International
Progress Report

IPR-05-09

Äspö Hard Rock Laboratory

Status Report
October – December 2004

Svensk Kärnbränslehantering AB

March 2005

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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 deep geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site.

The plans for SKB's research and development of technique during the period 2005–2010 are presented in SKB's RD&D-Programme 2001 /SKB, 2001/. The information given in the RD&D-Programme related to Äspö HRL is annually detailed in the Äspö HRL Planning Report /SKB, 2004/.

This Äspö HRL Status Report is a collection of the main achievements obtained during the fourth quarter 2004.

Technology

One of the goals for Äspö HRL is to demonstrate technology for and function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a real repository. A number of large-scale field experiments are therefore conducted at Äspö HRL: Canister Retrieval Test, Prototype Repository, Backfill and Plug Test, Long Term Test of Buffer Material, Cleaning and sealing of investigation boreholes, Injection grout for deep repositories, KBS-3 method with horizontal emplacement, Large Scale Gas Injection Test, and Temperature Buffer Test.

Geo-science

Geo-scientific research is a natural part of the activities at Äspö HRL. Studies with the major aims to increase the understanding of the rock mass material properties and to increase the knowledge of measurements that can be used in site investigations are important activities: Geological mapping and modelling, Rock stress measurements, Rock creep, Äspö Pillar Stability Experiment, Heat transport, and Seismic influence on the groundwater system.

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 the deep repository and to provide data for performance and safety assessment. The experiments performed at conditions expected to prevail at repository depth are: Tracer Retention Understanding Experiments (True Block Scale Continuation and True-1 Continuation), Long Term Diffusion Experiment, Radionuclide Retention Experiments, Colloid Project, Microbe Project, and Matrix Fluid Chemistry.

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

Äspö facility

An important part of the work at the Äspö facility is the administration, operation, and maintenance of instruments as well as development of investigation methods. Other issues are to keep the stationary hydro monitoring system (HMS) continuously available and to carry out the programme for monitoring of groundwater head and flow and the programme for monitoring of groundwater chemistry.

International co-operation

The Äspö HRL has so far attracted considerable international interest. Seven organisations from six countries participate during 2004 in the co-operation apart from SKB. In addition, SKB takes parts in several EC-projects.

Environmental research

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

Contents

1 General

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

One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. The underground part of the laboratory consists of a tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 460 m. The rock volume and the available underground excavations have to be divided between all the experiments performed at the Äspö HRL. In Figure 1-1 the allocation of the experimental sites in Äspö HRL are shown.

The Äspö HRL and the associated research, development, and demonstration tasks, managed by the Repository Technology Department within SKB, have so far attracted considerable international interest.

SKB's overall plans for research, development, and demonstration during the period 2005–2010 are presented in SKB's RD&D-Programme 2001 /SKB, 2001/. The planned activities related to Äspö HRL are detailed on a yearly basis in the Äspö HRL Planning Report. The role of the Planning Report is also to present the background and objectives of each experiment and activity. This Status Report concentrates on the work in progress and refers to the Planning Report /SKB, 2004/ for more background information. The Annual Report will in detail present and summarise new findings and results obtained during the present year.

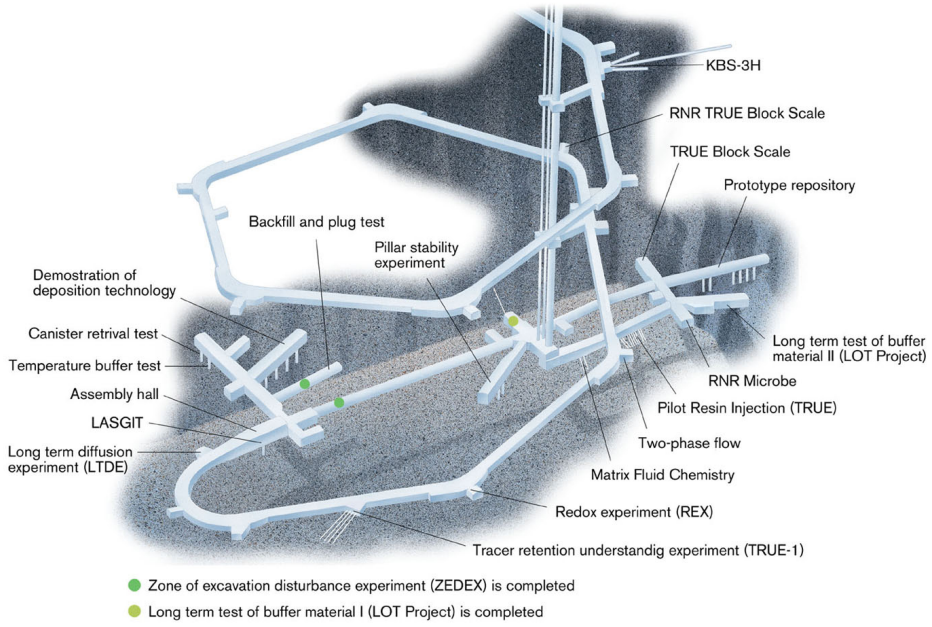


Figure 1-1 *Allocation of experimental sites in Äspö HRL from -220 m to -450 m level.*

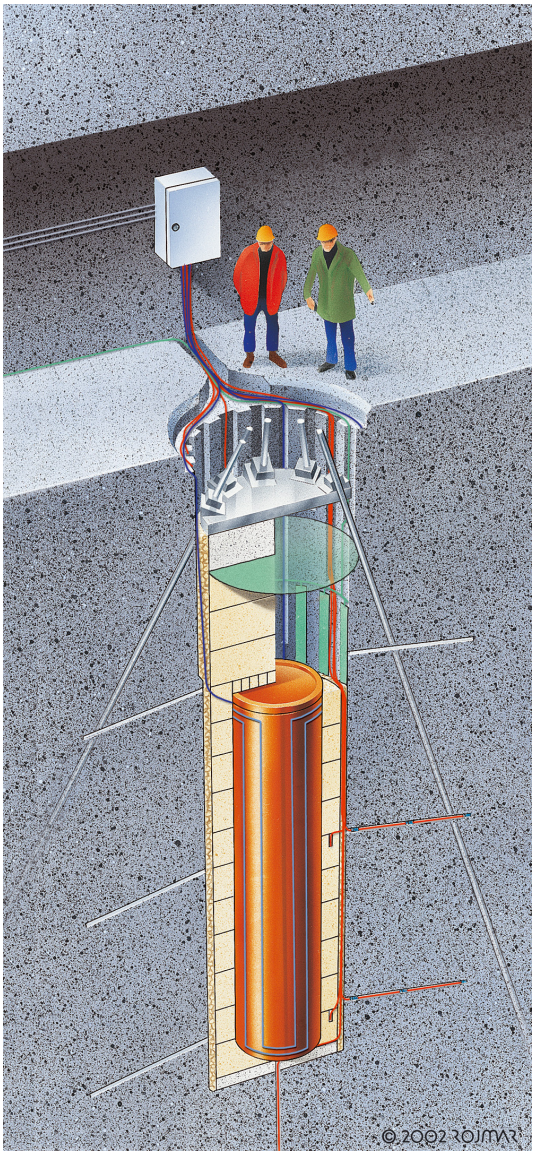
2 Technology

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

It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. The experiments focus on different aspects of engineering technology, see Figure 2-1, and performance testing, and will together form a major experimental programme.

Figure 2-1 *Deposition of a full scale canister in Äspö HRL.*

2.1 Canister Retrieval Test



The Canister Retrieval Test is aiming at demonstrating the readiness for recovering of emplaced canisters also after the time when the surrounding bentonite buffer is fully saturated.

In the Canister Retrieval Test two full-scale deposition holes have been drilled 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.

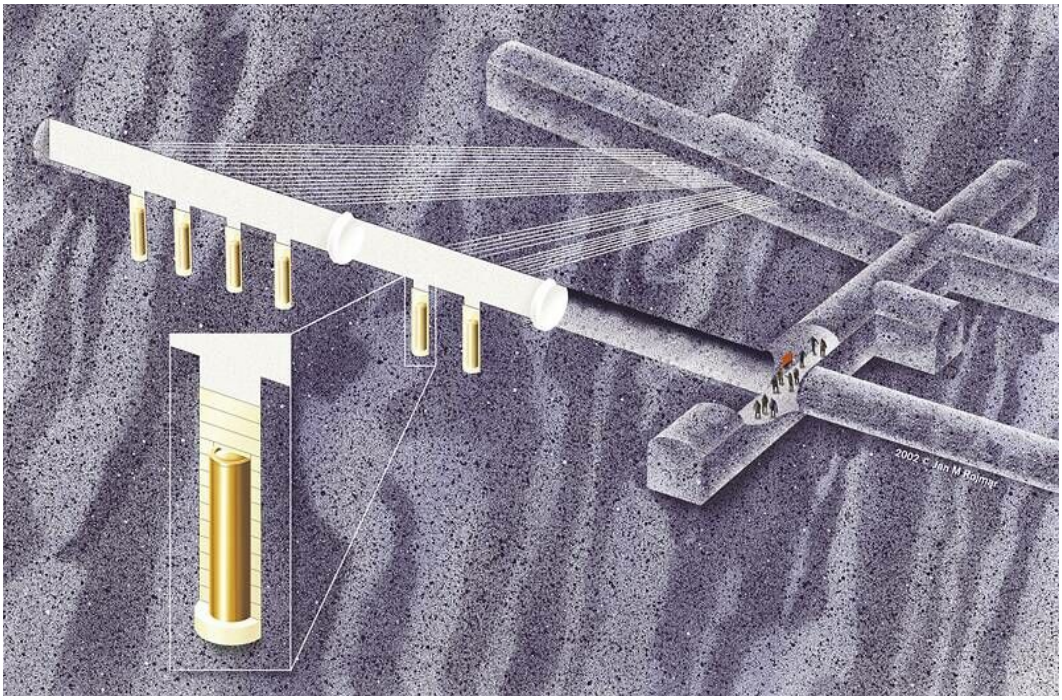
The test has been running for almost four years with continuous measurements of the wetting process, temperature, stresses, and strains.

Achievements

The artificial water supply to the bentonite has continued and the water pressure in the mats that distribute the water has been maintained at 800 kPa during the entire reporting period. The filters in the mats were back-flushed in October in order to avoid clogging.

The measurements of a large number of parameters to study the THM-processes and to provide a basis for e.g. modelling purposes have continued. A data report covering the period up to 1st of November 2004 /Goudarzi *et al.*, 2004a/ is available. Modelling of pressure, water content etc in the buffer during the saturation process is in progress although delayed. The saturation time for the 350 mm thick buffer along the canister was predicted to 2-3 years and to 5-10 years in the buffer below and above the canister. The relative humidity sensors indicate that the wetting of the bentonite between the rock and the canister continues and is close to water saturation, although the wetting still seems to be somewhat uneven.

2.2 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 deep repository system regarding geometry, materials, and rock environment.

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

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

Achievements

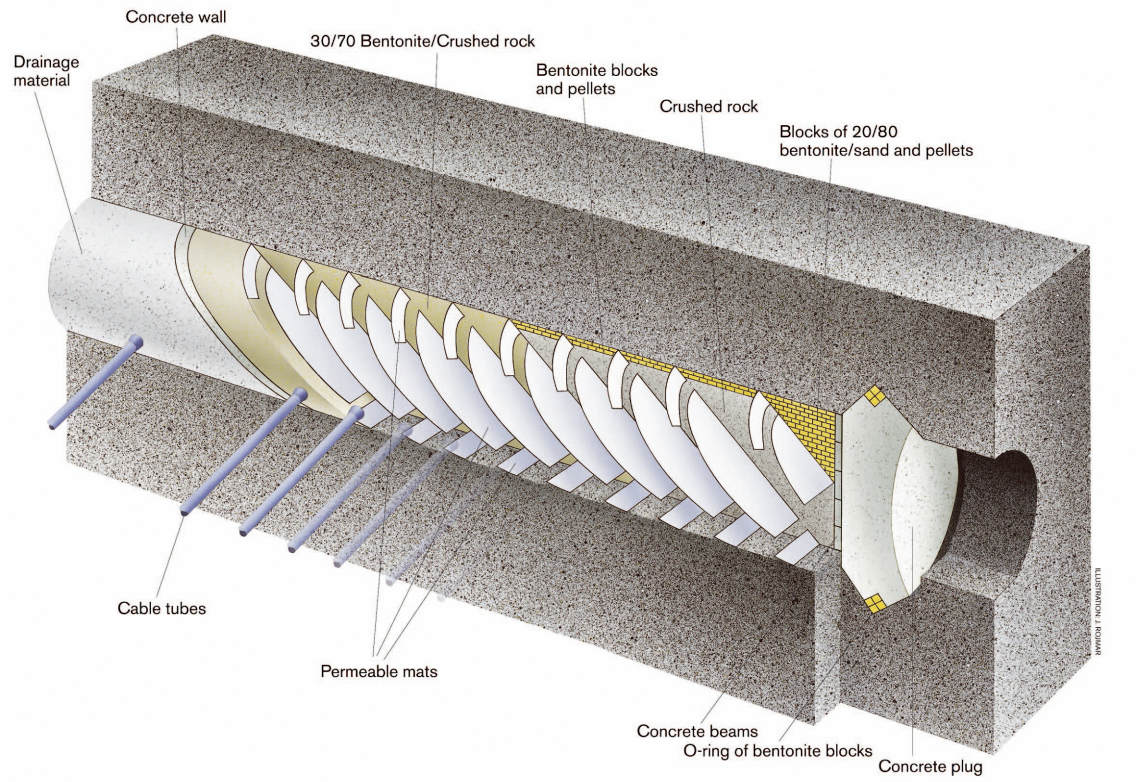
The data collection system comprises temperature, total pressure, pore water pressure, relative humidity and resistivity measurements in buffer and backfill, as well as temperature and water pressure measurements in boreholes in the rock around the tunnel. The collection of data is continuing and the sensors data report No: 11 covering the period up to 1st of September 2004 is printed. /Goudarzi and Johannesson, 2004/.

The final grouting of the outer plug was made in October. Hereafter, the drainage of the tunnel was closed, resulting in an increased water pressure in the backfill in both sections. In connection to this operation the electricity supply to the heater in one of the canisters in the inner section failed. The reason is probably a short circuit.

Overhauling of the data acquisition system and rebuilding of the power regulating system for the canisters are in progress. The measurements of the ground water flow are being finalised and the measurements of pH and Eh in boreholes have been initiated.

Sampling and analyses of gases in the buffer and the backfill were made in October with the aid of equipment and instruments from the Microbe Laboratory.

2.3 Backfill and Plug Test



The Backfill and Plug Test includes tests of backfill materials and emplacement methods and a test of 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 the filter mats started in late 1999. Wetting of the backfill continued until the backfill was very close to complete saturation at the end of 2002/beginning of 2003.

Achievements

Water saturation, water pressure and swelling pressure in the backfill and water pressure in the surrounding rock have been continuously measured and registered according to plan and sensors data report No: 9 covering the period up to 1st of July 2004 /Goudarzi *et al*., 2004b/ is printed.

The flow testing of the backfill materials, initiated during autumn 2003, has continued. The strategy for the testing is in the first stage to successively decrease the water pressure in the mat sections (each section comprises three mats) starting with the mats at the plug. The flow testing has continued in the tunnel part with a mixture of crushed rock and bentonite (30/70). The hydraulic gradient has been moved from section A3 to A2, see Figure 2-2. The water flow caused by the difference in water pressure between 500 kPa and 400 kPa has been measured and the hydraulic conductivity of the backfill in the measured sections is presently being evaluated.

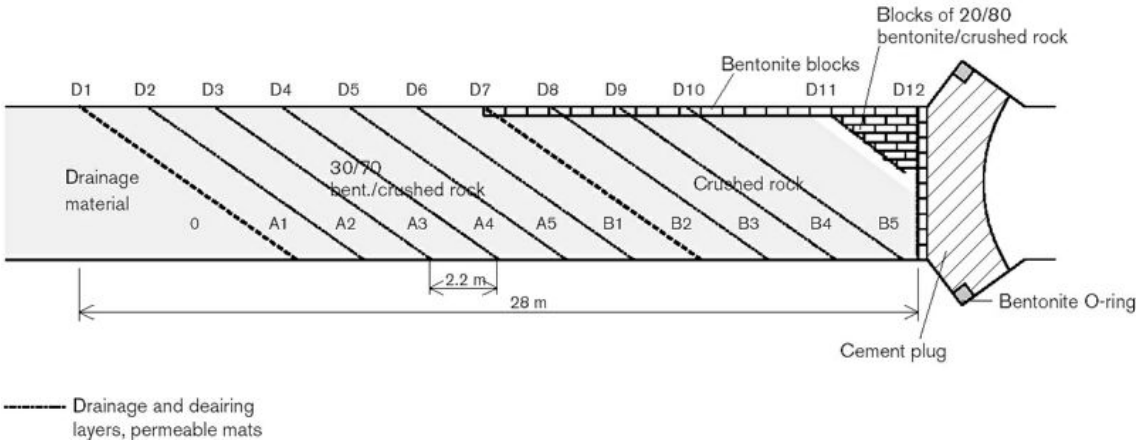
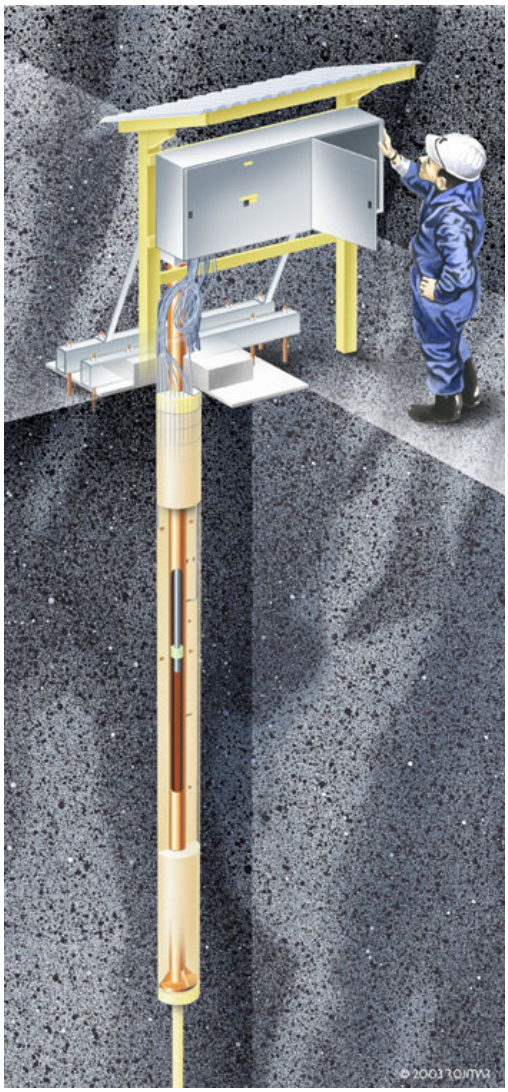


Figure 2-2 *Layout of the Backfill and Plug Test showing the numbering of the backfill sections and permeable mats.*

2.4 Long Term Test of Buffer Material



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

Five 300 mm diameter test holes with a depth around 4 m have been drilled and instrumented. Five test parcels were installed in 1999. The intended test temperatures of 90°C and 130°C have been reached. In 2001 a one-year parcel was extracted from the rock by overlapping core drilling. The remaining four long term test parcels are functioning well.

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

Achievements

The analysing work and testing with material from the extracted one-year parcel A0 (see Table 2-1) is completed.

The remaining four long term test parcels have functioned well and temperature, total pressure, water pressure, and water content are continuously measured and registered every hour. The monthly checks of the collected data have been done. A project meeting has been held to start the planning of the next extraction of one of the five year parcels, probably A2.

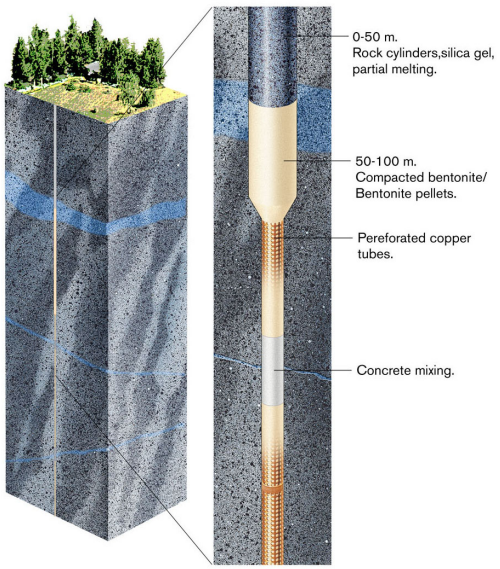
The drilling for the uptake is planned to start in September 2005, and will be preceded by predictive chemical modelling.

Table 2-1 Test series for the Long Term Test of Buffer Material.

Type	No.	max T (°C)	Controlled parameter	Time (years)	Remark
A	1	130	T, [K+], pH, am	1	Pilot test, reported
A	0	120-150	T, [K+], pH, am	1	Main test, analysed
A	2	120-150	T, [K+], pH, am	5	Main test, on-going
A	3	120-150	T	5	Main test, on-going
S	1	90	T	1	Pilot test, reported
S	2	90	T	5	Main test, on-going
S	3	90	T	>>5	Main test, on-going

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

2.5 Cleaning and sealing of investigation boreholes



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

The project comprises two phases. Phase 1 was mainly an inventory of available techniques, and Phase 2 aims to develop a complete cleaning and sealing concept and to demonstrate it.

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

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

Achievements

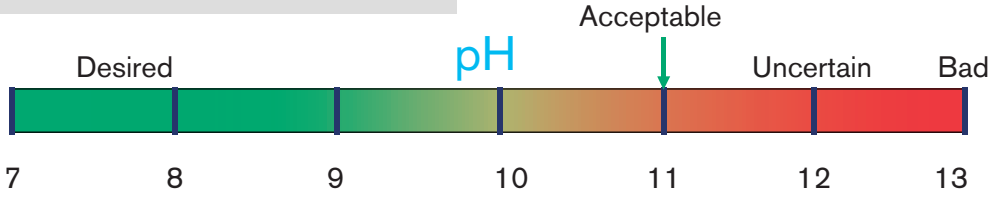
The first phase of the project is completed and the major conclusion was that smectite clay is recommended as main candidate material for sealing of boreholes in the forth-coming work. The second phase focuses on the development of a complete concept for cleaning and sealing of boreholes. The present design for the borehole seals consists of cylindrical pre-compacted clay blocks contained in perforated copper tubes that are jointed in conjunction with insertion into the boreholes. The final report on the basic concept for borehole plugging is finalised and ready for printing.

Laboratory studies of material for plugging boreholes are continued at Clay Technology AB and CBI (Swedish cement and concrete research institute). Manufacturing of machinery for perforation of cupper tube was tested during November and a proposal for automatic manufacturing of copper tubes has been presented.

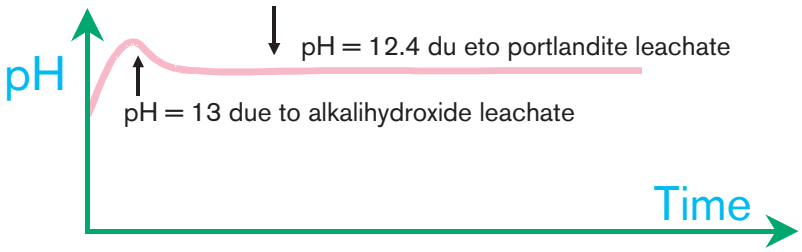
The planning of the third phase is in progress. Manufacturing of copper tubes for field testing has been ordered and a number of short boreholes in Äspö HRL have been drilled for testing the concept.

2.6 Injection grout for deep repositories

SAFETY ASSESSORS VIEW ON pH



PRINCIPLES FOR pH EVOLUTION OF STANDARD CEMENT



The use of low-pH products in the deep repository will probably be necessary in order to get leachates with a sufficiently low pH (≤11). A project concerning the use of low-pH cementitious products started in 2001 as a co-operation between SKB, Posiva, and NUMO.

The present objectives of the project are to achieve quantified, tested and approved low-pH injection grouts. The project is divided into four sub projects:

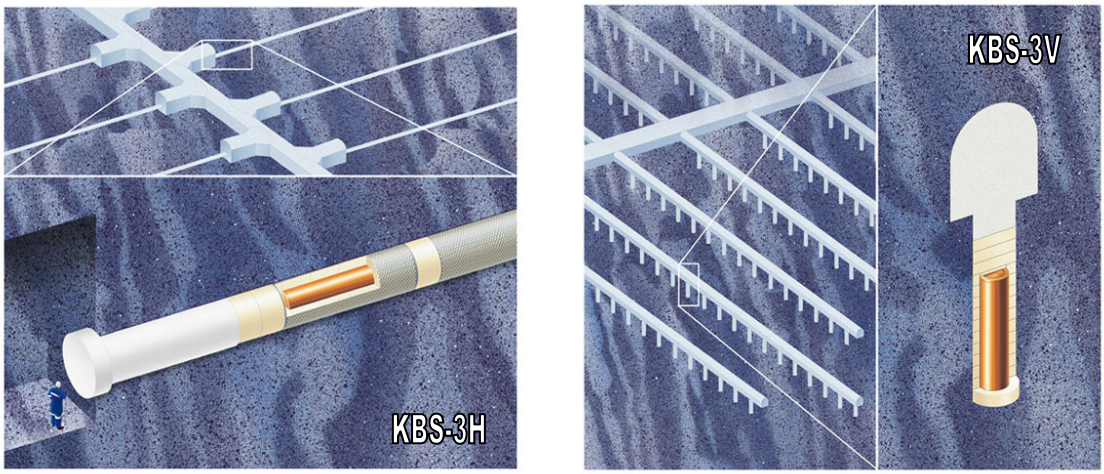
SP1 Low-pH cementitious injection grout for larger fractures.
SP2 Non-cementitious low-pH injection grout for smaller fractures.
SP3 Field testing in Finland.
SP4 Field testing in Sweden.

The test carried out at the Äspö HRL is part of SP4 – Field testing in Sweden. The sub-project comprises injection field tests with Silica Sol and the aim is to test if it penetrates into small fractures (< 100 μm). The test site is a rock pillar at the tunnel TASQ, section 0/670 and the grouting was carried out as part of the ordinary construction work.

Achievements

Preparations of the site prior to the grouting test were initiated already in 2003 and hydraulic pre-tests were carried out at the site in February. Grouting test with silica sol, was performed in March and a minimum grout spread of 0.4 m was observed in an adjacent hole. The grouting was followed up by complementary hydraulic testing during May. The hydraulic tests showed a sealing efficiency of 70 % in the affected rock mass. The sub-project SP4 (Field testing in Sweden) has been completed as part of the ordinary construction work. The grouting was accompanied by extra investigations and analysis during operation /Emmelin et al., 2004/.

2.7 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.

Achievements

The site for the demonstration of the method is located at 220 m depth in Äspö HRL. A niche, with a height of about 8 m and a bottom area of 25 x 15 m that will form the work area, has been excavated. The plan is to excavate two horizontal deposition holes, one short with a length of 15 metres and one long with a length of 95 metres. Originally, three horizontal holes were planned. It has been decided that the deposition holes will be excavated by blind horizontal raise boring and that the straightness of the pilot hole will be guaranteed by the use of active steering device.

The excavation of the short deposition hole (15 m), including drilling of a pilot-hole and up-reaming with Indau equipment of that hole to the desired deposition hole diameter (1.85 m) was finished in the beginning of November, see Figure 2-3. The quality achieved investigated by a number of methods for instance by laser scanning. The preliminary results indicate a high quality but in some places the required tolerances have been exceeded. However, the deposition hole can be used as planned.

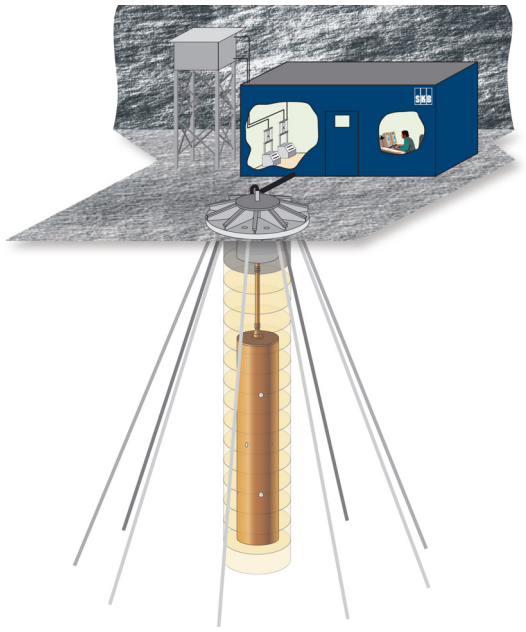
The drilling of the pilot-hole for the long deposition hole (95 m) started in the middle of November, with an active steering device. The drilling was, however, stopped due to problem with the equipment. A decision was taken that the drilling of the pilot-hole should be carried out with the same equipment as was used for the short pilot hole. Thus the Indau drilling machine was moved into place and a 311 mm wide hole was drilled. During drilling the alignment and direction of the hole was measured at an interval of about 15 m and the inclination was also checked by reading the altitude of the crone with water based vertical control technique. The drilling was successfully completed in the end of December and the up-reaming of the pilot-hole to a 1.85 m deposition hole will start in January.

The contractor has modified their up-reaming equipment in order to sharpen up the quality of the up-reaming of the hole. This is done mainly by constructing a much stiffer and longer stabiliser. The stabiliser is also provided with a bearing in the centre. Improvements have also been done on the system for water handling.

The barrier performance of the KBS-3H concept is studied by Posiva. Laboratory tests of the buffer behaviour performance are carried out by Clay Technology to study occurrence of erosion and piping in the buffer as well as in the distance blocks. Tests are performed both in scale of 1:10 and in semi full scale. The test program has been finalised. A summary report of the buffer research is being finalised during 2005.

Figure 2-3 *The project coordinator in the short horizontal deposition hole.*

2.8 Large Scale Gas Injection Test



A full-scale canister (without heaters) and a bentonite buffer will be installed in an available bored deposition hole in Äspö HRL. Water will be artificially supplied to the buffer at isothermal conditions.

When the buffer is fully saturated gas injection will start, first with small gas volumes and finally with volumes corresponding to gas formation from a defect full-size canister.

SKB has during several years performed a number of experiments with gas injection on MX-80 bentonite. Today, there is a relatively good understanding of the processes determining the gas transport. One remaining question is, however, the importance of the scale. All bentonite experiments so far have been performed in the centimetre scale and the extrapolation of the results from these experiments to repository scale is unclear. Therefore, the Large Scale Gas Injection Test (Lasgit) has been initiated.

The major aims of the project are to:
- Perform and evaluate full-scale gas injection tests based on the KBS-3 concept.
- Answer questions related to up-scaling.
- Get additional information on gas-transport processes.
- Obtain high quality data for testing and validation of models.
- Demonstrate that gas formation in a canister do not have obvious negative consequences for the repository barriers.

Achievements

The test will take place in an existing deposition hole (DA3147G01) in the TBM tunnel. The information available on the hole is sufficient and no new characterisation is planned. The preparations for the installation of the test are in progress.

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

The previously documented problem of pump leakage was potentially caused by particulate build-up in the pump control systems. To address the issue of particulate build-up the hydration water supply was switched to a nearby sealed borehole. Water entering the laboratory now passes through a three-stage filtration process removing particulate matter down to a 0.2 micron size fraction. In addition, the oxygen content of the hydration water has been significantly reduced, as interstitial water from the borehole is pumped directly into the laboratory without exposure to atmospheric conditions. In the project problems with instrumentation and pumps are now solved but they have caused delays in the project.

2.9 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, and the experimental resources needed to achieve this.

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

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

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

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

Achievements

The TBT-test is in the operation and data acquisition phase since March 2003. Two canisters with heaters, bentonite buffer, and sand infilling are installed in the deposition hole together with a system for artificial watering and a large number of sensors and cables for registration of e.g. saturation, pressures, and temperatures. Reporting of the installation phase is in progress.

The collection of data is continuing and data report No. 4 covering the period up to 1st of July 2004 has been published /Goudarzi *et al.*, 2004c/. Data acquisition is continuously ongoing and data is reported on a monthly basis. The data link from Äspö to Andra's head office in Paris has been functioning well. Evaluation and predictive modelling are in progress.

The function of the sand filter has received some attention during 2004. From the onset of the test, water was injected in the lower section of the sand filter only. Since the flow rate was observed to diminish, the injection points in the upper section were pressurised in April 2004. After this, the experiment has been wetted from both sections.

Present evaluation modelling addresses the development of stresses in Ring 9 around the upper heater and is planned to be finalised in the beginning of 2005.

2.10 Rock Shear Experiment

The Rock Shear Experiment (Rose) aims at observing the forces that would act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole. Such a displacement is considered to be caused by an earthquake, and the test set-up need to provide a shearing motion along the fracture that is equal to an expected shearing motion in real life. The first phase is a pre-study of design and feasibility. Scoping calculations are assumed to indicate the forces and shearing speed needed and thereby provide the basis for the design of the test set-up.

The *in situ* test set-up is planned to be installed at the site of the Äspö Pillar Stability Experiment when the rock mechanics test has been completed. Two full scale deposition holes then exist with a rock pillar of 1 m in between. One deposition hole will be used for the buffer and canister, while the other deposition hole is used for the shearing equipment.

Achievements

The first phase of the project, a pre-study of design and feasibility of the test, was performed and finalised during 2004. The preliminary results derived, which were presented at a meeting in Äspö in October, show that the test is feasible and can be performed with the required demands. A report is under preparation.

2.11 Learning from experiences

In this project, reference techniques for emplacement of buffer, canisters, backfilling, and closure are to be identified. Emplacement of buffer and canisters, and backfilling of tunnels have been experienced in Canister Retrieval Test, Prototype Repository and Backfill and Plug Test. These experiences are documented and the result evaluated with respect to possible improvements as well as limits with respect to water inflows.

The work comprises:

- Compilation of the results from more then ten years of performed engineering experiments in Äspö HRL.
- Compilation and evaluation of experience from emplacement of buffer and canisters, backfilling of tunnels, and estimation of acceptable water inflows for the applied methods.

Achievements

A report that describes the large series of experiments related to engineered barrier systems that have been conducted in SKB's underground laboratories and construction sites during the time period 1981 to 2003 is available in a draft version. The review of the draft report is finalised and the report will be published as an IPR report in Äspö´s report series.

2.12 Task Force on Engineered Barrier Systems

The Task Force on Engineered Barrier Systems has been on stand-by as long as the Prototype Repository EC-project was operative, i.e. through the first quarter of 2004. The prioritised work on modelling of THMC-processes in buffer during saturation was conducted within the Prototype Repository EC-project.

A Task Force related meeting on buffer and backfill modelling was held in Lund in March /Pusch and Svemar, 2004/. The participants were modellers representing waste-handling organisations in Europe, Japan and North America. The overall conclusion from the workshop was that modelling of some of the major physical processes in buffers and backfills can be made with sufficient accuracy. A number of important issues for further research in the framework of the Task Force were identified, e.g. prediction of access to water from the bedrock is required for adequate modelling of the hydration of buffers and backfills.

Achievements

A planning meeting for the project took place in September and a kick-off meeting was held the 28th October. At that meeting two tasks were chosen for the Task Force work, namely: a) THM processes in buffer materials and b) Gas migration in buffer material, having the objectives to:

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

Participating organisations are: SKB, Andra, BMWA, CRIEPI, Enresa, Nagra, Posiva, OPG, and RAWRA (Czech Republic).

3 Geo-science

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

3.1 Geological mapping and modelling

This project aims at performing a pre-investigation for developing a new method and system for underground mapping to be used in the construction of a future deep repository. The major reasons to develop a new system for underground mapping are aspects on time required, precision in mapping, traceability and objectivity. A higher degree of objectivity achieved with a more automated method is considered important. Increased traceability means that SKB will have better possibilities to establish the tunnel environment pre-rock support and pre-backfilling, thereby showing foundations for interpretations concerning geology, rock mechanics and tunnel maintenance. At this initial stage, the major objective is to find different alternative techniques that could be used as a base for a new mapping system. Contact has been taken with Posiva, in order to establish a co-operation in finding an efficient system for digital underground mapping.

Achievements

A report from the geological mapping of the 71 m long TASQ-tunnel has been completed /Magnor, 2004/. Geological mapping of two of the three depositions holes in TASQ has been performed, DQ0063 and DQ0066. The results have been digitised and fed into the TMS database. Deposition hole DO0010G01 at 420 m depth has been mapped in the traditional way and laser scanned for comparison. A complementary mapping of the drillcore (Boremap) from KG0010B01 has been performed by Geosigma AB.

The work of updating the three dimensional RVS models of Äspö will continue. Data from mapping and modelling of the TASQ-tunnel will be added to the present RVS models. Further improvements in the models will be added as deformation zones and other geological features are established.

An updated rock-name terminology has been established in cooperation with site investigations Oskarshamn and Geological Survey of Sweden. The updated terminology will be used by both Äspö and site investigations Oskarshamn.

The relation between fine-grained granitic dykes and structures at the Äspö HRL has been studied as an undergraduate thesis (Jonsson S). A new thesis has been initiated concerning a NW-SE set of brittle fractures in the Äspö rock volume.

3.2 Rock stress measurements

It is important to know the limitations and shortcomings of different rock stress measurement techniques to be able to make correct assessments of the *in situ* stress field from the measured results. Rock stress measurements with different techniques (bore probe, doorstopper and hydraulic fracturing) have during the years been performed as well as numerical modelling of the stress. The strategy for rock stress measurements will be presented in a report.

Achievements

The work, done in co-operation with Posiva, with the objective to quality assure overcoring data is in progress. No results are yet available.

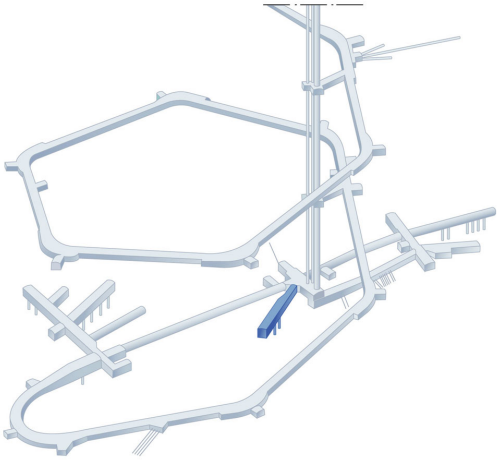
3.3 Rock creep

The aim with this project is to increase the understanding of the material properties of rock and rock-mass and to develop better conceptual models for the influence of the rock damaged zone and rock creep on rock stability.

Achievements

A literature study and scooping numerical modelling with a three-dimensional coupled hydromechanical computer code (3Dec) have been performed. The reporting of the results from the modelling and the literature study is ongoing. The review of the literature study is finalised.

3.4 Äspö Pillar Stability Experiment



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

In addition, the capabilities of two- and three-dimensional mechanical and thermal predictions will be compared.

The pillar was created between two vertical deposition holes drilled in the floor of the tunnel.

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

A new tunnel was excavated at Äspö HRL to ensure that the experiment is carried out in a rock mass with a virgin stress field. The site is located at the -450 m level. The tunnel has an arched floor designed to concentrate the stresses in the centre of it. The arched floor was excavated as a separate bench to minimise the excavation damaged zone in the floor.

Achievements

The heating phase of the experiment was finished in mid July. Spalling occurred to almost 5 m depth in the open borehole and good measuring series were achieved with all the instruments used. After the removal of the instruments and the instrument support construction in the hole, it was extensively photo documented. The pillar wall was also laser-scanned to get an as good three dimensional survey of the final deformations as possible. After removal of the rock slabs formed, the pillar wall was laser-scanned again to document the final width and depth extent of the spalling. However, the laser scanning was more difficult to interpret than anticipated. Work is therefore being done to refine the data set. The field experiment report is delayed and is scheduled to be finished for review before the summer 2005. The photograph above is taken along the pillar centre from the hole bottom and up during the removal of the rock slabs created during the spalling process.

The work to remove the pillar in large blocks has started. The pillar has to be de-stressed before the sawing can take place since high stresses are concentrated in it. Extensive numerical modelling has been performed to optimise the slot with regard to geometry and drilling sequence. The de-stress slot outside the pillar volume has been drilled and the first of totally five pillar blocks has been sawn and lifted out. The sawing takes longer time than anticipated and is now scheduled to be finished in late January 2005.

3.5 Heat transport

This project is connected to the Prototype Repository and the aim is to analyse the thermal properties in different scales and clarify relevant scales for the thermal process around a repository by sensitivity analyses. The work includes inverse modelling of thermal properties, measurements of thermal properties of the rock in different scales and examination of the distribution of thermal conductivities from density loggings. The heat evolution in the Prototype Repository has been monitored since September 2001 and collected thermal data can be seen as a good basis for the Heat transport project. The main topics are:

- Verification of prognosis made on thermal properties in the Prototype Repository by the use of inverse modelling.
- Evaluation of scale dependency of thermal properties and anisotropies by analyses of available density loggings from Äspö HRL, measurements on thermal properties, and inverse modelling.
- Development of a methodology for upscaling of thermal data to a relevant scale for the canister.
- Analyses of uncertainties in existing data and the utility of continued data collection (data worth analysis or value of information analysis).

Achievements

Three reports dealing with heat transport were completed during 2002 and 2003 /Sundberg, 2002; 2003a; Sundberg *et al.*, 2003/ and a strategy for the thermal model development during site investigations has been presented /Sundberg, 2003b/.

3.6 Seismic influence on the groundwater system

The Hydro Monitoring System (HMS) registers at the moment the piezometric head in 409 positions underground in the Äspö HRL. An induced change of the head with more than 2 kPa triggers an intensive sampling. All measured data are stored in a database.

The data in the database are assumed to bear witness of different seismic activities in Sweden but also abroad, dependent on the magnitude of the event. By analysing the data on changes in the piezometric head at Äspö connections to specific seismic events are expected to be established. For example, the effects of blasts in Äspö HRL as well as in Clab, during the extension of the underground storage capacity, were analysed.

Achievements

Data from the HMS are stored in the database pending analysis. A special computer code is under development that may run and compare the HMS database with other databases, like Sicada or the national seismological database.

4 Natural barriers

At the Äspö HRL experiments are performed at conditions that are expected to prevail at repository depth. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The goals are to increase the scientific knowledge of the safety margins of the deep 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. Processes that influence migration of species along a natural rock fracture are shown Figure 4-1.

Tests of models for groundwater flow, radionuclide migration and chemical/biological processes are one of the main purposes of the Äspö HRL. The programme includes projects with the aim to evaluate the usefulness and reliability of different models and to develop and test methods for determination of parameters required as input to the models.

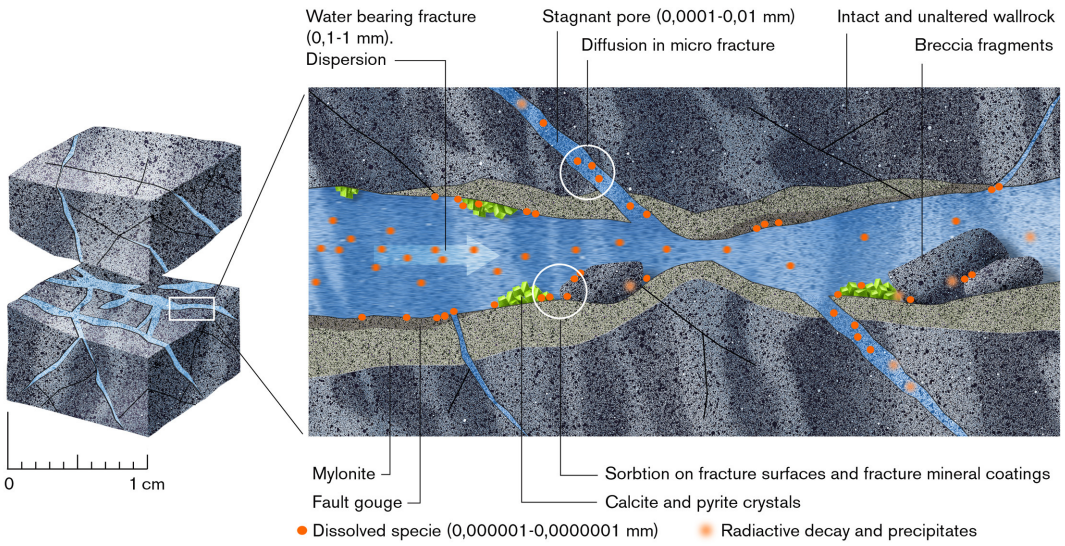
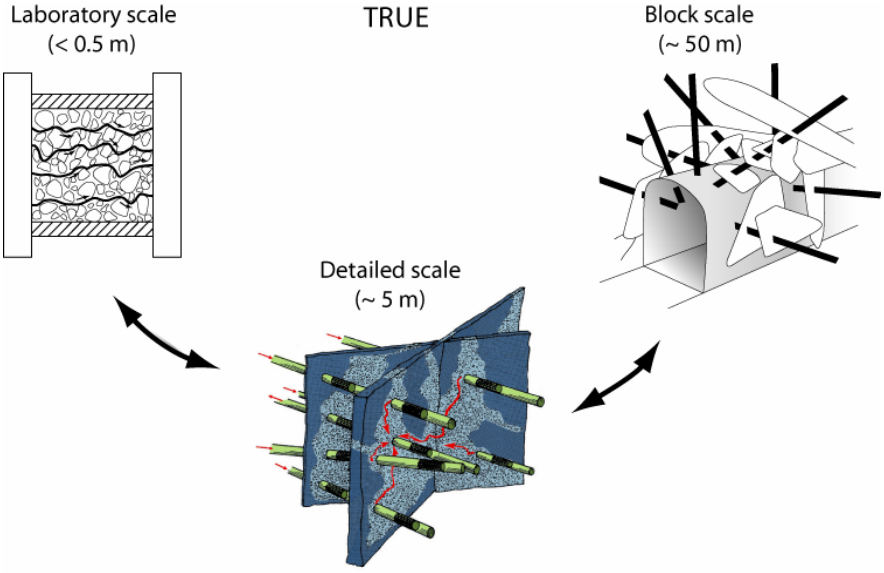


Figure 4-1 *Processes that influence migration of species along a natural rock fracture.*

4.1 Tracer Retention Understanding Experiments



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

The first *in situ* experiment (True-1) performed in the detailed scale and the True Block Scale series of experiments have come to their respective conclusion and the evaluation and final reporting are completed. Complementary field work and modelling are currently performed as part of two separate but closely coordinated continuation projects.

The True Block Scale Continuation project aims at obtaining additional understanding of the True Block Scale site.

The True-1 Continuation project is a continuation of the True-1 experiment. According to present plans the True-1 site will be injected with resin and excavated and analysed. 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. Furthermore, attempts are made to assess fracture apertures using radon concentrations in groundwater.

4.1.1 True Block Scale Continuation

The True Block Scale Continuation (BS2) project has its main focus on the existing True Block Scale site. The True Block Scale Continuation is divided into two separate phases:

BS2a Complementary modelling work in support of BS2 *in situ* tests. Continuation of the True Block Scale (Phase C) pumping and sampling including employment of developed enrichment techniques to lower detection limits.

BS2b Additional *in situ* tracer tests based on the outcome of the BS2a analysis. *In situ* tests are preceded by reassessment of the need to optimise/remediate the piezometer array. The specific objectives of BS2b are to be formulated on the basis of the outcome of BS2a.

Achievements

The main work in progress is on BS2b. The official part of BS2b sorbing experiments was concluded as planned in mid September but sampling on a low level of ambition will be continued until the end of the year. Breakthrough at the pumping section in KI0025F03:R3 (Structure #19) was observed of all tracers administered in the two injection sections in KI0025F02:R3 (Structure #19) and KI0025F02:R2 (background fracture BG#1, formerly denoted Structure #25). The reporting of the evaluation of the official part of the BS2b sorbing tests is underway.

Model predictions were conducted by four modelling teams, representing different modelling methodologies and model codes, all previously employed in the True Block Scale project. The modelling teams included Posiva VTT, JNC-Golder, Andra-Itasca and SKB-KTH/WRE. The results of the model predictions were reviewed at a technical committee meeting in Stockholm early November 2004, including comparisons with experimental results. It was noted that predictions for injection in Structure #19 overall were good, with good mapping of the shape of the breakthrough curves, although the magnitude was not captured in full. The predictions for BG#1 were not equally good.

Reporting of four cross hole interference tests (CPT-1 through CPT-4) aimed at identifying suitable sink and injection sections for the planned injection tests is in published /Andersson *et al.*, 2004/.

4.1.2 True-1 Continuation

The True-1 Continuation project is a continuation of the True-1 experiments, and the experimental focus is placed on the True-1 site. The continuation aims at conducting the planned injection of epoxy resin at the True-1 site. However, before conducting such an impregnation, some complementary cross-hole hydraulic interference tests combined with tracer dilution tests are foreseen. These tests are intended to shed light on the possible three-dimensional aspects of transport at the site. The planned tests would employ both previously used sink sections and some not employed in the already performed tests.

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

Achievements

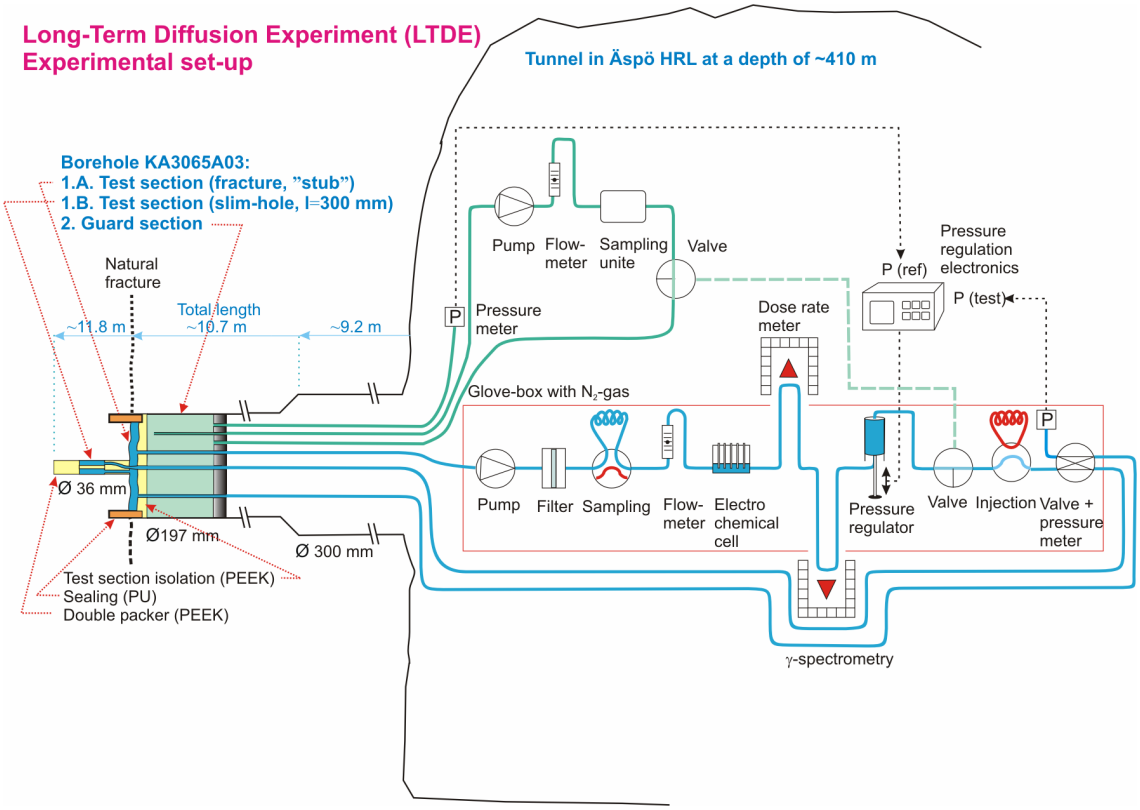
In the fault rock zone characterisation /Stigsson *et al.*, 2003; Mæresk *et al*., 2004/ over coring has been performed on in total seven sections where injection of uranine-labelled epoxy has been performed. The 76 mm pilot boreholes were over cored to a diameter of 300 mm, resulting in 277 mm cores which have been sawed into slices. Ongoing activities include work in three areas: Image processing with the aim to get images with desired colour and contrast of the slices, Image analysis to find the desired parameters, and three dimmensional visualisation to get the overall correlation between slices.

Draft versions of three scientific papers on the True team analysis of the True-1 experiments have been produced and reviewed.

The TRUE-1 Completion with epoxy injection Feature A at the True-1 site has been initiated and a project manager for this has been appointed. A complication for the scheduling of planned future work at the True-1 site lies in the fact that the True-1 and LTDE (see section 4.2) sites are hydraulically connected. A priority for advancing LTDE has been set by SKB and consequently, the resin impregnation at the True-1 site will be postponed until vital parts of LTDE have been accomplished. According to the present plans resin injection will be possible 2006 at the True-1 site.

The finalisation of the laboratory sorption program, including the reporting, is in progress. Supporting fracture mineralogical analyses are still pending.

4.2 Long Term Diffusion Experiment



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

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

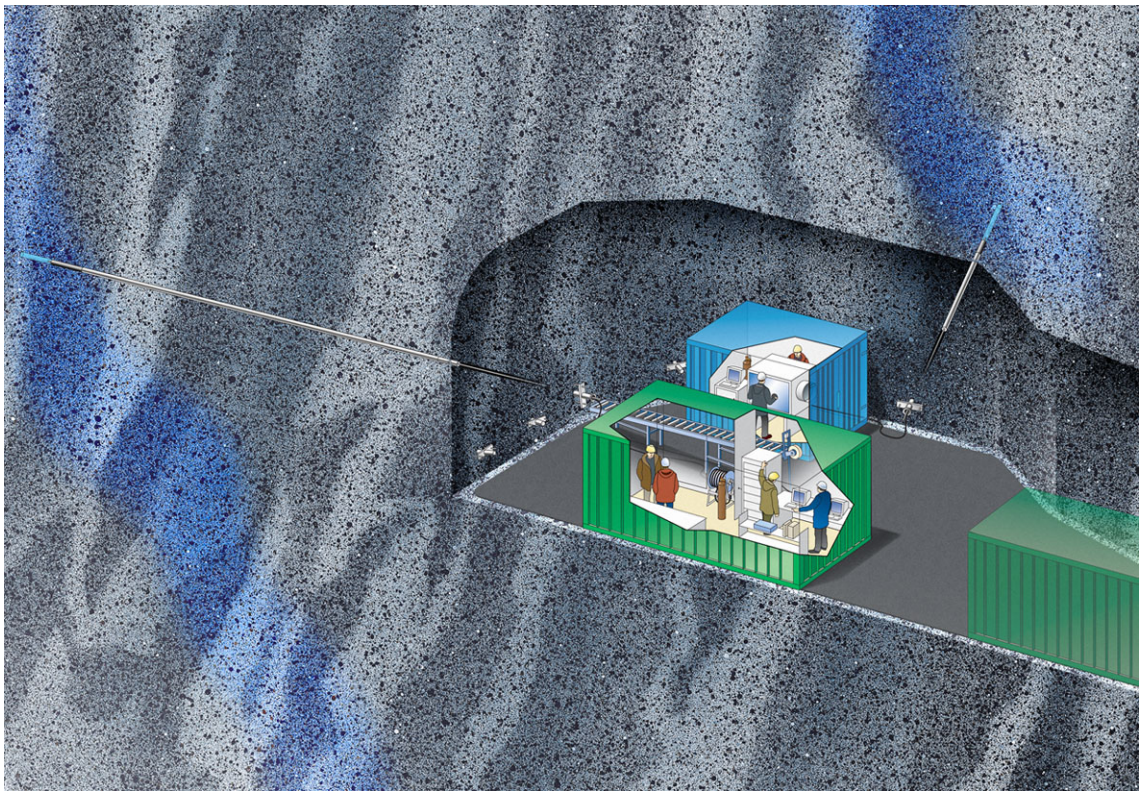
A core stub with a natural fracture surface is isolated in the bottom of a large diameter telescoped borehole and a small-diameter borehole is drilled through the core stub and beyond into the intact unaltered bedrock. Tracers will be circulated over a period of three to four years after which the borehole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

Achievements

Accomplished activities during this quarter have been on installations, installation tests and documentation. The final test of the electrochemical flow cell for pH and redox measurements showed that the electronic "box" was not stable enough and a new electronic unit for the electrochemical flow cell has been ordered. Delivery is set to beginning of January. The cause to earlier problems with electronics that could not control the pressure regulation in the test section has been identified. The electronic unit has been repaired and tested in the LTDE experimental set-up and the pressure regulation now works according to specifications.

The pre-test programme for evaluation of the hydrological conditions in the vicinity of the experimental borehole, KA3065A03, and possible hydrological interferences from other activities in Äspö HRL is completed and the evaluation and documentation is in progress. The planning for the first part of the *in situ* experiments has started.

4.3 Radionuclide Retention Experiments



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

The experiments are carried out in special borehole laboratories, Chemlab 1 and Chemlab 2, designed for different kinds of *in situ* experiments.

The laboratories are installed in boreholes and experiments can be carried out on bentonite samples and on tiny rock fractures in drill cores at *in situ* conditions. The focus is on:

- Radiolysis experiments in Chemlab 1, influence of radiolysis products on the migration of the redox-sensitive element technetium in bentonite.
- Migration of actinides in Chemlab 2, experiments with actinides in a rock fracture.

Achievements − Radiolysis experiments

In the end of 2002, two kinds of radiolysis experiments were performed. In the indirect radiolysis experiments the groundwater is irradiated before it comes in contact with the experiment cell containing bentonite and reduced technetium. In the other type, direct radiolysis experiments, the irradiation source is placed in the experiment cell, close to the reduced technetium.

The experiments have been analysed and the major conclusions are that technetium was to some extent oxidised in the direct radiolysis experiment and had started to diffuse whereas in the indirect radiolysis experiment technetium was only found at its original position and had probably not been oxidised. The evaluation of data is finished and the final report /Jansson and Eriksen, 2005/ is in print. No additional radiolysis experiments are planned.

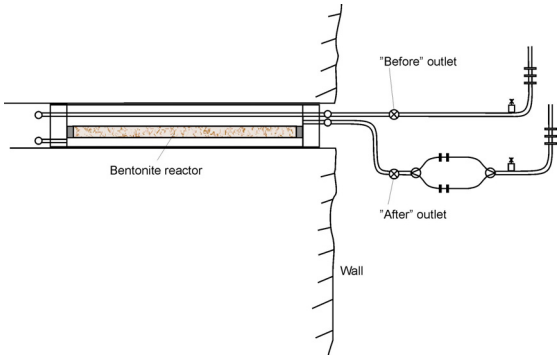
The future plan is to perform experiments on "Radionuclide Retention - transport resistance at the buffer/rock interface" in Chemlab-1. It has been reported that there is a transport resistance when radionuclides change media from diffusing in bentonite clay to transport with groundwater in a fracture. The project aims at examining whether this resistance exists and if so, the magnitude of the resistance shall be determined.

Achievements − Migration of actinides

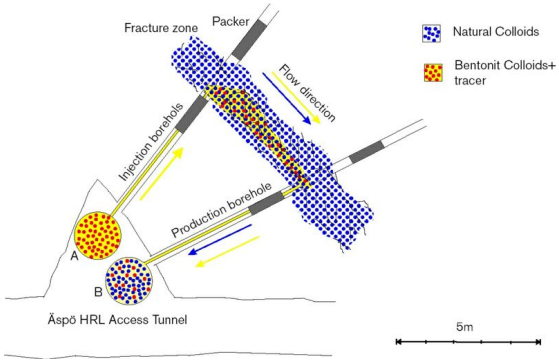
In these experiments the retention of redox sensitive radionuclides in a rock core with a longitudinal natural fracture is investigated. After saturation with groundwater, radionuclides are injected into the fracture. Groundwater is then pumped through the fracture for a long period of time. The water exiting the core is collected in fractions in a glove box placed in the gallery. In the first two field experiments the retention of the actinides Pu, Am and Np has been investigated. The last field experiment with U and Tc is still running in February 2005, due to a somewhat unexpected increase in uranium concentration in the outlet solution. The actinide migration experiments are a co-operation between SKB and FZK/INE.

The future plan is to perform "Radionuclide Retention - spent fuel leaching" experiments in Chemlab-2. The project will examine which radionuclides are released and in what extent when spent nuclear fuel is leached with groundwater under repository conditions.

4.4 Colloid Project



Borehole Specific Measurements



Colloid Dipole Experiment

In the Colloid Project the concentration, stability, and mobility of colloids in the Äspö environment are studied. The project comprises studies of the potential of colloids to enhance solute transport and the potential of bentonite clay as a source for colloid generation. The Colloid Project includes laboratory experiments, background measurements, borehole specific measurements, and colloid dipole experiments.

Achievements

The borehole specific measurements that were initiated in January 2003, when six "colloid reactors" were installed in four boreholes in Äspö HRL and in two boreholes at Olkiluoto, have all been finalised. The compilation of the final report including laboratory experiments, background measurements and borehole specific measurements is foreseen to be ready in April 2005.

The preparations for the Colloid Dipole experiment that will be carried out in co-operation between SKB, INE, AECL and Posiva are in progress. Several planning meetings have been held and a project plan has been sent for approval.

Preparation and stability experiments of colloids to be used in the experiment will be started as soon as necessary equipment is purchased. Based on results from tests with conservative tracers, Feature A at the True-1 site seems to be a suitable location for the experiments. The experiments will be performed in collaboration with the True-1 team.

A measuring campaign of natural colloids in the groundwater was performed at the turn of the month October/November. The measurements of colloids (LIBD-measurements) were performed in boreholes HA2780A, KKTT3:R3 KXTT4:R4 and KA1755A. Water sampling was conducted in KR0012B, SA1229A, HA1330B, KA1755A, SA2074A, SA2273A, KA3110A and KXTT4:R4. Electric conductivity, pH, Eh, and O_2-content in the water will be analysed. The results from the measuring campaign are now being evaluated in Karlsruhe.

4.5 Microbe Project

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

- To offer proper circumstances for research on the effect of microbial activity on the long-term chemical stability of the repository environment.
- To provide *in situ* conditions for the study of bio-mobilisation of radionuclides.
- To present a range of conditions relevant for the study of bio-immobilisation of radionuclides.
- To enable investigations of bio-corrosion of copper under conditions relevant for a high level radioactive waste repository.
- To constitute a reference site for testing and development of metods used in the site investigations

The main Microbe site is on the 450-m level where a laboratory container has been installed with laboratory benches, an anaerobic gas box and an advanced climate control system. Three core drilled holes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures are connected to the Microbe laboratory via tubings. Each borehole has been equipped with a circulation system offering a total of 2000 cm^2 of test surface.

Retention of naturally occurring trace elements in the groundwater by Biological Iron Oxides is investigated at a site at tunnel length 2200A m. There is a vault with a borehole that delivers groundwater rich in ferrous iron and iron oxidising bacteria. The borehole is connected to two 200 x 30 x 20 cm artificial channels that mimic ditches in the tunnel. The channels have rock and artificial plastic support that stimulate Biological Iron Oxide formation.

At 907A m tunnel length, a small vault supports a ditch with groundwater that is rich in ferrous oxides and iron oxidising bacteria This ditch was used as a natural analogue to the artificial channels at 2200A m. The site was destroyed by a flooding event fall 2003 and is now abonded.

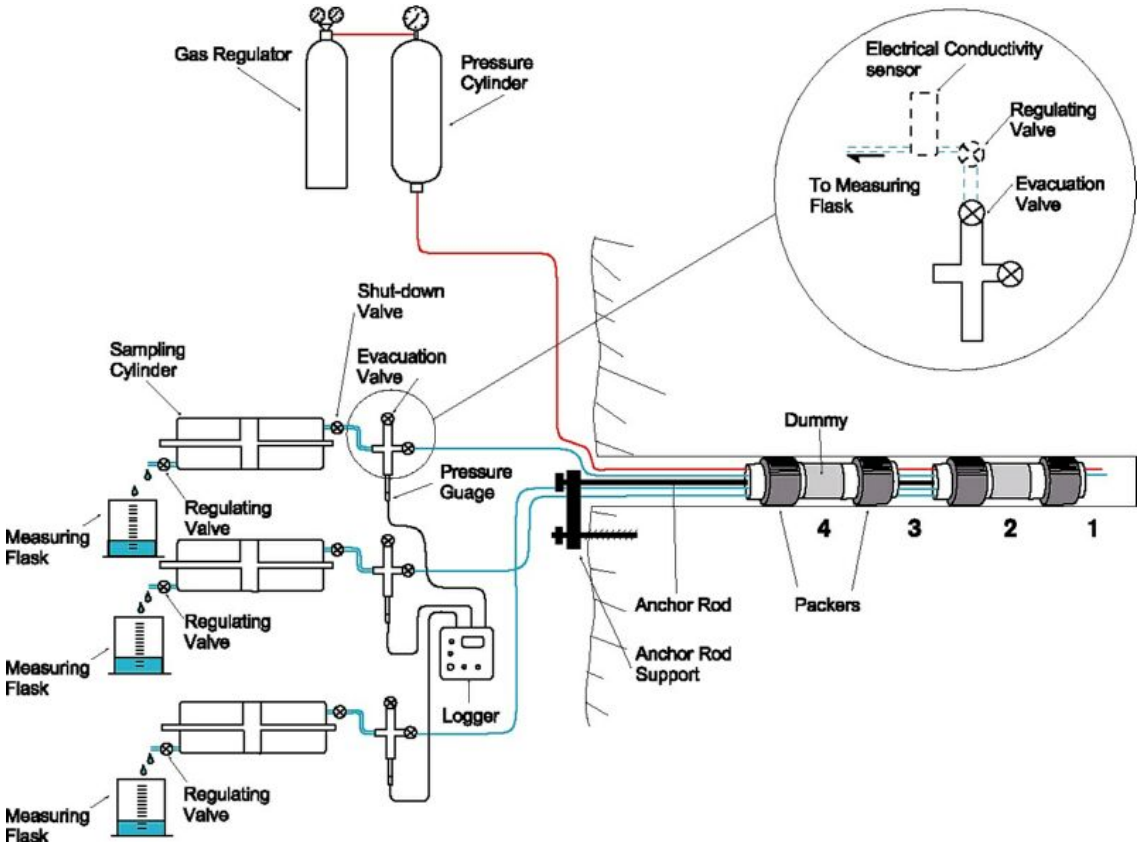
A unique ecosystem of sulphur oxidising bacteria existed at tunnel length 1127B m, in the sulphur pond. Apart from being an intriguing site from a microbiological perspective, it offered possibility to investigate microbial effects on the sulphur cycle in underground environments. However, changes in groundwater flows during 2003 has dried out the site and it can not be used in the Microbe experiments.

Achievements

In the Microbe laboratory, new biofilm experiments with mineral and glass surfaces have been loaded and started during mid February 2004 using the KJ0052F03 circulation. Sampling of the biofilm and rock chip minerals was sampled from flow cells in KJ0052F03 for radionuclide sorption experiments at Nuclear Chemistry, Chalmers, during September where the immobilisation of radionuclides on the biofilms was investigated. Papers are presently being produced.

Microbial biofilms and groundwater were sampled during this quarter from all three circulations (boreholes KJ0050F01, KJ0052F01 and KJ0052F03). The diversity results from MPN analysis (automated technique for most-probable-number) will be included in an Äspö HRL international progress report (IPR-05-05).

4.6 Matrix Fluid Chemistry



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

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

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

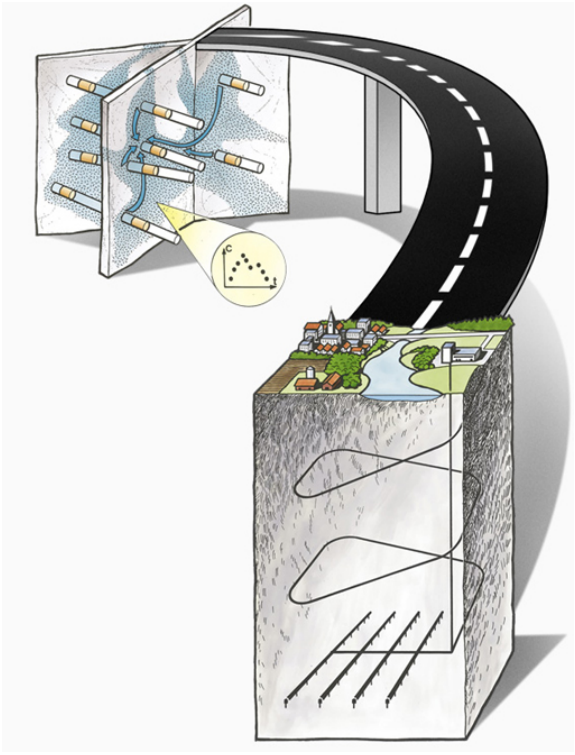
A continuation phase will focus on areas of uncertainty which remain to be addressed.

Achievements

The continuation phase is proceeding slowly. The feasibility study is focussed on the impact of tunnel construction (Äspö Pillar Stability Experiment) on the hydrogeology and hydrochemistry in the vicinity of the experimental matrix borehole KF0051A01. Porosity measurements on drillcore material to supplement data from the Matrix Fluid Chemistry Experiment have been carried out successfully and reporting is in progress.

The porosity measurements have been reported /Tullborg and Larson, 2004/ whereas the impact study is delayed and is about to start.

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



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

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

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

Achievements

In the Task Force, work has been in progress mainly in Task 6 − Performance Assessment Modelling Using Site Characterisation Data. Task 6 tries to bridge the gap between Performance Assessment (PA) and Site Characterisation (SC) models by applying both approaches for the same tracer experiment. It is hoped that this will help to identify the relevant conceptualisations (in processes/structures) for long term PA predictions and identify site characterisation data requirements to support PA calculations.

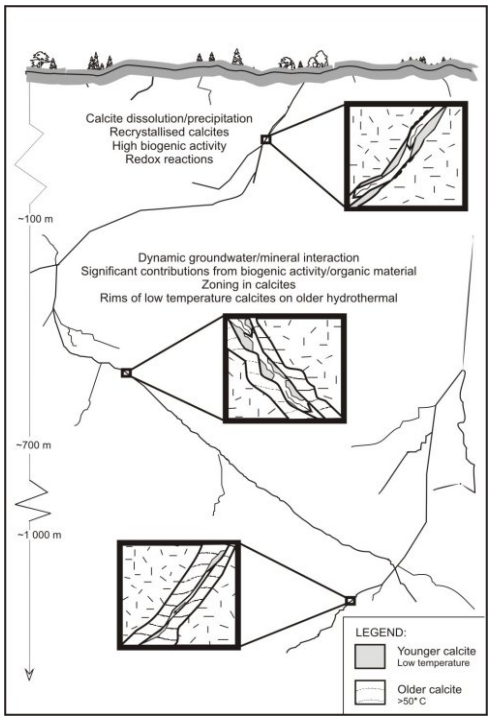
Modelling and review of modelling are proceeding according to the updated plan decided on at a meeting in Naantali in Finland in September. At this meeting it was also decided to initiate a new task - Task 7, which concerns a long-term pumping test in Onkalo.

The status of the specific modelling tasks is given in brackets in Table 4-1.

Table 4-1 Status of the specific modelling tasks.

Sub-task	Status
6A	Model and reproduce selected True-1 tests with a PA model and/or a SC model to provide a common reference. (Finalised, modelling reports printed, and external review in progress).
6B	Model selected PA cases at the True-1 site with new PA relevant (long term/base case) boundary conditions and temporal scales. This task serves as means to understand the differences between the use of SC-type and PA-type models, and the influence of various assumptions made for PA calculations for extrapolation in time. (Finalised, modelling reports printed, and external review in progress).
6C	Develop semi-synthetic, fractured granite hydrostructural models. Two scales are supported (200 m block scale and 2000 m site-scale). The models are developed based on data from the Prototype Repository, True Block Scale, True-1, and Fracture Characterisation and Classification project (FCC). (Finalised, printed as /Dershowitz *et al.*, 2003/, and external review in progress).
6D	This sub-task is similar to sub-task 6A, and is using the synthetic structural model in addition to a 50 to 100 m scale True-Block Scale tracer experiment. (In progress, draft reports available).
6E	This sub-task extends the sub-task 6D transport calculations to a reference set of PA time scales and boundary conditions. (In progress, draft reports available).
6F	Task 6F is a sensitivity study, which is proposed to address simple test cases, individual tasks to explore processes, and to test model functionality. (In progress).
7	Long-term pumping experiment. (To be initiated).

4.8 Padamot



Potential calcite-groundwater interaction at various depths at Äspö.

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

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

The project comprises analytical and modelling tasks. Deep borehole cores from rocks at the Äspö Underground Laboratory and Laxemar (KLX01) are used in the analytical study.

Achievements

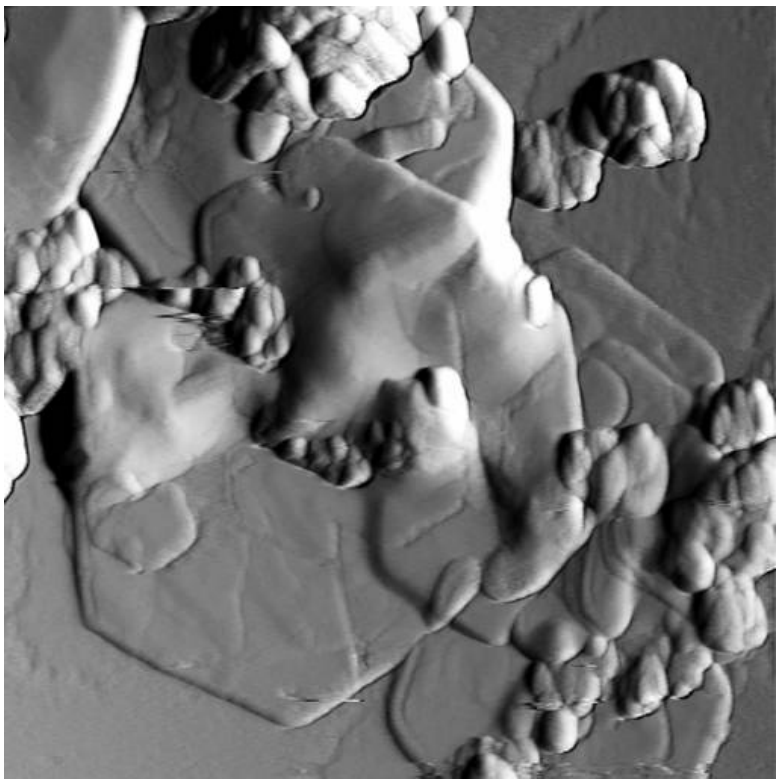
The final reporting for Work Package 2 – Palaeohydrogeological Characterisation of Sites – is still ongoing. The results from the different project groups are found on the Padamot website hosted by British Geological Survey, UK.

The overall picture given from the analytical results on calcites from KLX01 confirms changes in groundwater compositions true time (supported by Fluid Inclusion studies, Laser ICP geochemistry and morphological studies). Fresh water at depth of 800 to 950 meter is indicated, which is about 500 m deeper than at present. However there are no indications so far that this fresh water brought oxidising conditions to large depth. The biomarker analyses of six calcite samples ranging in depth from 13 to more than 900 m carried out at Universidad Polytecnica in Madrid indicate the presence of biogenic material in all samples ranging to 940 m. More tests are needed to confirm this.

In conclusion it can be assumed that the salinity front has varied a lot being both more shallow and deeper than the present and the calcite coatings show often complex growth patterns indicating that the same parts of the fractures systems have been active during quite different conditions, and probably stayed open for long periods of time.

A final meeting within the EC- part of the project took place in Prague in October. However, the SKB part of the project (analytical study of cores from Äspö HRL and Laxemar) will be extended and are planned to continue until 2006. The continuation will include studies of analyses of biomarkers in calcite and the use of laser analyses for Sr- and U-series.

4.9 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 the organic processes. Another area of interest is the radionuclide retention capacity provided by Fe-oxides and -oxyhydroxides in terms of sorption capacity and immobilisation.

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

Achievements

The three year project on Fe-oxides started late autumn 2003. A project meeting was held in Copenhagen in August to discuss work carried out and plans for the autumn.

The present status is that green rust (layered Fe(II,III) hydroxide with a greenish colour, and containing water and anions such as CO_3^{2-}, SO_4^{2-} and Cl^- in the interlayer) has been successfully identified to character and composition. This job will continue based on natural water samples from Äspö and Bornholm for comparison. Within the study of Fe-oxides in the fracture samples three groups can be identified: a)Hematite of "old" hydrothermal origin, b) Possible resent precipitates from the Äspö HRL tunnel and c) Samples artificial Fe-oxides as a product of the drilling. Different methods have been tested for identification of the Fe-oxides. A manuscript on the *double spike Fe iron isotope analysis method* is complete and has been submitted to Geochimica et Cosmochmica Acta. The *X-ray analysis* of the fracture material from the KOV01 borehole (located near SKB's Canister Laboratory in Oskarshamn) is finished. The same samples have also been analysed using *Mössbauer Spectroscopy*, to identify the iron-phases with confidence.

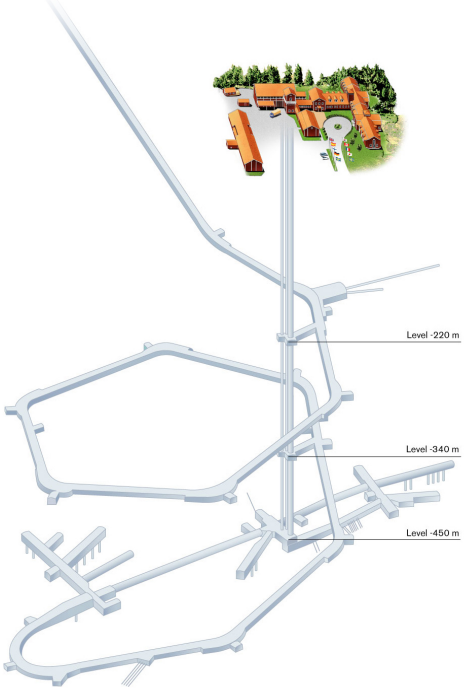
Transformation of green rust to other Fe-compounds at controlled redox conditions that are similar to natural conditions has been studied. The emphasis of this work is on immobilisation of contaminants, including Eu(III). Up to now, the work has focussed on development of the method. The next step will be to study the morphological changes during the formation and transformation of green rust on a substrate of high purity metallic Fe at a variety of potentials to resemble different redox environments in the subsurface. The study of Green rust mineral structure is moving forward. At the moment we are making the structural calculations. To test and improve the model, we have also investigated new samples of Green rust.

Samples of Green rust in natural settings have been collect at Bornholm and at a waste disposal site on Fyn during December. This sampling will provide information to a paper on natural occurrences of Green rust.

5 Äspö facility

An important part of the Äspö facility is the administration, operation, and maintenance of instruments as well as development of investigation methods. Other issues are to keep the stationary hydro monitoring system (HMS) continuously available and to carry out the programme for monitoring of groundwater head and flow and the programme for monitoring of groundwater chemistry.

5.1 Facility operation



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

This includes preventative and remedy maintenance in order to withhold high availability in all systems as drainage, electrical power, ventilation, alarm and communications in the Hard Rock Laboratory.

Achievements

Maintenance and operation of the above and underground facilities are running as well as improvements of the safety and working environment. The availability of the facility systems has continued to be high (above 99%), which means that the goal for 2004 will be fulfilled.

Implementation of a PC-based maintenance system has continued during the second half of 2004 and the majority of the technical systems are documented in a database. The aims with the implementation of the system are to increase the efficiency and quality assure the maintenances work within the HRL.

An automatic registration and object-monitoring system was taken into operation for testing in the end of 2003. The system has not functioned as expected and the contract with the supplier was cancelled. As a basis for the evaluation of alternative suppliers a pre-study of hard- and software for alternative registration and object monitoring systems has been carried out during this quarter. Tests of some systems have showed promising results which will be reported during the first quarter 2005.

A steering and control system for soft starts and stops of the pumps has been installed in the underground drainage system and is now in operation. The installation has decreased both the electric current needed at starts with 60% and the pressure pulse in the water pipes at stops with 20%. A sump at -340 m level is shown in Figure 5-1.

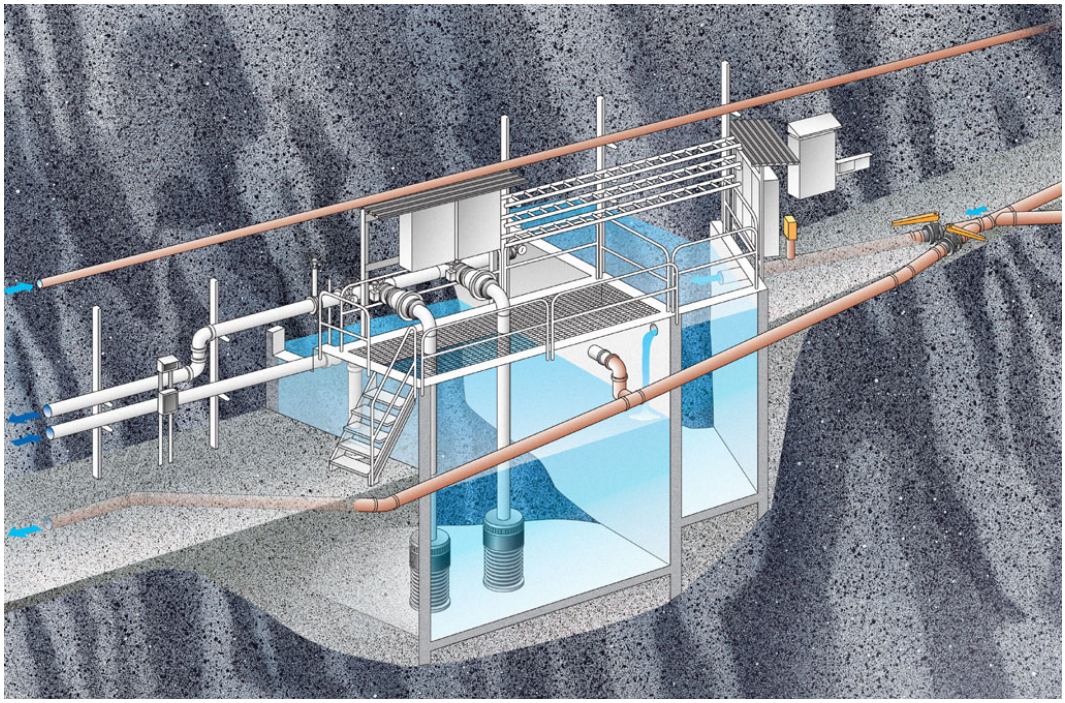
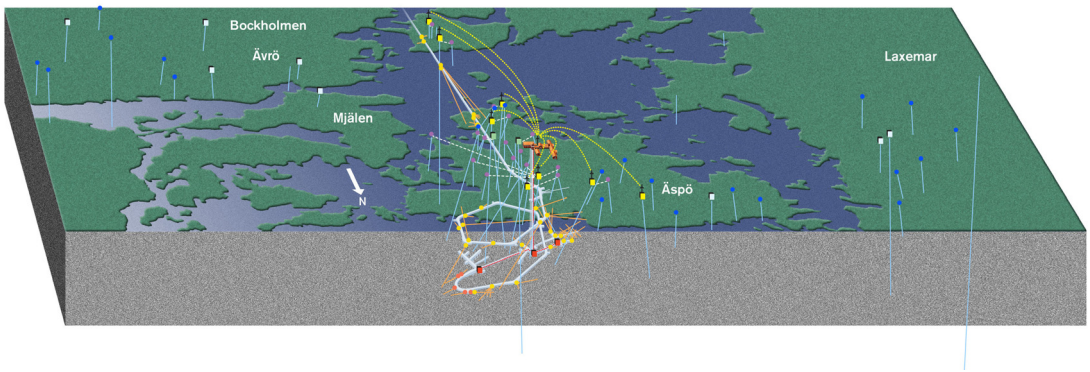


Figure 5-1 *Sump number 4 at -340 m level.*

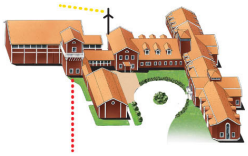
The ventilation system for the underground facility has been mapped and a package of measures to increase the air flow in Äspö HRL has been identified. The prognosis of 30% increase in airflow without increase in energy consumption. The guaranteed air flow was not initially obtained and some more improvements have been made. Rebuilding of the ventilation system has continued and operation tests indicate that the prognosis can be fulfilled.

A data network (Äspö.net) including a system for supervision of facilities and a server where all experimental data will be stored is in operation. Data from five more experiments have been moved to the server and 15 experiments are connected to the network. It has been decided to exclude data from HMS and the installation of the Baslab (located in Clab) systems is delayed but is planned to be finished in the beginning of next year.

5.2 Hydro Monitoring System



Measurement Station with radio and computer network situated at the site office.



- Monitored borehole communicating by radio.
- Logger - stand alone.
- Logger - on line.
- Borehole - manually measured.
- Borhole - monitored.
- Measurement Station in the tunnel.
- A/D converter connected directly to a measurement station.
- Logger - communicating with a measurement station on a Borre data network.

The computerised Hydro Monitoring System (HMS), is a network of boreholes and measurement stations where e.g. data of groundwater head, salinity, electrical conductivity, Eh and pH are collected on-line. The data are recorded by more than 400 transducers installed in boreholes on Äspö as well as in boreholes located in the tunnel. All data are transmitted to the main office at Äspö, by radio or modems.

Weekly quality controls of preliminary groundwater head data are performed. Absolute calibration of data is performed three to four times per year. This work involves comparison with groundwater levels checked manually in percussion drilled boreholes and in core drilled boreholes. The scope of maintaining such a monitoring network has scientific as well as legal grounds.

Achievements

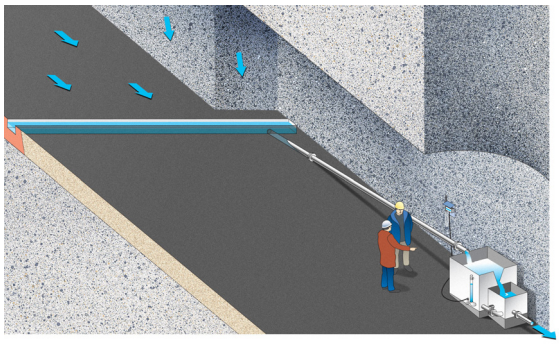
The system has been performing well. However, improvements are continuously made on the monitoring system to increase the performance of the system. The calibration of groundwater head data made in October show good correspondence in groundwater levels.

5.3 Programme for monitoring of groundwater head and flow

The monitoring of water levels in surface based boreholes started in 1987. The tunnel excavation started in October 1990 and the first groundwater head (pressure) measurements from tunnel based boreholes were performed in March 1992.

The monitoring is administrated by the computerised hydro monitoring system (HMS), comprising a network of boreholes of which many are equipped with hydraulically inflatable packers, measuring the pressure by means of transducers. Manual levelling is also obtained from the surface boreholes on a regular basis.

Water seeping through the tunnel walls is diverted to trenches and further to 21 weirs where the flow is measured.



Achievements

The monitoring points from the previous year have been maintained. The system will continue to support the experiments undertaken and meet the requirements stipulated by the water rights court.

The work to summarise the monitoring during 2004 is in progress. A report describing instrumentation and measurement methods and summarising the monitoring during 2003 is available /Nyberg *et al.,* 2004/.

5.4 Programme for monitoring of groundwater chemistry

During the Construction Phase of the Äspö HRL, different types of water samples were collected and analysed with the purpose of monitoring the groundwater chemistry and its evolution as the construction proceeded. At the beginning of the Operational Phase, sampling was replaced by a groundwater chemistry monitoring programme, aiming at a sufficient cover of the hydrogeochemical conditions with respect to time and space within the Äspö HRL. This programme is designed to provide information to determine where, within the rock mass, the hydrogeochemical changes are taking place and at what time stationary conditions are established.

Achievements

The annual monitoring campaign was performed as planned in September and initial data gave a broad general geochemical overview geochemical groundwater composition in the tunnel, see Figure 5-2. Chloride concentration varied in general from 590 mg/l to around 9 700 mg/l from the most shallow boreholes to the deepest ones. A few samples showed increased chloride concentrations up to about 14 500 mg/l also in respect of other main components.

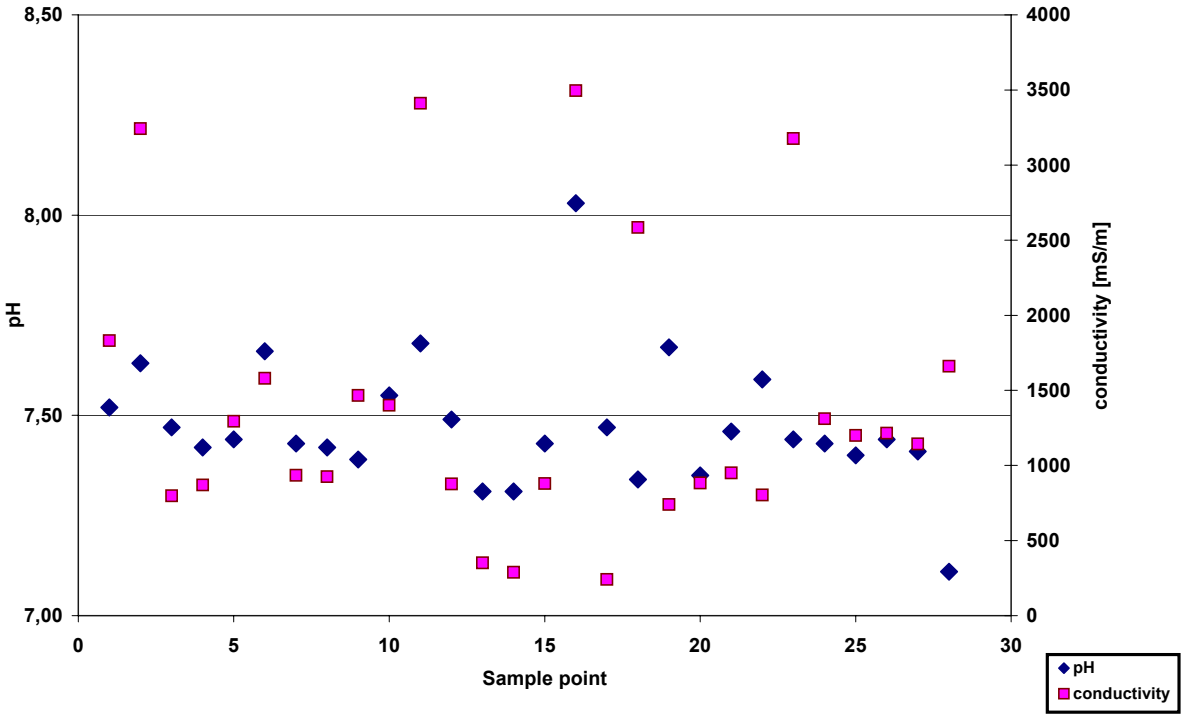


Figure 5-2 *Measured pH and electric conductivity in the groundwater in the different sample points. Data is from monitoring campaign in September 2004.*

6 International co-operation

Seven organisations from six countries participate in the co-operation at Äspö HRL during 2004 besides SKB. OPG (Canada) became a new participant in January 2004 and Nagra (Switzerland) has left the central and active core of participants, but continue in the Matrix Fluid Chemistry project as well as in the Task Force on Modelling of Groundwater Flow and Transport of Solutes.

Most of the participating organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several organisations are participating in the Äspö Task Force on 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.

Projects in the Äspö HRL during 2004	Andra	BMWA	Enresa	CRIEPI	JNC	OPG	Posiva
Technology							
Prototype Repository	X	X	X	X	X		X
Backfill and Plug Test			X				
Long Term Test of Buffer Material							X
Cleaning and sealing of investigation boreholes							X
Injection grout for deep repositories							X
KBS-3 method with horizontal emplacement			X			X	X
Large Scale Gas Injection Test	X	X	X		X	X	X
Temperature Buffer Test	X	X	X				
Geo-science							
Äspö Pillar Stability Experiment						X	X
Natural barriers							
Tracer Retention Understanding Experiments	X		X		X		X
Radionuclide Retention Project		X					
Colloid Project		X					X
Microbe Project		X					
Matrix Fluid Chemistry							
Task Force on Modelling of Groundwater Flow and Transport of Solutes	X	X	X	X	X	X	X

Participating organisations:
Agence nationale pour la gestion des déchets radioactifs, Andra, France
Bundesministerium für Wirtschaft und Arbeit, BMWA, Germany
Empresa Nacional de Residuos Radiactivos, Enresa, Spain
Central Research Institute of the Electronic Power Industry, Criepi, Japan
Japan Nuclear Cycle Development Institute, JNC, Japan
Ontario Power Generation Inc., OPG, Canada
Posiva Oy, Finland

EC-projects

SKB has taken part in several EC-projects of which the representation was channelled through Repository Technology. Three of these projects have been co-ordinated through Repository Technology and were finalised in the end of 2004: Prototype Repository, Cluster Repository Project (Crop) and Net.Excel. During this quarter also the projects listed below are in the stage of being finalised.

In addition to EC-projects, SKB takes part in work within the IAEA Network of Centres of Excellence.

Febex II – Full-scale engineered barriers experiment in crystalline host rock phase II
(1999-07-01 – 2004-10-31 after prolongation with 10 months)
Co-ordinator: Empresa Nacional de Residuos Radiactivos, Spain
Participating countries: Belgium, Czech Republic, Finland, France, Germany, Spain, Sweden, and Switzerland

Safeti – Seismic validation of 3-D thermo-mechanical models for the prediction of the rock damage around radioactive spent fuel waste (2001-09-01 – 2004-09-01)
Co-ordinator: The University of Liverpool (Dep of Earth Sciences), United Kingdom
Participating countries: France, Sweden and United Kingdom

Padamot – Paleohydrogeological data analysis and model testing (2001-12-01 – 2004-11-30)
Co-ordinator: Nirex Ltd, United Kingdom
Participating countries: Czech Republic, Spain, Sweden and United Kingdom

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7 Environmental research

7.1 Äspö Research School

Kalmar University's Research School in Environmental Science at Äspö HRL, called Äspö Research School, started in October 2002. This School is the result of an agreement between SKB and Kalmar University. It combines two important regional resources, i.e. Äspö HRL and Kalmar University's Environmental Science Section. The activity within the School will lead to: a) Development of new scientific knowledge, b) Increase of geo and environmental scientific competence in the region and c) Utilisation of the Äspö HRL for environmental research. Currently the scientific team consists of a professor of Environmental geology (Dr. Mats Åström), three assistant supervisors and six Ph.D. students. The research activity focuses on biogeochemical systems, in particular in the identification and quantification of dispersion and transport mechanisms of contaminants (mainly metals) in and between soils, sediments, water, biota and upper crystalline bedrock. In addition to financial support from SKB and University of Kalmar, the School receives funding from the city of Oskarshamn.

Achievements

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

8 Documentation

During the period October – December 2004, the following reports have been published and distributed.

8.1 Äspö International Progress Reports

Stigsson M, Hermansson J, Forssberg O, 2003. TRUE-1 Continuation project. Fault rock zones characterisation. Review of existing structural information and construction of local RVS models of four potential experimental sites. IPR-03-49, Svensk Kärnbränslehantering AB

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8.2 Technical Documents and International Technical Documents

Eight Technical Documents have been published during the fourth quarter 2004.

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