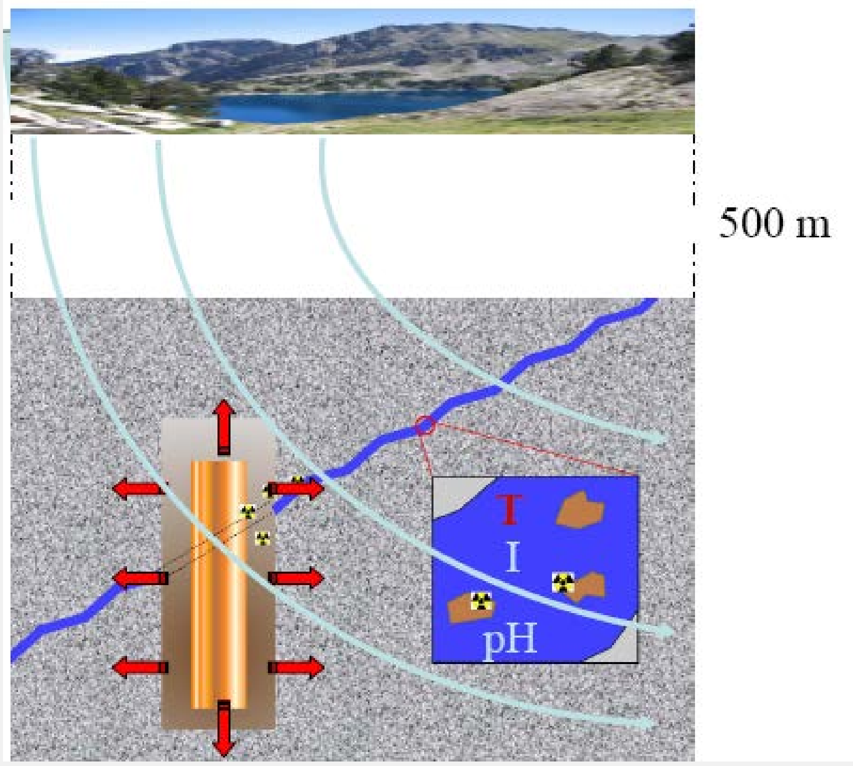
Tracers were circulated over a period of 6 ½ months after which the borehole was over cored. This activity is followed by analyses of tracer content.

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

All experimental parts of the project are completed and data have been printed into data tables for further delivery to the Sicada data base. The laboratory batch sorption tests and sorption/diffusion tests with intact rock pieces have been evaluated and sorption coefficients determined and a first draft report is compiled. Evaluation, modelling and reporting of the in situ experiment are ongoing.

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 melt water 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 the second four-month period, samples from the montmorillonite colloid transport experiments in Grimsel have been prepared, which will be analysed with the SPC-equipment (Single Particle Counting) in September. Samples will be sent to the partners for analyses. Calibrations with different colloids have also been performed.

The major achievements have been the completion of two articles which are sent in to scientific journals for review. One of the articles is summarising the colloid sorption and transport experiments performed in columns filled with fracture filling minerals. Colloid sorption is detectable in transport experiments and can explain the retardation in the transport experiments performed in columns filled with fracture filling minerals.

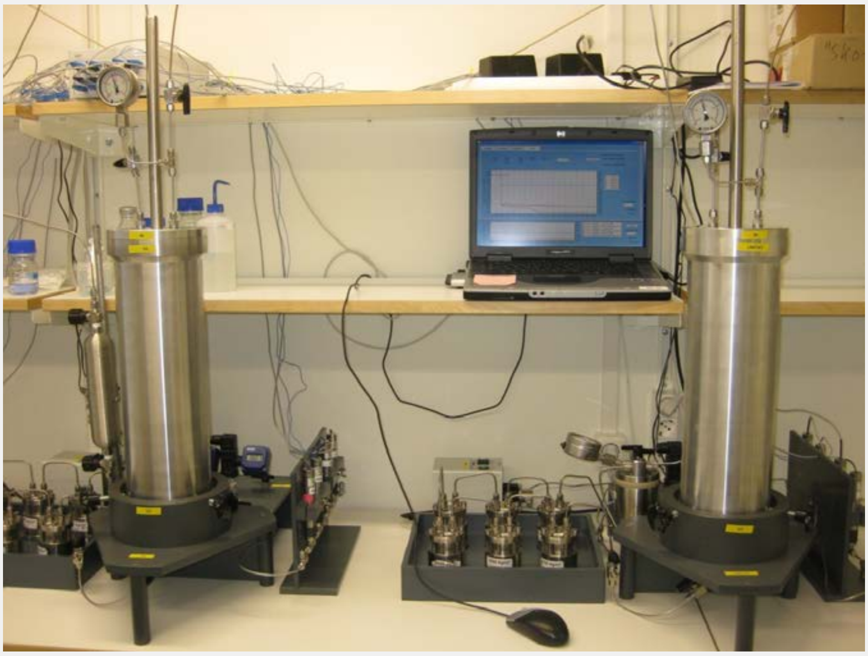
Colloids have been found to adsorb to minerals even under unfavourable conditions. The other article describes the experiments with bentonite erosion in a synthetic Plexiglas fracture, performed by AECL in collaboration with the Royal Institute of Technology. The bentonite erosion experiments give comparable colloid concentrations outside the bentonite buffer, as static sedimentation and generation experiments.

3.5 Microbe Projects

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

The study of microbial processes in the laboratory gives valuable contributions to our knowledge about microbial processes in repository environments. However, the results obtained by laboratory studies must be tested in a repository like environment. The reasons are several. Firstly, at repository depth, the hydrostatic pressure reaches close to 50 bars, a setting that is very difficult to reproduce in the laboratory. The high pressure will influence chemical equilibrium and the content of dissolved gases. Secondly, the geochemical environment of deep groundwater, on which microbial life depends and influence, is complex. Dissolved salts and trace elements, and particularly the redox chemistry and the carbonate system are characteristics that are very difficult to mimic in a university laboratory. Thirdly, natural ecosystems, such as those in deep groundwater, are composed of a large number of different species in various mixes /Pedersen 2001/.

The laboratory is best suited for pure cultures and therefore the effect from consortia of many participating species in natural ecosystems cannot easily be investigated there. The limitations of investigations arrayed above in a laboratory situated on ground have resulted in the construction and set-up of an underground laboratory in the Äspö HRL tunnel. The site is denoted the Microbe Laboratory and is situated at the -450 m level, see below.



Pressure resistant micro-electrodes are used to analyse redox and pH in the circulation systems.

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

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

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

The major objectives are to:

- Offer proper circumstances for research on the effect of microbial activity on the long-term chemical stability of the repository environment.
- Provide in situ conditions for the study of bio-mobilisation of radionuclides.
- Present a range of conditions relevant for the study of bio-immobilisation of radionuclides.
- Enable investigations of bio-corrosion of copper under conditions relevant for a high level radioactive waste repository.
- Constitute a site for research within other projects that require an underground site for microbiological investigations.

3.5.1 Micored

Sampling of rock pieces that have been exposed in a flow cell to circulating groundwater in one of the circulation systems on the Microbe site. Subsequently, DNA analysis reveals amount and types of microorganisms that have attached and grown on the rock pieces.

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 level.

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

The work within the Micored project will:

- Clarify the contribution from microorganisms to stable and low redox potentials in groundwater.
- Demonstrate and quantify the ability of microorganisms to consume oxygen in the near- and far-field areas.
- Explore the relation between content and distribution of gas and microorganisms in deep groundwater.

Achievements

Two series of experiments were completed during 2009 where the influence of hydrogen, acetate and lactate on growth of sulphate reducing bacteria (SRB) has been investigated with groundwater from KJ0050F01 and KJ0052F01. The growth was followed by analysis of DNA specific for SRB. Redox potential was analysed with microelectrodes and with field electrodes. The experiments were successful and data analysis is presently ongoing. A third series was started in March 2010, where the influence of hydrogen on microbial processes was investigated. A forth series was started in May, where the influence of pulses of oxygen is investigated on six different configurations sulphate reducing bacteria systems.
All of the performed series of experiments have been successful and analyses and data compilation are presently ongoing.

3.5.2 Micomig

Drill cores with fractures from drill site KA1362A in the Äspö HRL tunnel.

Upper left: Fracture surface at the 4.3 m position in drill hole KA1362A-6 showing calcite crystals mixed with grey and black minerals.

Lower left: Fracture surface at the 4.7 m position in drill hole KA1362A-6 showing large amounts of white calcite on top of black iron-sulphide precipitates. Sulphate-reducing bacteria were detected in this fracture by cloning and sequencing.

Upper right: Fracture surface at the 2.5 m position in drill hole KA1362A-6 showing large amounts of green and dark red minerals.

Lower right: Fracture surface at the 0.8 m position in drill hole KA1362A-2 showing black minerals. Calcite crystals were observed as well.

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.

Almost all microorganisms are attacked by viruses. A successful attack may result in several hundred new viruses. The size of virus is well within the range of colloids. The influence of such viruses on colloid related processes can be significant, as the numbers of viruses in groundwater may reach several billion particles per litre.

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

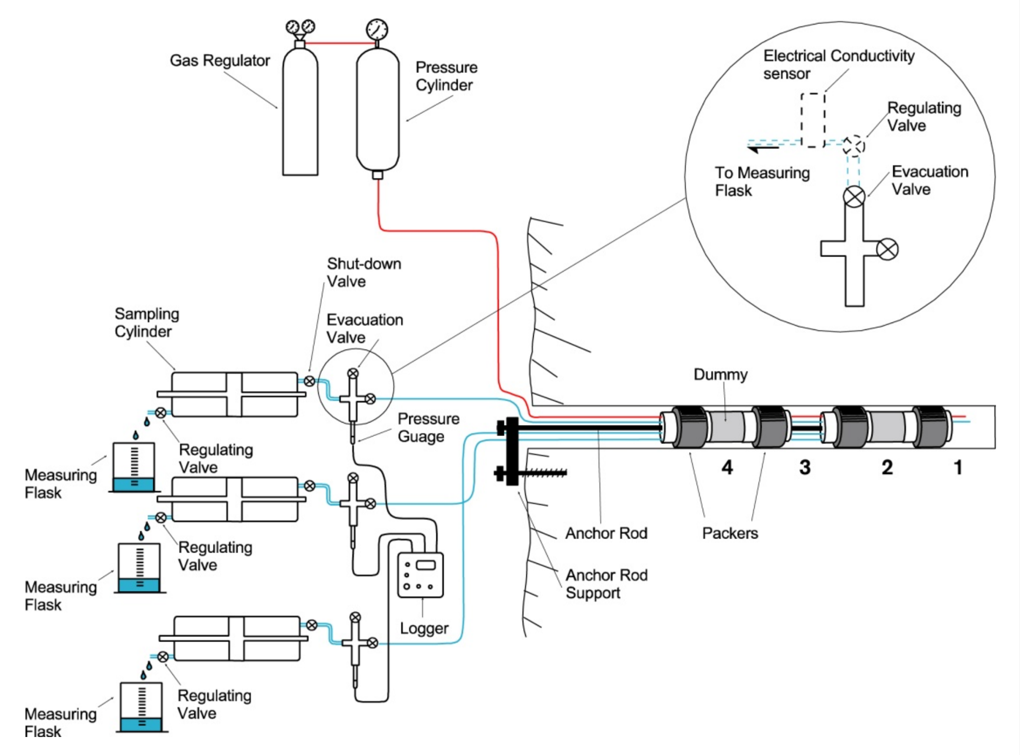
The major objectives are to:

- Evaluate the influence from microbial complexing agents on radionuclide migration.
- Explore the influence of microbial biofilms on radionuclide sorption and matrix diffusion.
- Analyse the possibility of a colloidal effect from viruses in groundwater on radionuclide mobility.

Achievements

No work has been performed within the project during the second four-month period of 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.

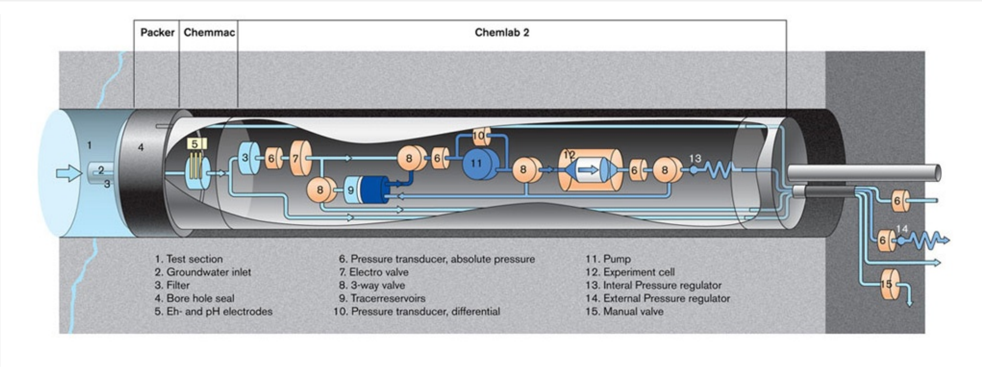
Achievements

No work has so far been performed within the project during 2010. Reporting is the only remaining activity within the project which will be finalised during 2011.

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 will formally be 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.

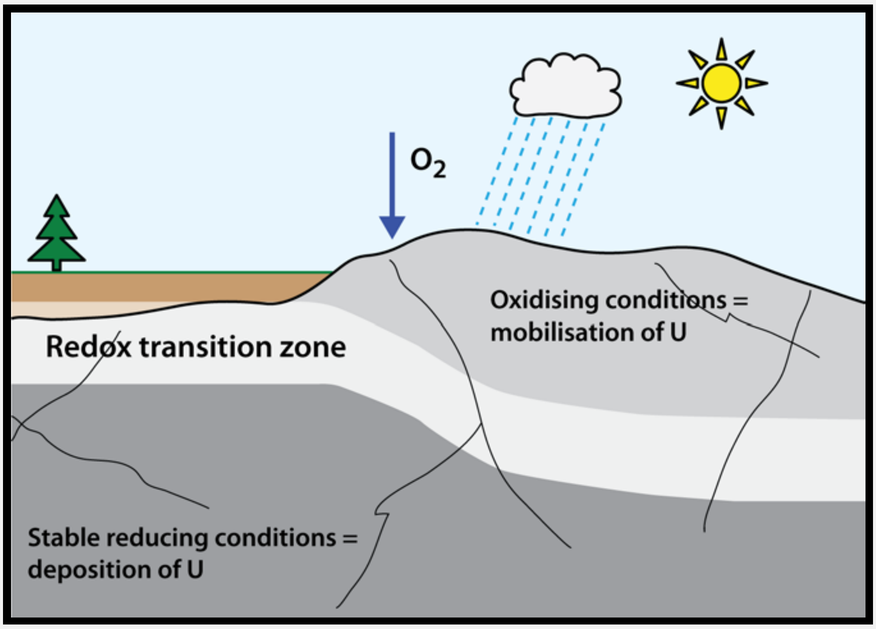
If a canister fails and radionuclides are released, they will diffuse through the bentonite buffer. If there is a fracture intersecting the deposition hole, the water flowing in the fracture will pick up radionuclides from the bentonite buffer.
The transport resistance is concentrated to the interface 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 to 94%. The aim of the project is to perform studies to verify the magnitude of this resistance.
The experiment will be performed in the laboratory, where a fracture is simulated as a 1 mm 'fracture' between two Plexiglas plates. The equipment for the laboratory experiments has been used in the Bentonite Erosion project.

The equipment includes a water pump for very low flow rates. The design of field experiments depends on the outcome of the laboratory experiments.

Achievements

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

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:

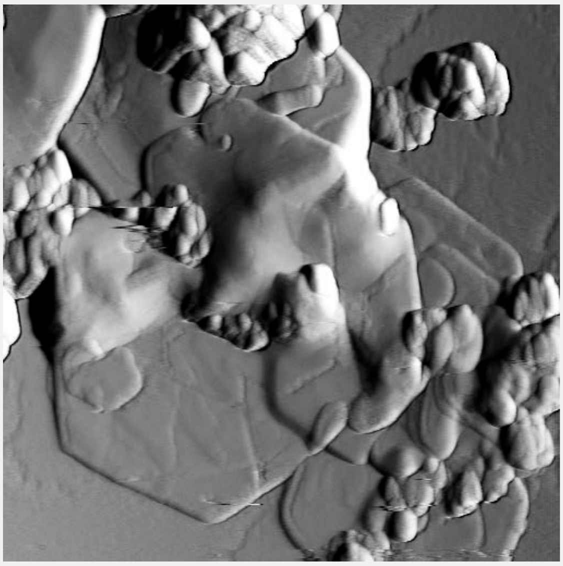
- Further developments of analytical techniques for uranium series analyses applied on fracture mineral samples and inter-laboratory comparisons.
- The use of these analyses for determination of the redox conditions during glacial and postglacial time.
- A summary of the experiences from the palaeohydrogeological 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 activity so far in this project during 2010.

3.9 Fe-oxides in Fractures



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

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

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

Following the original project, a continuation phase 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

The University of Copenhagen has completed its mission and the text documents from them will be reviewed. The project will formally be finalised during 2010 and a technical report and two international progress reports will be published in the SKB series.

3.10 Investigation of Sulphide Production Processes in Groundwater

Black precipitate and a strong smell of hydrogen sulphide gas in the standpipes of borehole KAS03. The borehole equipment (iron bars, plastic tubing and rubber packers) was installed more than 20 years ago for groundwater and pressure monitoring purposes.

Elevated sulphide concentrations in groundwater have been observed in some boreholes during the site investigations at Laxemar and Forsmark as well as in boreholes investigated during the pre-investigation phase at Äspö. Since sulphide can react with the copper canister, assessment of the variation of sulphide in space and time is of outmost importance in the waste disposal programme. Sulphate reduction at temperatures and pressures prevailing in deep groundwater environment is a microbiological process. Sulphate reducing bacteria (SRB) use the S atom in the sulphate molecule as an electron-acceptor and the reduced product is hydrogen sulphide. The energy and electron donor for SRB can be hydrogen or organic compounds such as methane, acetate, photosynthetic organic carbon or leaching carbon from equipment details.

The project is proposed to meet the demand for a better understanding of the processes behind microbial sulphate reduction in core drilled boreholes and also to assess any possible influence of the borehole and borehole equipment on the sulphide concentration.

Core drilled boreholes are equipped for monitoring purposes. The equipments are manufactured from stainless steel, iron, different kinds of plastics and rubber. The water standpipes constitute the part of the borehole equipment with a range from the ground level to up to tens of meters down. A plastic tubing connects the water in the standpipe to the water in the section.

Overall, the composition of water in the standpipe is different from that in the borehole section. It contains for example more organic material and dissolved and particulate sulphide. When sampling section water, a portable pump (connected to an empty tubing) is lowered down to the bottom of the standpipe. The water and precipitate in the standpipe is then a possible source of contamination during water sampling. In addition, differences in water composition may create chemical gradients that give rise to chemical and microbiological reactions.

Achievements

A draft of the final project report is currently under audit. The results from the project have been summarised in a final project report and presented at a meeting initiated by SKB with the Biogeochemical group, which is a network consisting of scientists working with biogeochemical related topics. The final project report is a draft version of the report to be published in SKB's site investigation report series.

The results from the project suggest that sulphide is produced in stagnant water in core drilled boreholes and that the obtained sulphide concentration during water sampling is dependent on the volume of discharged water. This is in accordance with results from the hydrochemical monitoring programme in Forsmark, where a plug flow model was successfully applied to describe the variation in the sulphide concentration with discharged water volume in different boreholes. The model included the location of present water bearing fractures and their transmissivities. These findings will be helpful when designing future monitoring programmes.

3.11 Swiw-tests with Synthetic Groundwater

Injection of tracer in fracture.

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

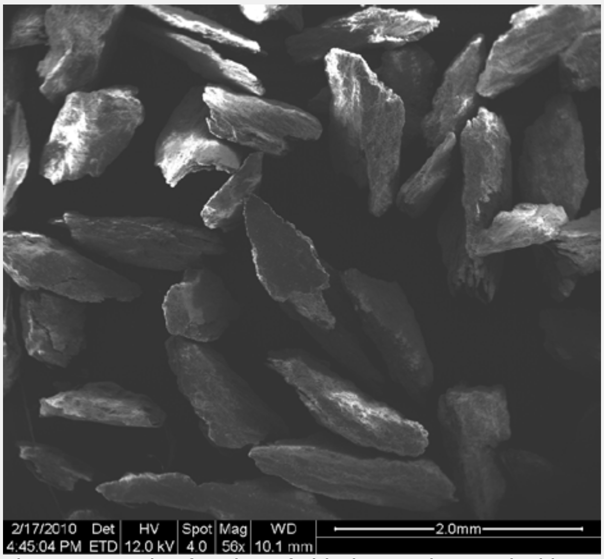
The general objective of the Swiw test with synthetic groundwater is to increase the understanding of the dominating retention processes and to obtain new information on fracture aperture and diffusion. The basic idea is to perform Swiw tests with synthetic groundwater with a somewhat altered composition,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

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

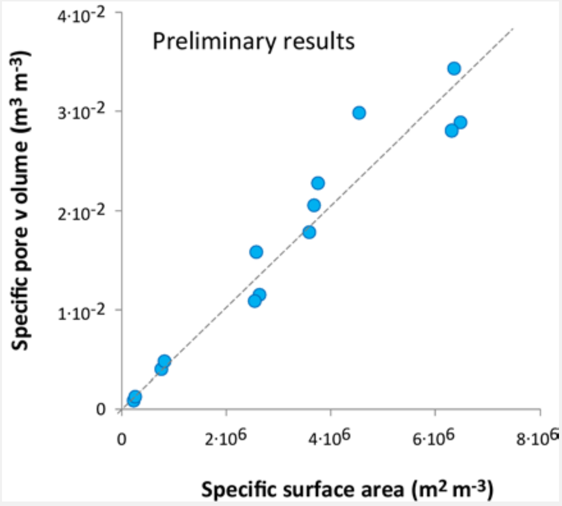
Achievements

The second Swiw pre-test, with 48 hours waiting period but otherwise identical to the first Swiw pre-test, has been carried out during the period. The results of the tests show that the equipment and test site is suited for the main Swiw tests with synthetic groundwater. The question is, however, raised if the waiting period should be more than the planned 48 hours in the main Swiw test. This is because when comparing the first Swiw pre-test without waiting phase with the second Swiw pre-test with waiting phase, there are no obvious effects of diffusion in the breakthrough curve of the second Swiw pre-test.

3.12 Äspö Model for Radionuclide Sorption



The 1-2 mm size fraction of chlorite as observed with SEM (Scanning electron microscopy).



The specific pore volume [m^3 m^{-3}] as function of specific surface area [m^2 m^{-3}] as observed for different size fractions of a chlorite sample.

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 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 second four-month period of 2010, determinations of the specific surface area of pure minerals using nitrogen and krypton gas were continued. In the BET-method, an inert gas (N_2(g) or Kr(g)) is sorbed to the surface of a substrate with known mass, and the sorption data is interpreted in terms of available surface area of the sample. Comparison of results from N_2(g) or Kr(g) adsorption showed to be similar for many of the minerals studied, see Figure 3-2. In order to test the reproducibility of the employed method for the mineral powders used, additional analyses for the two minerals, K-feldspar and chlorite, were also carried out.

Porosity determinations on some of the particle size fractions of the crushed mineral samples were initiated. In this method, the sorption/desorption behaviour of Kr(g) on the mineral sample is used to indicate pore volume and pore size. After testing and development of the method, the first, preliminary results for chlorite, K-feldspar and magnetite have been obtained. The results indicate that for the studied particle size range (0.075-8 mm), the characteristic pore size of one mineral does not vary systematically with the particle size. However, the specific pore volume seems to increase with decreasing particle size. This behaviour on particle size is similar as the one previously observed for the BET-surface area. For chlorite, a seemingly linear relation between the pore volume and the surface area was obtained (see figure above). Such dependence can be expected if the surface area is physically closely related to the pores of the sample. During the coming months, the method for determining porosity will be further tested and more mineral samples will be analysed, if the method is found reliable.

As a step toward better characterisation of the particle size fractions of the minerals, scanning electron microscopy (SEM) investigations have started. For chlorite of 1-2 mm size, see picture above, these first investigations confirmed the expected platy, parallelepiped form of the particles. They furthermore showed that the particles are almost entirely of adhering fine particles, which is needed for representative radionuclide sorption experiments and BET and porosimetry determinations.

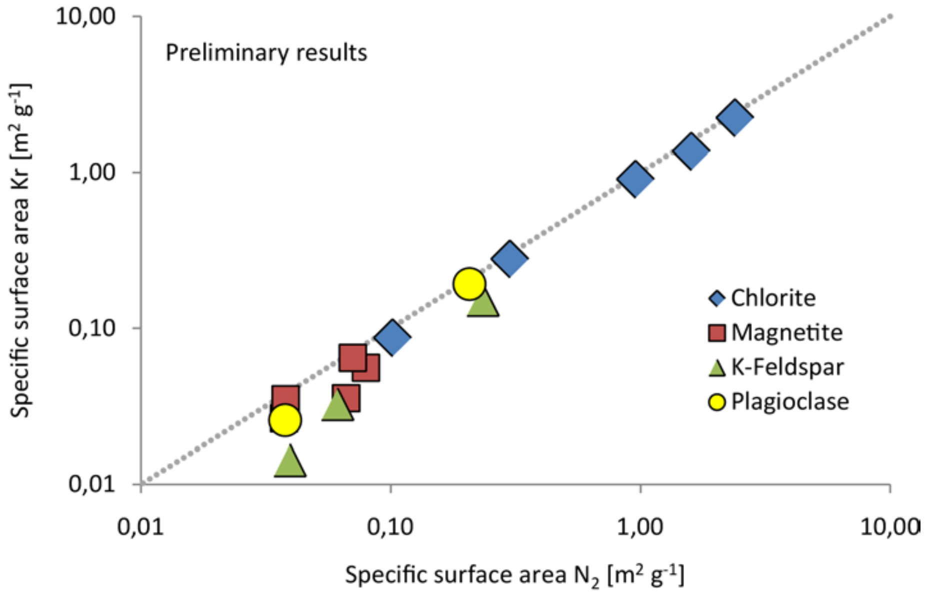
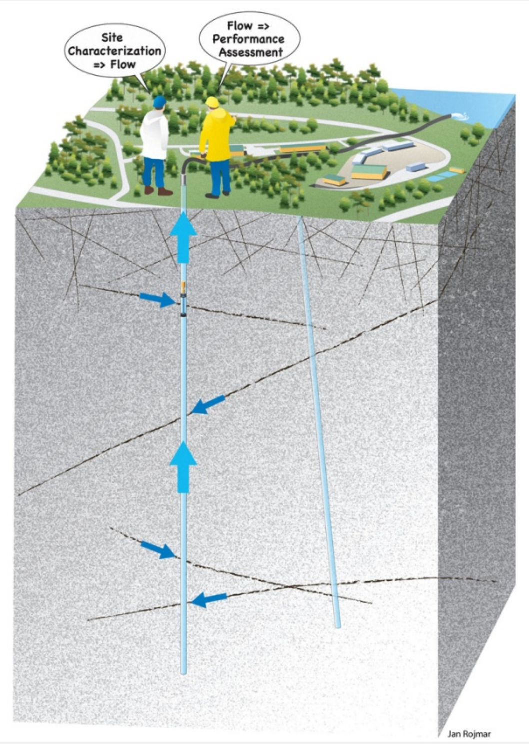


Figure 3-2. *Specific surface area as determined from Kr(g) sorption as function of the area determined from N_2(g) adsorption for four minerals. N.B. Logarithmic scale.*

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



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

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

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

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

Achievements

During the second 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. The status of the specific modelling tasks within Task 7 is given within brackets in Table 3-1.

Task 8 is addressing the interaction between the bentonite and the rock. Furthermore, 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.

The minutes from the 26th Task Force meeting in Spain has been sent out. At this meeting, a joint session was held with the Task Force on Engineered Barrier Systems, which enabled discussion on Task 8, and hopefully a start on some type of collaboration between the task forces including exchange of knowledge.

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

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. (Updated results presented at the 26th Task Force meeting in Spain).
7C	Here focus is on deposition hole scale issues, resolving geomechanics, buffers, and hydraulic views of fractures. (Updated results presented at the 26th Task Force meeting in Spain).
7D	Tentatively sub-task 7D concerns integration on all scales.

4 Engineered barriers

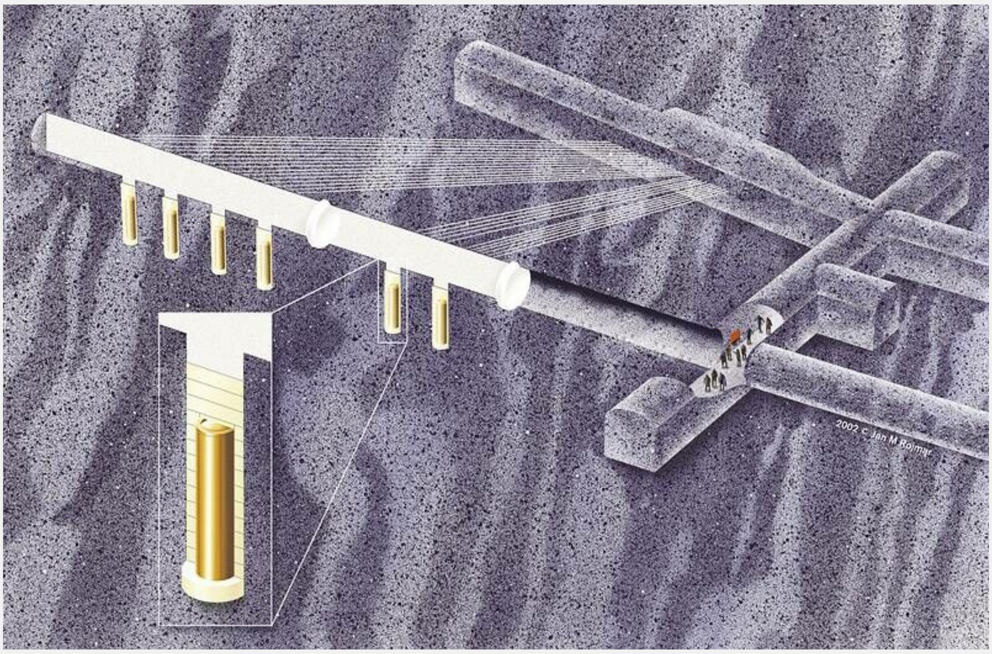
4.1 General

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 heater 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, pore water pressure, relative humidity and resistivity measurements in buffer and backfill, as well as temperature and water pressure measurements in boreholes in the rock around the tunnel. The collection of data is in progress and the data report No. 23 covering the period up to May 2010 has been finalised and will soon be published.

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

Sampling of gas and water from the buffer and backfill has continued during the period and some analyses have been carried out.

Hydraulic tests (single hole tests) were made at the end of 2009 in order to estimate the transmissivity of the rock around the Prototype Repository. Work with the report is ongoing and the results from the tests will be published as an international progress report.

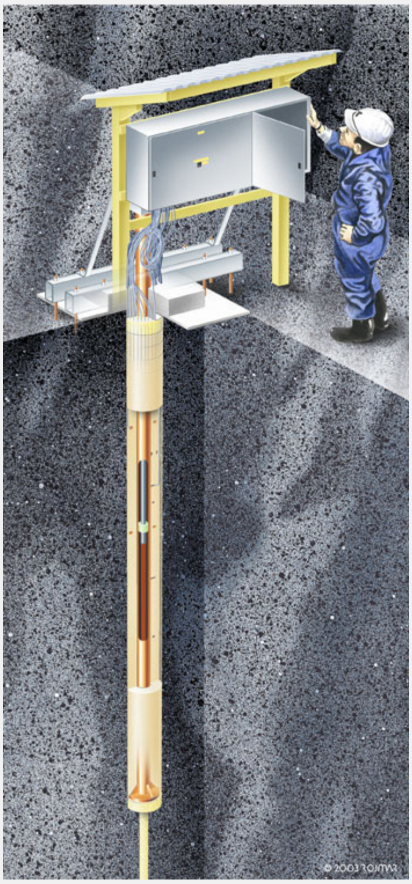
The third tracer dilution campaign during the Prototype Repository operation period was performed in January 2010. The purpose was to estimate the groundwater flows and hydraulic gradients in the vicinity of the boreholes and will function as a reference for comparison with results from modelling and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

The Prototype Repository will be 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 (section II which contains deposition holes 5 and 6) will be excavated 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.

A new project has been organised and started - Retrieval of the Prototype Repository – with the intention to dismantle the outer section after a period of 7 years of natural wetting. The excavation will be performed during 2011 and laboratory analyses, canister investigations and checking of sensors will be performed during 2010. The results will be summarised and reported in 2013. The retrieval of the Prototype Repository is a SKB – Posiva joint work.

4.3 Long Term Test of Buffer Material



Schematic drawing of a test parcel.

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 are made.

The test parcels are also used to study other processes in bentonite such as cation diffusion, microbiology, copper corrosion and gas transport under conditions similar to those expected in a KBS-3 repository.

Achievements

All the field equipment has been working well during the second four-month period of 2010 and data from the three ongoing test parcels have been collected and controlled, see Table 4-1.

The report concerning the A0 test has been sent to the two final reviewers and the plan is to publish the results in January 2011.

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:

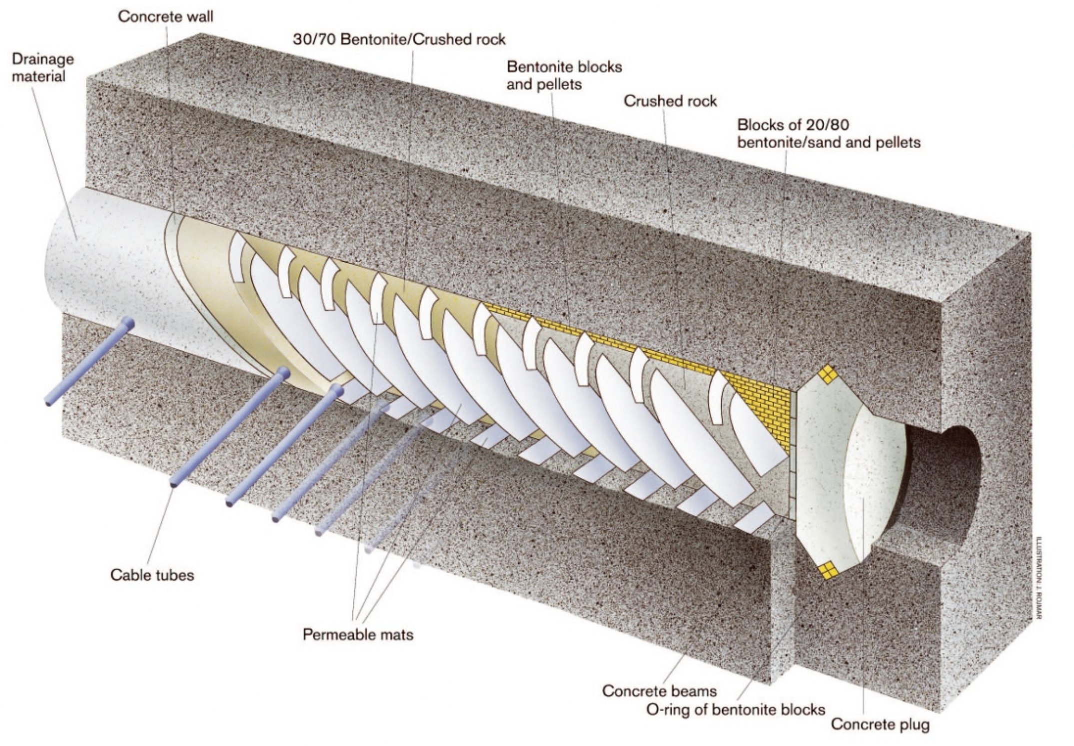
- Compare different buffer materials concerning mineral stability and physical properties, both in laboratory tests of the reference materials but also after exposure in field tests.
- Study the interaction between metallic iron and bentonite. This is possible since the central heaters are placed in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

Achievements

The work with analyses of material from parcel 1 (retrieved in May 2009) has continued during the second four-month period of 2010. The analyses financed by SKB are focusing on three materials: MX-80, Deponit CAN and Asha 505. The work is performed by Daniel Svensson, SKB (mineralogy), Clay Technology AB (physical properties) and MICANS (microbiology). The preliminary result from the laboratory analyses show that the degree of saturation was high in all positions of the test parcel (water content and density has been determined in all blocks). Swelling pressure and hydraulic conductivity have been determined in some positions for the three materials of main interest. A slight decrease in swelling pressure could be determined, especially for the Asha 505 material. X-ray Absorption Near Edge Structure (XANES) spectroscopy was performed at i811 at MAX-Lab, Lund. The clay blocks were sampled radially 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 two test parcels running have been collected and controlled during the period. A report, including results from the work with characterisation of the reference materials, the work with termination of test parcel 1 and results from analyses of the test material is under preparation.

4.5 Backfill and Plug Test



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

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

The entire test set-up with backfill, instrumentation and casting of the plug was finished in the end of September 1999 and the wetting of the 30/70 mixture through filter mats started in late 1999. The backfill was completely water satu-rated in 2003 and flow testing for measurement of the hydraulic conductivity was running between 2003 and 2006.

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

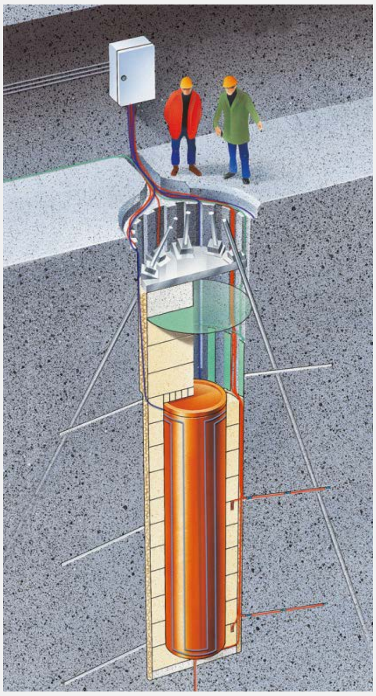
Achievements

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

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

The project is now under discussion and for now there is now no plan for the project or any decision made for the project.

4.6 Canister Retrieval Test



The Canister Retrieval Test (CRT) 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

Work concerning modelling of the natural homogenisation process of the buffer in the experiment was presented at the Engineered Barrier Systems Task Force meeting in May.

In addition, CRT modelling performed was presented at the "Workshop for Code_Bright users" in May. The title of the presentation was "Two modifications of Code_Bright-BBM to facilitate the representation of bentonite clay" and a paper was also written /Kristensson and Åkesson 2010/.

A SKB-report and an article on the buffer analyses will be finalised during 2010.

4.7 Temperature Buffer Test

The French organisation Andra carries out the Temperature Buffer Test (TBT) at Äspö HRL in co-operation with SKB. The aims of the TBT are to evaluate the benefits of extending the current understanding of the THM behaviour of engineered barriers during the water saturation transient to include high temperatures, above 100°C.

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

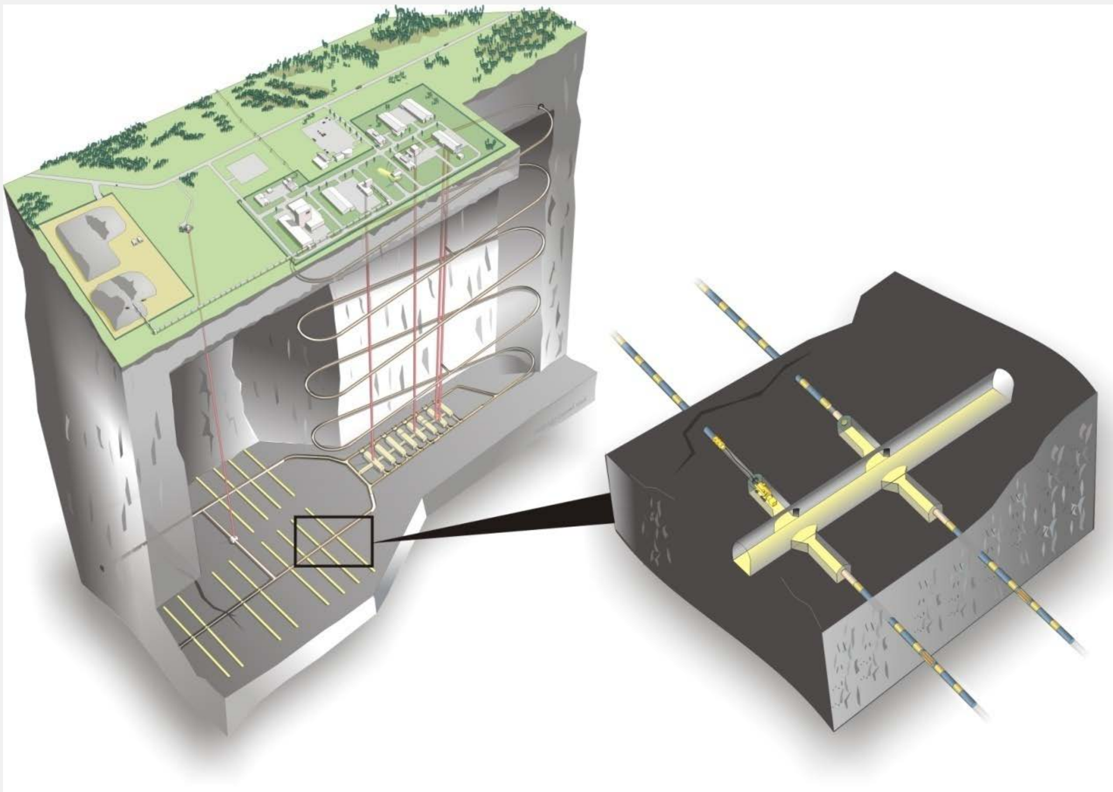
The test is located in the same test area as the Canister Retrieval Test, which is in the main test area at the -420 m level. The experiment includes two heaters in the axis of the deposition hole, one on top of the other, separated by a compacted bentonite block. The heaters are 3 m long and 610 mm in diameter and are constructed in carbon steel. Each one simulates a different type of confinement system: a bentonite buffer only (bottom section) and a bentonite buffer with inner sand shield (upper section). An artificial water pressure is applied in a slot between the buffer and rock, which is filled with sand and functions as a filter.

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

Achievements

The TBT experiment has now been fully dismantled. The determination of water content and density in bentonite core samples is also completed. The hydro-mechanical and chemical/mineralogical characterisation of bentonite has been launched during the period and currently is ongoing. The function control of collected sensors is also still ongoing. A project meeting was held in Paris on May 21. The reporting of the dismantling operation is ongoing and will continue during the autumn.

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 emplace-ment 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 six month compartment plug test phase is currently running. In the test the void behind the plug is filled with pellets and the water pressure kept at 5 MPa. Preliminary results indicate that the leakage through the plug is continuously low. The water consumption to maintain pressure is also low, indicating that the pellets are performing according to plan and sealing the fractures leading water away from the test volume.

The six month test will be completed at the end of September 2010 and the result included in the report being delivered at the end of the project phase. Discussions whether to perform a high pressure plug failure test is ongoing.

The planning of the sub system test phase has continued and the work follows the schedule. The completed project plan will be presented at the end of the project phase. Parts of the next phase of the project have also been incorporated in the LUCOEX EU application.

Fault localisation studies have been carried out on the KBS-3H deposition machine and a more extensive analysis has been ordered from NaviTec Systems Oy to define what improvements are needed on the control system for reliable operation. The analysis will be finalised in 2010 and should outline how to proceed with the development of the control system and which mechanical and sensor changes are required for reliable control. The work on the deposition machine is done in close connection and to a large extent by SKB's TDM group (Machine and system technology).

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

In the second third of 2010 (May – August; Day 1914 – Day 2037) the gas test in filter FL903 was completed. The test was started on the 28th May 2009 (day 1577). This period also included the hydraulic test following the gas test and preparation for the next stage of testing.

The evolution of injection gas pressure and flow into the clay is shown in Figure 4-2 and is a continuation of the results reported for the last four-month of 2009. As seen, the system continually over- and under-shoots as the pressure changes with time, as previously reported for laboratory experiments.

A hydraulic constant head test followed the completion of the gas test filter in FL903. The results of this test are shown in Figure 4-3, along with all of the three previous hydraulic test results. A similar curve is seen in the test results before and after the second gas test. This shows that the gas testing has had little effect on the hydraulic properties of the bentonite buffer. Comparing the hydraulic head tests for the two gas tests conducted shows that the buffer has continued to hydrate and mature, as seen by reduction in hydraulic conductivity and specific storage.

Neon gas sampling in the pressure relief holes following the completion of the hydraulic constant head testing showed that neon was now present outside of the Lasgit deposition hole.

During this reporting period a paper was submitted for peer review as part of the special publication of presentations at the 4th International Meeting on Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, Nantes 2010 /Cuss et al. 2010/.

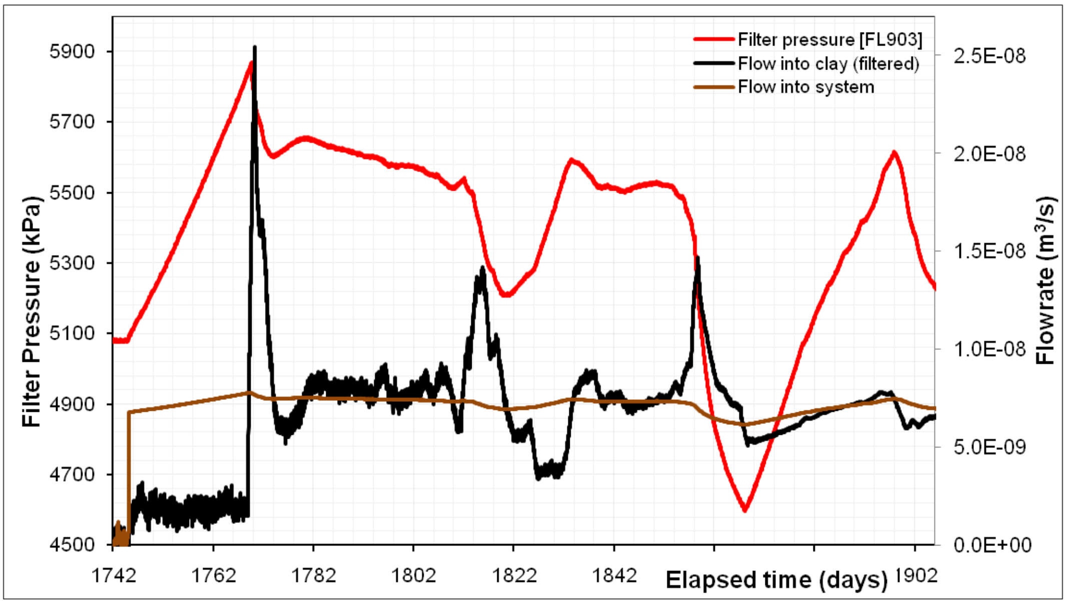


Figure 4-2. *The evolution of the injection gas pressure and the flow into the clay. The start of gas flow into the clay occurred at 5,833 kPa and the maximum gas pressure experienced was 5,872 kPa.*

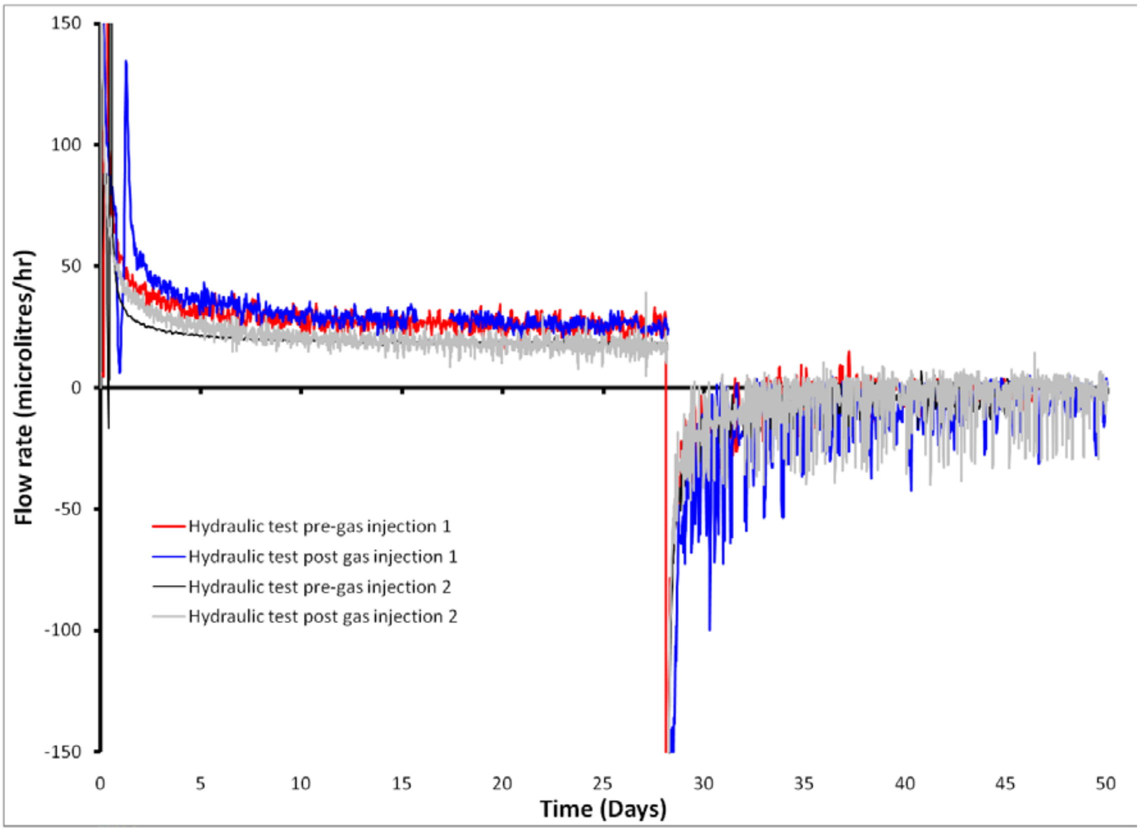
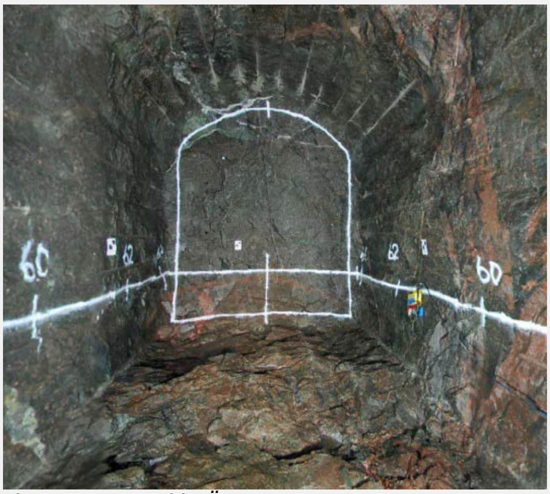


Figure 4-3. *The result for constant head tests conducted before and after the two gas injection tests conducted in filter FL903. The results show that the gas injection has little effect on the hydraulic performance on the buffer and that over time the bentonite has continued to mature, as seen by a reduction in flow rate.*

4.10 Sealing of Tunnel at Great Depth



The Tass-tunnel in Äspö HRL.

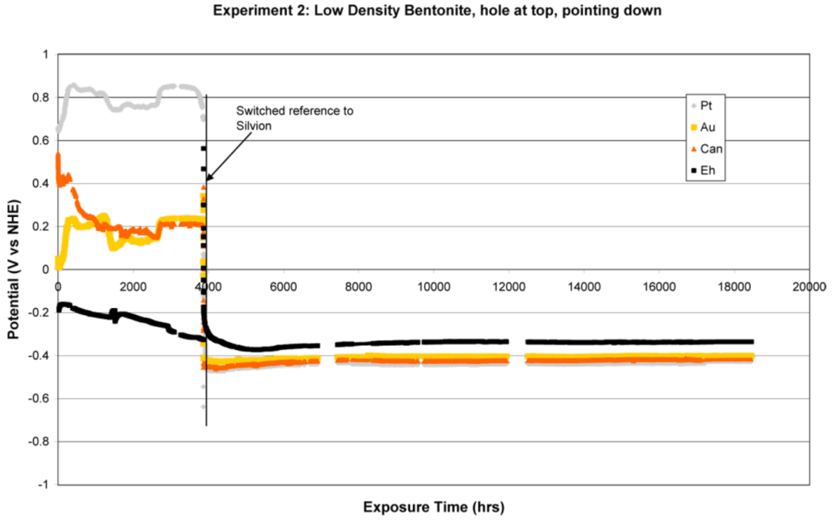
Although the repository facility will be located in rock mass of good quality with mostly relatively low fracturing, sealing by means of rock grouting will be necessary. Ordinary grouts based on cement cannot penetrate very fine fractures and due to long term safety reasons a sealing agent that produces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

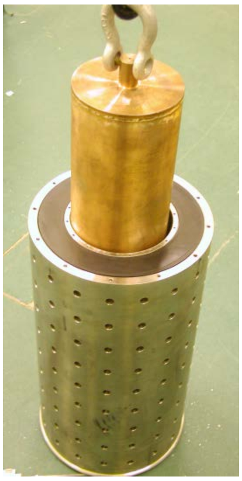
Achievements

The field works within the project are completed and measurements of leakage into the tunnel are the only ongoing work in field. Final reporting of the project is proceeding and is planned to be completed during the end of 2010.

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. Planning for the removal of experiment 3 is in further progress.

Project status has been presented at the TEF meeting at the 26th of May, and at the "4th International workshop on long-term prediction of corrosion damage in nuclear Waste systems" in Bruges, Belgium, 28th of June – 2nd of July 2010.

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 the major, important fracture zones that should be hydraulically separated. The results from the conceptual modelling work will be presented in a final report by the end of the year.

During the second four-month period of 2010, data and information have been collected from the different sub-projects. For the coming four months the data will be evaluated and reports will be written. Four reports, describing the results from Phase 4, are planned to be finalised at the end of the year.

4.13 Concrete and Clay

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

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

The project was initiated during 2009 and during 2010- 2012, a total of about 15 experiments will be prepared and installed at different sites in the Äspö tunnel.

The project is expected to run for up to 30 years but according to present plans the first experiments will be over-cored and retrieved and analysed already after 3 years. Experiments will then be retrieved at regular intervals and only a few will be left for the entire 30 year period.

Achievements

During the first stage of this project, long term studies of the degradation of waste in a cement based matrix have been initiated. This work has included grouting of a number of 1 meter long cylinders with a diameter of 300 mm in which different waste materials such as metals (aluminium, iron, steel and zinc) and organic materials (paper, rubber, cotton etc) were deposited. These cylinders were then placed in holes in the tunnel floor in one of the selected sites (the niche NASA0507A).

During the period May to August 2010, stage 1 of the project has been closed and the planning of the work for stage 2 was initiated. So far the main work has been focused on finding suitable sites for the experiments. During the next four-month period the planning of stage 2 will continue, which includes planning of the drilling of investigation holes on the selected sites as well as a preliminary selection of experiments for stage 2. The aim is to perform the site characterisation during early 2011 which means that the planning has to be completed during the end of 2010.

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 has for many years had a close co-operation with Posiva (Finland) and Numo (Japan) in this field. The main focus of the low-pH programme during 2008 and 2009 has mainly been on developing formulas for low-pH concrete to be used for construction of the sealing plugs for the deposition tunnels. In 2009 new field tests with rock bolts and shotcrete for rock support was performed at Äspö.

Achievements

The work during the first eight months of 2010 has mainly been limited to follow up the activities from 2009 on rock bolts and rock support. The design work of the plugs for the deposition tunnel has required additional investigations of the material parameters of the low-pH concrete.

The main activity during the reporting period has been the preparation of an official report of the work performed during 2009. The report is expected to be ready at the end of 2010. During the reporting period also the preparation for over coring of the first set of rock bolts has been ongoing, as well as follow-up of the corrosion experiments with carbon steel rock bolts in low-pH concrete.

The work within the pH-project has been ongoing during the reporting period. In February pH-measurements had been performed in nine laboratories in six different countries. Analysis of the results was done during March and April and an interim report was presented mid April.

In June 2010 “real” samples of low pH-products have been prepared by four members of the consortium. The pH-measurements were done during September in the same laboratories as in the previous phase. The analysis of the results and reporting of this second phase will be ongoing up to the later part of 2010. The pH-project is expected to be finished in April/May 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

An evaluation of the construction between friction and vault plug has been made and the choice for further design development will be a vault plug of low-pH concrete, see Figure 4-4. All important documents and results have been compiled in a decision document to ensure the traceability of the choices made for the reference design. Other results from the project are:

- Conditions, demands and function descriptions.
- Construction documents.
- Method description and a control programme.

The project has reached the final phase which is to compile the complete results in a report in the SKB series, which will be published during spring 2011. The results are now handed over to a newly started 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 experiment in Äspö HRL at approximately -450 m depth during 2011. A pilot study of the planned full scale experiment was approved in August 2010.

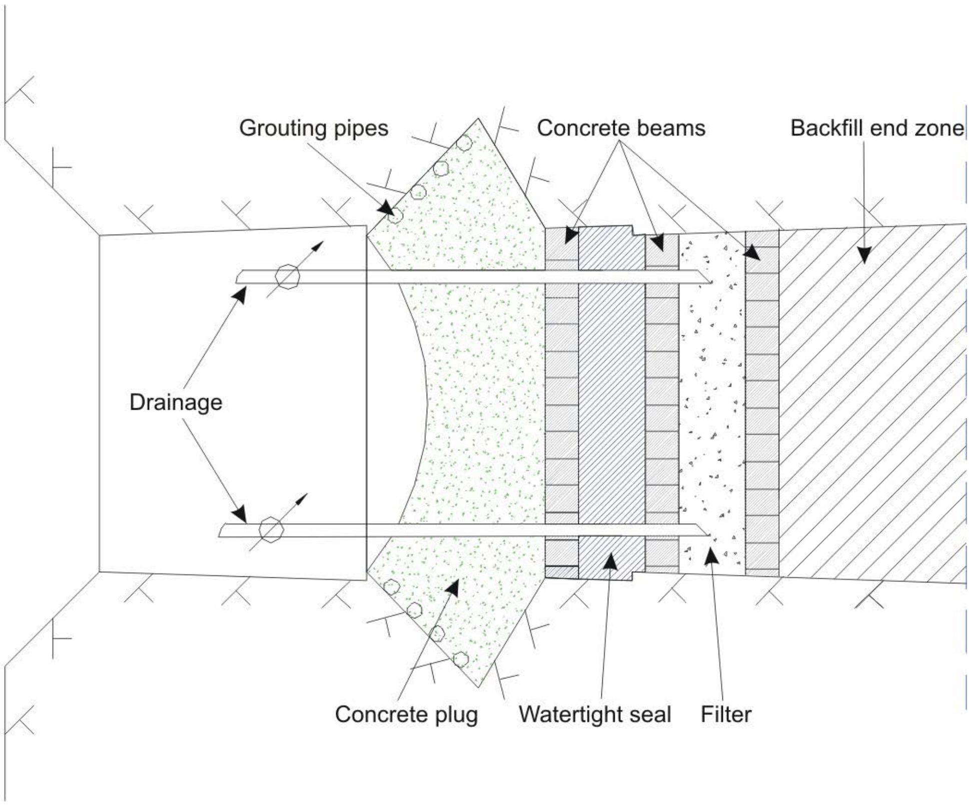


Figure 4-4. *The reference design for end plugs for deposition tunnels.*

4.16 Task Force on Engineered Barrier Systems

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

Task 1 - THM modelling of processes during water transfer in buffer, backfill and near-field rock. Only crystalline rock is considered initially, although other rock types could be incorporated later.
Task 2 - Gas migration in saturated buffer.

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

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

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

Achievements

The 11th meeting of the Task Force on Engineered Barrier Systems was held in Barcelona in May. In this meeting half a day was devoted to the geochemistry session, ¾ of a day was devoted to the THM session and ¾ of a day was used for a joint meeting with the Task Force on Ground Water Modelling, regarding Task 8.

Task Force THM/Gas
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. The teams have finished their calculations but some reporting remains. Five of the teams have modelled the entire test, while the other three have only modelled the central section. The final results of the modelling of the Canister Retrieval Test were presented in the meeting in Barcelona in May. Altogether 8 modelling teams have been modelling this test. The reporting of the work has continued during the last four-month period.

Four detailed suggestions of modelling tasks for the next phase of the Task Force were presented during the meeting. Further preparations of these tasks have been made during summer 2010. The planned next phase includes so far the following tasks:

- **Sensitivity analyses -** This task implies sensitivity analyses with simple models. 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 influence of different conditions and parameter values will then be investigated with sensitivity analyses by varying parameters and conditions.
- **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.
- **Homogenisation** - This is a task related to erosion and subsequent homogenisation of the buffer but can also refer to homogenisation in general.
- **Prototype Repository** - This task is to model one of the two outer deposition holes in the Prototype Repository in Äspö HRL. A preliminary task definition has been delivered to the modelling teams and was presented during the meeting in Barcelona in May.

Task Force Geochemistry

An "intermediate" workshop for the geochemical part of the EBS Task Force was held in Speyer, Germany 30th of June – 1st of July, 2010. Among the topics were:

- The creator of the reactive transport code CRUNCHFLOW, Carl Steefel, presented newly implemented multi-porosity features and also gave a hands-on tutorial in using the program. Carl Steefel will most probably continue his interactions with the geochemical group of the EBS Task Force.
- Experimental and theoretical considerations of couplings between transport phenomena (water flow, ionic diffusion) and swelling pressure response in compacted bentonite were presented by Clay Technology.
- The in-house multi-purpose code QPAC were presented by Quintessa. This code allows for implementation of the ion-equilibrium approach to compacted bentonite.
- Discussion of the applicability of multi-porosity and interlayer-only (ion equilibrium) models.

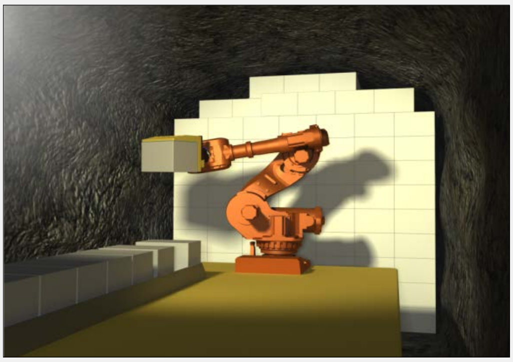
Work on a final report on the activities during the first phase of the geochemical part of the EBS Task Force (2006-2009) is ongoing, and will be presented by the involved groups at the upcoming meeting in Prague, in November 2010.

5 Mechanical- and system engineering

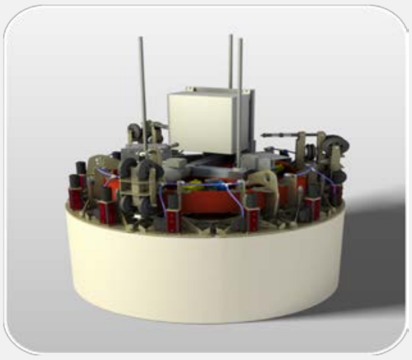
5.1 General

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 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, buffer emplacement, deposition machine, logistics study, multipurpose vehicle for heavy transports, transport system, drill and production system.

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 that need to be developed for the future final repository have been identified in an inventory project. A total of 175 different products and components known today are to be developed. Preliminary plans were made on when the production of machines must begin and when they should be completed. In addition, assessment could be made whether production of prototypes are necessary. The number of objects and affiliated information is due to change since the specifications are working documents.

The development of a model for costs has been included in the work. Several projects within mechanical- and system engineering are ongoing and the activities in some of the different projects are described in the text below.

Equipment for backfilling

In the project design and testing of backfilling equipment are performed. The simulation of a concept showed that a robot should be able to place 220 tons of backfilling blocks per day, which presently is a requirement for the logistics in the final repository for spent fuel. Future work includes building and testing a prototype of the handling equipment, which will consist of a mobile platform and an industrial robot with a vacuum tool. Testing will be performed both at the bentonite laboratory and at Äspö HRL at the -420m-level.

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 steering gear of the emplacement tool was completed during the first four-month period of 2010. The tool uses vacuum to lift the bentonite rings and is 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.

Presently 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, sequence and how the tests are documented. Performance of the tests is estimated to start shortly.

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 initial trial run commenced in the beginning of 2010 and product information on the deposition machine was developed. During the second four-month period of 2010 fine tuning of the software have continued and the earlier errors in the software have been corrected. A remote connection was installed and deployed and Navitec System are now using the remote connection for maintenance and fine tuning of the software. In addition, an uninterruptible power supply (UPS) has been installed for the screens in the driver cabin.

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) will be 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.

To perform tendering and ordering of the vehicle, a project was initialised during the spring and has resulted in advertisement on the European homepage of Simap Information on public procurement. SKB has received five offers and is, after an evaluation procedure, in negotiations with a supplier.

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 3 to 4 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.

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

Transport system

A feasibility study aiming at finding a solution for the transportation of buffer and backfill material has been carried out during the first eight months of 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 is produced.

The intention is now for the feasibility study to pass into a project. A project plan with analysis of consequences and a project directive are under development. The aim is to increase the level of detail of the concept and develop specifications of requirements for the equipment included.

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.

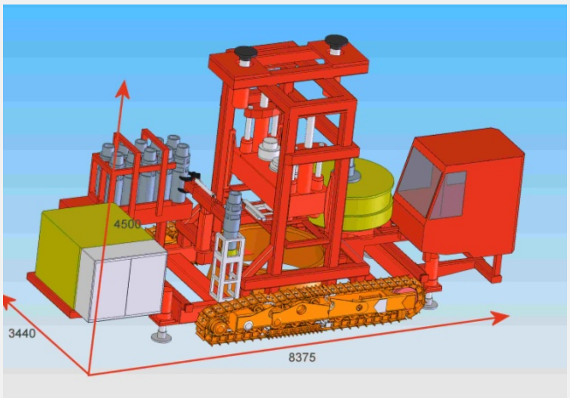
Production system

Within this project, a prototype is to be developed of a comprehensive automatic system for the management and control of transport and production logistics for the final repository. Preparatory work has been made during the period and the project will formally start in October 2010.

Drilling Machine for Deposition Holes

A feasibility study of a self propelled drilling machine using the push reaming technique has been performed by SKB and the study was completed late 2008. The requirements for the deposition holes are very stringent as well as production rate and costs for the drilling of the deposition holes.

From early 2009, SKB and Posiva have discussed to form a joint project for the continued work with the drilling machine. However, Posiva is now expected to have a new drill available for these purposes during 2011 and SKB are currently following Posiva's work on the subject.



Artist impression of the drilling machine for deposition holes with preliminary dimensions.

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 stringent requirement on the deposition hole and still have high production rate required for the final repository.

This technology has also 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 the -220 m level in Äspö HRL.

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.

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

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

The 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 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

Test set-up for the deposition tunnel in half-scale.

Before building a final repository, where the operating conditions include deposition of about 150 canisters annually, 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

During the second four months no tests have been done. Tests will be 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 will include stacking of blocks on different bed materials, with and without concurrent water inflow. 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.

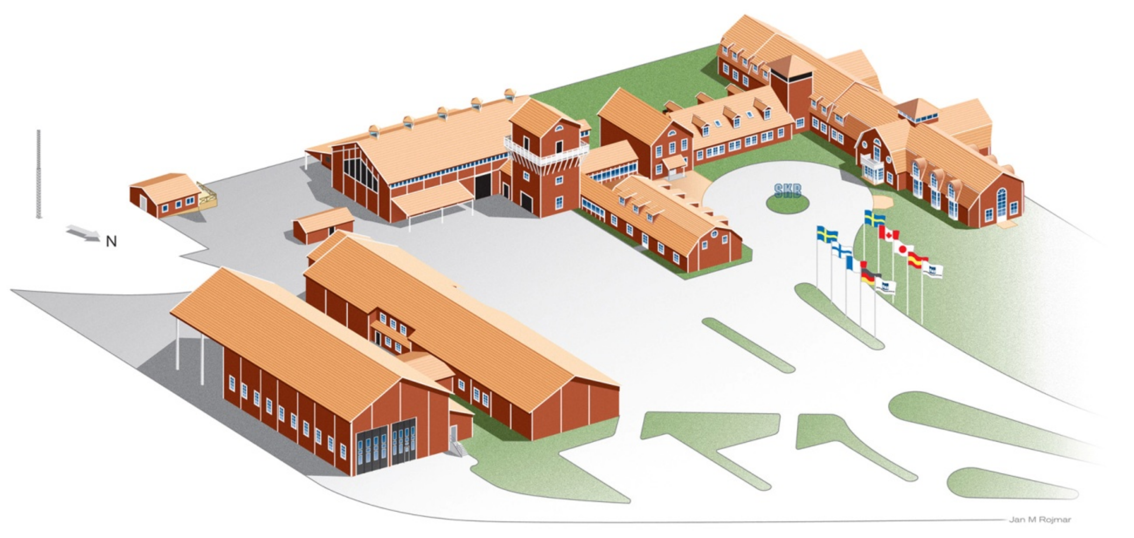
The second part includes a test series in which “wetted pellets” is placed in contact with “dry pellets” for simulating quick water saturation of parts of the tunnel backfill separated by less wet pellet fill into which water flows at a late stage. The major objective of the experiments in these tests 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 filling from an inflow spot can change 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.

A report from sub-project 1 is ready for review and a report from sub-project 2 will be ready during autumn. The project should be finished before the end of the year.

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 facility has been stable during the first eight months of 2010 and the underground facility has only been closed for planned stops.

The rock maintenance has been carried out as planned during this four-month period, and the new work platform works as planned. The works of maintenance is now both faster and safer. The updating of facility documentation and construction drawings is continuous ongoing.

The exchange of cable ladders, to a stainless steel model, in the elevator shaft between the levels -340 m and -220 m has been carried out during the summer and work on upgrading elevator machine has been performed. A new computer security has been installed and the unit has been replaced by a new and more modern model. To maintain security, the tunnel was closed off while the work was going on, and only emergency work was carried out.

Work to restore the Tasq-tunnel after completing the experiments has begun. In the tunnel new measuring dykes will be casted, and then the roadway will be paved with asphalt.

During the planning of the excavation of the outer part of the Prototype Repository it was found that in order to do the necessary analyses a good geotechnical laboratory is required. After much discussion it was decided that the present goods receipts will be converted to that purpose. The goods receipt must then move to the current drilling core archive, which now needs smaller space since many cores can be stored elsewhere. Drawings for the new geotechnical laboratory are going to be produced and the conversion to a geotechnical laboratory will begin during the autumn.

6.4 Communication Oskarshamn

As from May 2010 the former Public relations and visitor services group, TDI, organisationally is transferred to the reorganised Communications department within SKB. The group and its personnel is however still located at Äspö HRL and have a continuously close co-operation with the facility and the daily coordination of underground activities.

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 Äspö facility, Clab and the Canister Laboratory.

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

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

The team also has the responsibility for the production of SKB's exhibitions.

As from May 2010 the group is a part of the Department of Communications.

Achievements

SKB facilities have been visited by 7,683 persons during the second four-month period of 2010. The numbers of visitors to SKB's main facilities are listed in Table 6-1.

There have been a number of VIP-visits during the period, and many of them have been international: TAEC, Japan (Forsmark and Oskarshamn) NDA, England (Forsmark and Oskarshamn), Dutch Ministry of Economic Affairs (Forsmark), Taiwan Power Company (Forsmark), EDF, France (Oskarshamn). There have also been visits from IF-Metall, Swedish Radiation Safety Authority with guests, researchers from the Linné University and the Royal Institute of Technology as well as the Swedish Research Council, just to mention a few.

Table 6-1. Number of visitors to SKB's main facilities.

SKB facility	Number of visitors June - August 2010
Central interim storage facility for spent nuclear fuel	606
Canister Laboratory	633
Äspö HRL	3,630
Final repository for radioactive operational waste (SFR)	2,814

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.

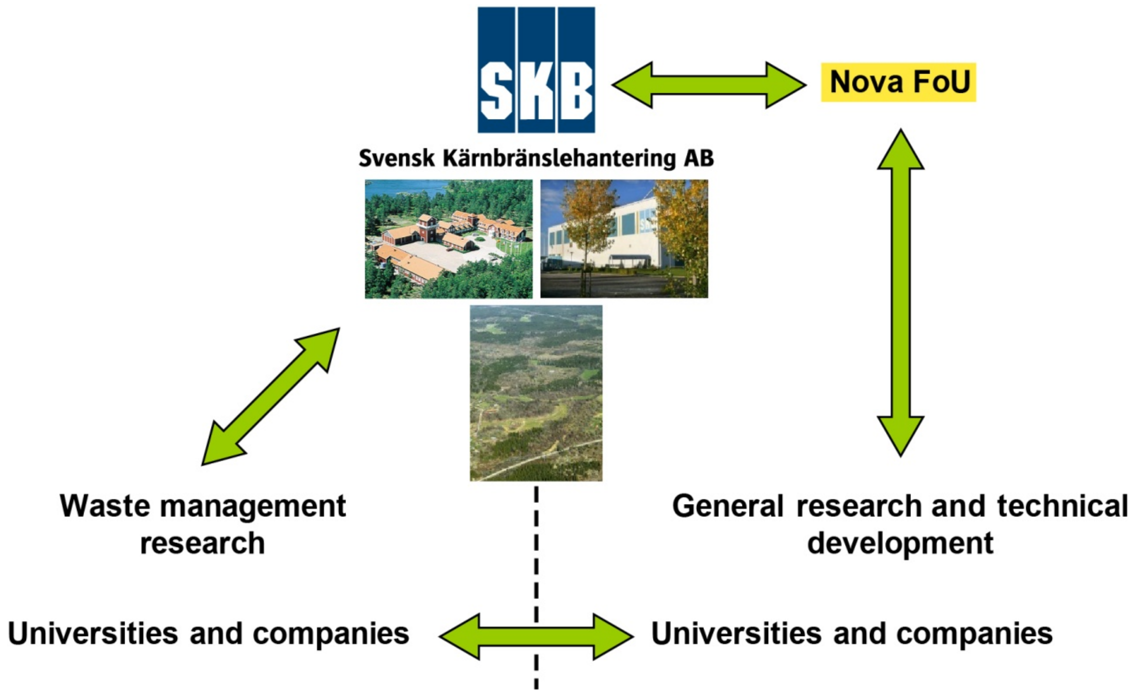


Figure 7-1. *Nova FoU provides access to the SKB facilities and data for universities and companies for general research and technical development. Nuclear waste management research is handled by SKB.*

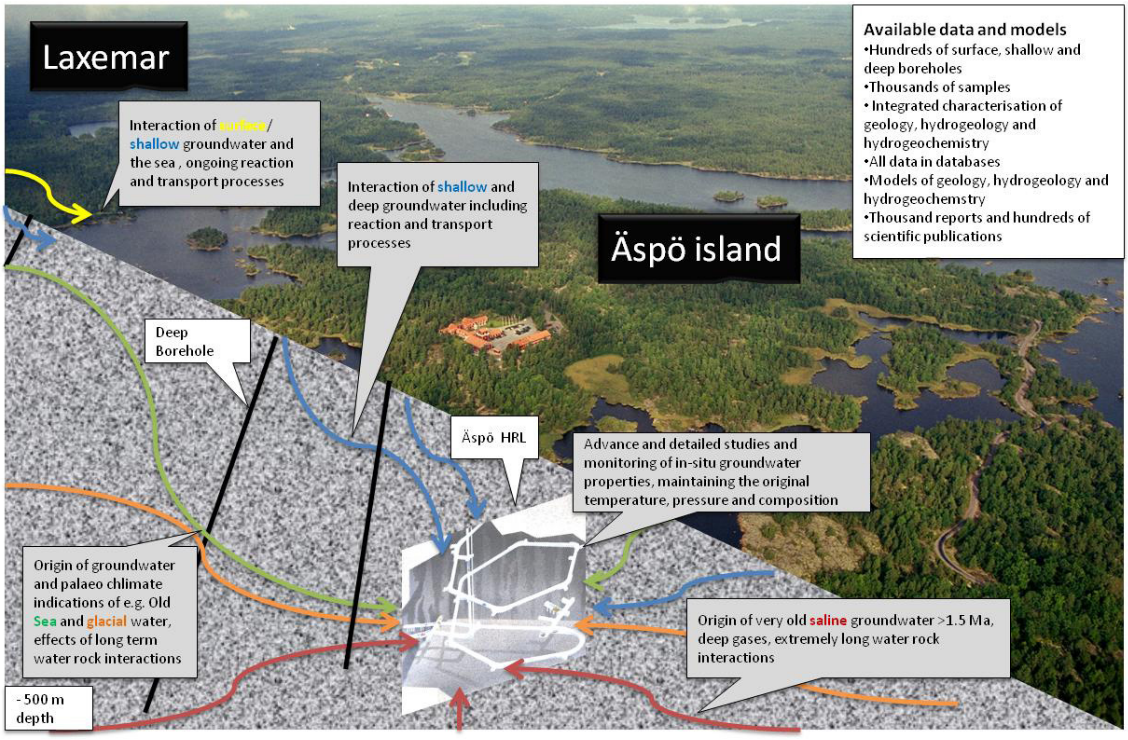


Figure 7-2. *The Äspö and Laxemar areas have been studied in terms of geology, hydrogeology, hydrogeochemistry and ecology. This information can be used for a number of purposes, for example to describe the water cycle and hydrogeochemical processes in 3D.*

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 work and technical development 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 space

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:

- Lanthanoids 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)

The status of the 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 groundwater 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 M3 modelling, and (3) the relationship between lanthanoid concentrations and drilling-water % in groundwater samples have been studied.

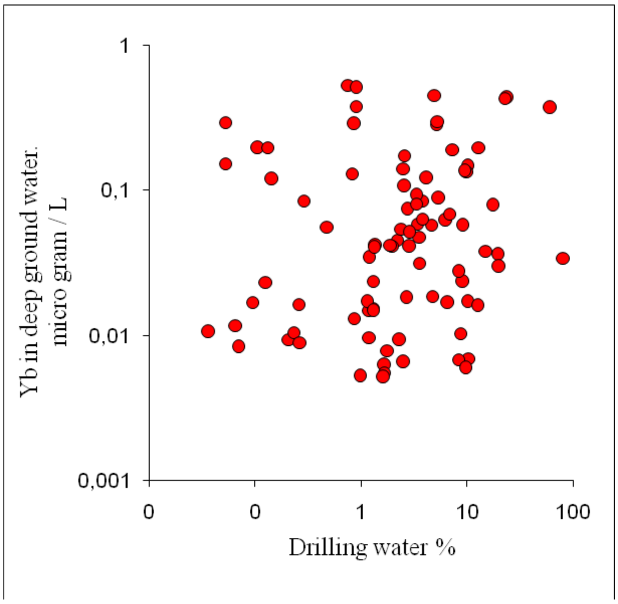


Figure 7-3. *Scatterplot of drilling-water percentage and lanthanoid concentrations in groundwater.*

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.

The calcites show overall a strong relative enrichment of the light lanthanoids, which also is to be expected from partition coefficients obtained in other previous laboratory experiments. The extent to which the light lanthanoids are enriched however varies substantially, and 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 actinoids) 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 (this stream was included within Site Investigation Oskarshamn, see **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).

Work with writing an article concerning the fluoride in Kärrsviks stream catchment is ongoing and will be finished by the end of 2010.

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 ground waters 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 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.

The major results for the Äspö SDM project are:

- Meteoric and glacial reference water dominates in the mixtures (Figure 7-5).
- 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, changes in mixing proportion with time are noticed. These changes are connected with the increase of the salinity (Figure 7-5).
- 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.

Spin-off effects from the project:

- The Äspö SDM project is used as a test case for methods and descriptions to be used when constructing the final repository.
- The modelling will give understanding of the groundwater evolution during and after the tunnel constructions in crystalline bedrock.

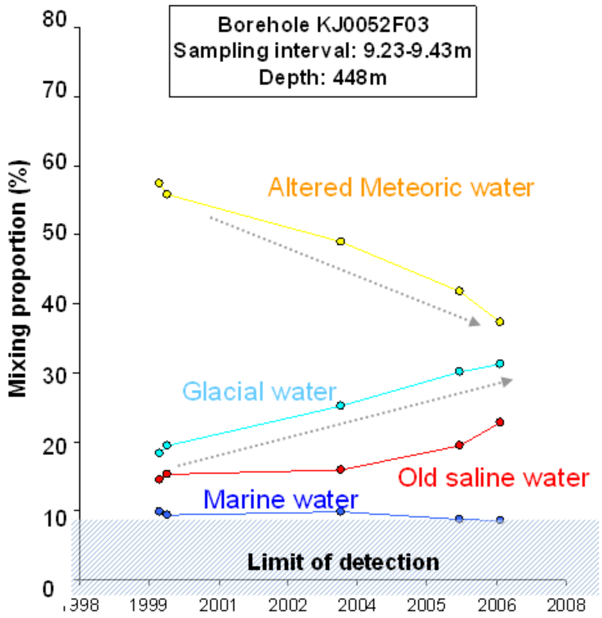


Figure 7-5. Changes of the mixing proportions with time in the borehole KJ0052F03 in the Äspö tunnel.

7.3.4 Geobiology of microbial mats in the Äspö tunnel

Aim and setup

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), 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. The project will continue until the end of 2011.

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 co-operation with SP, Borås) and Raman spectroscopy.

Microbiological Results

16S rDNA-DGGE analyses reveal that fluid-borne microorganisms of aquifers (down to location 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-oxidizer *Gallionella ferruginea*, are generally multilayered systems with bacteria similar to ammonia-oxidizers like *Nitrosomonas sp*., to the sulphur-oxidizing *Thiocapsa sp*. and the lithoheterotrophic alpha-proteobacterium *Citricella thiooxidans.* As the most representative for the deep biosphere system, the aquifer of the deepest section of the Tasf-tunnel clearly differs in community composition, biofilm structure and complexity from all other sites investigated.

Geochemical results

Analysis of Trace and Rare Earth Element (TREE) accumulations within iron oxidizing microbial mat communities in the dark and air-tight flow reactors in the Tasa-tunnel (1327B) 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.

ToF-SIMS was implemented as a new method for identifying organic biomarkers and spatially resolve their distribution directly on geobiological samples. ToF-SIMS imaging was successfully applied to microscopic cryosections of mineralised microbial mats to correlate specific components (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 existed during a late glacial period, when the fracture was reactivated and water conducting.

Potential spin-off effects from the project

Microbial mats accumulating TREE may potentially be used for the recovery of precious trace elements, thereby cleaning the water. 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. During the fall, the plan is to complete the computations of the transit time distributions and present a first outline of a manuscript for a technical journal.

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 7-6) 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.

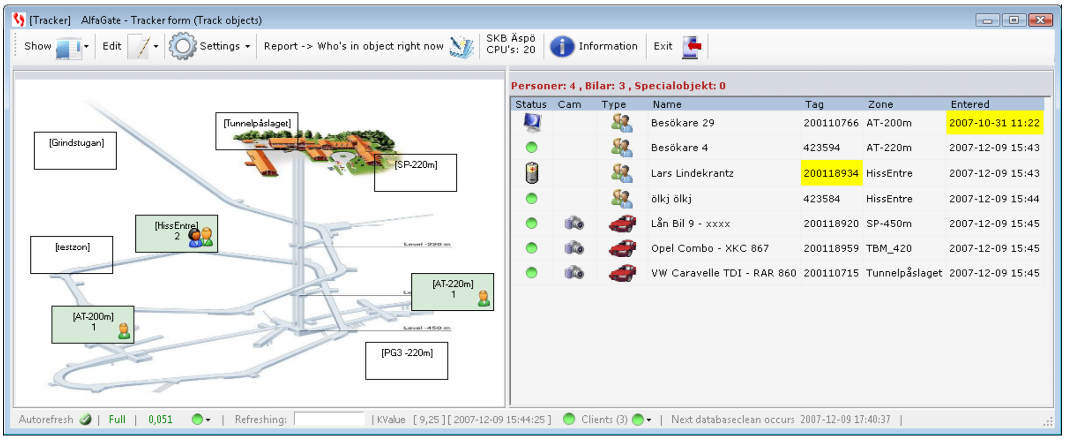


Figure 7-6. *AlfaGate Tracker is the visualisation system which shows the locations of the persons in the Äspö HRL.*

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 effects from the project are that there is a great commercial interest for the system in Sweden and abroad. Additional local competences are needed in the company and co-operation 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 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 aim of the project is to develop technology to utilise excess low graded heat from industry. A feasibility study is ongoing and will list six possible research projects within this field. The next step is to get funding to make applications for different energy project in EU and in Sweden including the Swedish Energy Agency. This part of the project will approximately finish before the end of this year. The spin-off effect of this project is that it will create local competence in a field of potential global interest.

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. 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.

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

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
Radioactive Waste Repository Authority, Rawra, Czech Republic

* Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, Switzerland left the central and active core of participants 2003 but are nevertheless supporting the Äpsö acitivites and participates in the specific projects that the table 8-1 shows.

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. Several of the participating organisations also take part in the project Alternative Buffer Materials.

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 May - August 2010, the following reports have been published and distributed.

9.1 Äspö International Progress Reports

SKB, 2010a. Äspö Hard Rock Laboratory. Planning Report for 2010. SKB IPR-10-06, Svensk Kärnbränslehantering AB.

Wass E and Nyberg G, 2010. Hydro Monitoring Programme. Report for 2009. SKB IPR-10-08. Svensk Kärnbränslehantering AB.

SKB, 2010b. Äspö Hard Rock Laboratory. Status Report. September - December 2009. SKB IPR-10-09. Svensk Kärnbränslehantering AB.

9.2 Technical Documents and International Technical Documents

Three Technical Documents have been published during the period May - August 2010.

10 References

Andersson C, Johansson Å, 2002. Boring of full scale deposition holes at the Äspö Hard Rock Laboratory. Operational experiences including boring performance and a work time analysis. SKB TR-02-26, Svensk Kärnbränslehantering AB.

Andersson P, Byegård J, Billaux D, Cvetkovic V, Dershowitz W, Doe T, Hermanson J, Poteri A, Tullborg E-L, Winberg A, 2007. TRUE Block Scale Continuation Project. Final Report. SKB TR-06-42, Svensk Kärnbränslehantering AB.

Autio J, 1997. Characterization of the excavation disturbance caused by boring of the experimental full scale deposition holes in the Research Tunnel at Olkiluoto. SKB TR-97-24, Svensk Kärnbränslehantering AB.

Cuss R J, Harrington J F, Noy DJ, Wikman A and Sellin P, 2010. Large scale gas injection test (Lasgit): Results from two gas injection tests. Part of the special publication of presentations at the 4th International Meeting on Clays in Natural and Engineered Barriers for Radioactive Waste Confinement, Nantes 2010.

Cvetkovic V, 2010. Significance of fracture rim zone heterogeneity for tracer transport in crystalline rock, Water Resources Research, doi: 10.1029/2009WR007755.

Cvetkovic V, Frampton A, 2010. Transport and retention from single to multiple fractures in crystalline rock at Äspo (Sweden): 2. Fracture network simulations and generic retention model, Water Resources Research, doi:10.1029/2009WR008030.

Cvetkovic V, Cheng H, Byegard J, Winberg A, Tullborg E-L and Widestrand H, 2010. Transport and retention from single to multiple fractures in crystalline rock at Äspo (Sweden): 1. Evaluation of tracer test results and sensitivity analysis, Water Resources Research, doi:10.1029/2009WR008013.

Kristensson O, Åkesson M, 2010. "Two modifications of Code_Bright-BBM to facilitate the representation of bentonite clay", in the precedings of the "Workshop for Code_Bright users", UPC, Barcelona.

Magnor B, Hardenby C, Kemppainen K, Eng A, 2007. Rock Characterisation System - Rocs. Final report - feasibility study, phase l. State-of-the-art in 3D surveying technology. SKB IPR-06-07, Svensk Kärnbränslehantering AB.

Mathurin F A, Kalinowski B E, Åström M, Laaksoharju M, 2010. Temporal evolution of groundwater chemistry in fractured bedrock at depth between 400 and 700 m: results of the M3 modelling. Extended abstract to 13th Water-Rock Interaction (WRI-13) in Guanajuato, Mexico, 2010.

Pedersen K, 2001. Diversity and activity of microorganisms in deep igneous rock aquifers of the Fennoscandian Shield. In Subsurface microbiology and biogeochemistry. Edited by Fredrickson J.K. and Fletcher M. Wiley-Liss Inc., New York. pp 97-139.

Pedersen K, 2002. Microbial processes in the disposal of high level radioactive waste 500 m underground in Fennoscandian shield rocks. In Interactions of microorganisms with radionuclides. Edited by Keith-Roach M.J. and Livens F.R. Elsevier, Amsterdam. pp 279-311.

SKB, 2007. Fud-programme 2007. Program för forskning, utveckling och demonstration av metoder för hantering och slutförvaring av kärnavfall. Svensk Kärnbränslehantering AB (In Swedish).

SKB, 2010. Äspö Hard Rock Laboratory. Planning Report for 2010. SKB IPR-10-06, Svensk Kärnbränslehantering AB.

Smellie J A T, Waberg H N, Frape S K, 2003. Matrix fluid chemistry experiment. Final report. June 1998-March 2003. SKB R-03-18, Svensk Kärnbränslehantering AB.

Wass E, Nyberg G, 2010. Hydro Monitoring Programme. Report for 2009. SKB IPR-10-08. Svensk Kärnbränslehantering AB.

Winberg A, Andersson P, Hermanson J, Byegård J, Cvetkovic V, Birgersson L, 2000. Äspö Hard Rock Laboratory. Final report of the first stage of the tracer retention understanding experiments. SKB TR-00-07, Svensk Kärnbränslehantering AB.

Winberg A, Andersson P, Byegård J, Poteri A, Cvetkovic V, Dershowitz W, Doe T, Hermanson J, Gómez-Hernández J, Hautojärvi A, Billaux D, Tullborg E-L, Holton D, Meier P, Medina A, 2003. Final report of the TRUE Block Scale project. 4. Synthesis of flow, transport and retention in the block scale. SKB TR-02-16, Svensk Kärnbränslehantering AB.