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Äspö Hard Rock Laboratory

Planning Report for 2006

Svensk Kärnbränslehantering AB

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Äspö Hard Rock Laboratory

The Äspö Hard Rock Laboratory
Planning Report for 2006

This report presents the planned activities for year 2006 with background, objectives, experimental concepts (where applicable) and scope of work. It details the programme for the Äspö Hard Rock Laboratory described in SKB's Research, Development and Demonstration Programme 2004, and serves as a basis for the management of the laboratory. The plan is revised annually. The activities are further detailed in activity plans for the Repository Technology department covering a time period of five years.

The role of the Planning Report is to present the background and objectives of each experiment. Thereby the Status Reports may concentrate on work in progress and refer to the Planning Report for more background information. The Annual Report will in detail present new findings and results.

Svensk Kärnbränslehantering AB

Repository Technology

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Director

Executive summary

General

The Äspö Hard Rock Laboratory (HRL), in the Simpevarp area in the municipality of Oskarshamn constitutes an important part of SKB's work with the design and construction of a deep geological repository for final disposal of spent nuclear fuel. This work includes the development of test methods for use in the characterisation of a suitable site. One of the fundamental reasons for the construction of an underground laboratory by SKB was that the laboratory enables research, development and demonstration in a realistic and undisturbed rock environment, down to repository depth. Most of the research is concerned with processes of importance for the long-term safety of a future deep repository. 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.

SKB's overall plans for research into and the development of technology to be carried out at Äspö HRL are described in the RD&D-Programme for the period of 2005-2010. The Äspö HRL Planning Report develops and gives more details of the planned research and development. Planning for Äspö HRL is revised annually. In this report an overview of the activities planned for the calendar year 2006 is given. Considerable international interest has been shown in Äspö HRL and its associated research, as well as in the development and demonstration tasks, which are managed by the Repository Technology Unit within SKB.

Geo-science

Geo-scientific research is a basic activity at Äspö HRL and is conducted in the fields of geology, hydrogeology, geochemistry and rock mechanics. The main aim of the current studies is to develop geoscientific models and increase understanding of the properties of the rock mass, as well as to develop applicable method of measurement. From 2006, the work will follow an annual geoscientific programme. An important part of the planned work, which is to begin in 2006, is the development of the new Äspö site description together with a detailed hydro-structural model of the main experimental level (-450 m).

Major activities are *Geological mapping and modelling*, all the rock surfaces in the tunnel and drill cores at Äspö have been mapped in order to increase understanding of the geometries and properties of rocks and rock structures. The resulting information is subsequently used as input in the 3D modelling. During 2006, the mapping of additional short drill holes, to be drilled early in the year, will be carried out. A detailed 3D structural geological and hydrogeological model of the -450 m level has been initiated. A new project with the aim of establishing the true width of deformation zones by using magnetic anisotropy has been started. Both activities are planned to be completed during 2006.

The project *Rock Characterisation System* is a feasibility study aiming to increase the objectivity, precision and traceability of the collected data and to decrease the time required for mapping and data treatment. The first part of the study, establishing of the technical state-of-art, was completed during 2005 and a test of data collection methods has been performed. The major task for 2006 will be to establish a detailed specification of requirements for a new rock characterisation system for use in the construction of a deep repository.

Seismic influence on the groundwater system will be studied by analysing data on changes in the piezometric head registered by the Hydro Monitoring System (HMS). Special software is under development that may facilitate the comparison of the HMS database with other databases, e.g. SKB's site investigation database (Sicada) or the national seismological database. The plans for 2006 are to finalise the software development and to analyse the impact of earthquakes and effects of blasts in Äspö HRL. For this, the disturbances coupled to the blasting in connection with construction of the TASQ-tunnel and with the extension of the central interim storage for spent nuclear fuel will be investigated, as well as the effects of the earthquakes in Turkey in 1999 and in the Indian Ocean in 2004.

The main objective of the project *Inflow predictions* is to make better predictions of the water inflow into deposition holes and tunnels. The results from a number of large field tests show that the inflow into a large diameter hole or a tunnel is often less than predicted from observation in a borehole. This phenomenon is not yet well understood. During 2005 extensive numerical analyses was conducted in order to provide information about the influence of the effective stress redistribution, caused by excavation, on water inflow. At the Äspö Pillar Stability site, the evolution over time of water flow into the excavation has been monitored and a report describing the mechanical modelling study of the de-stressing of the pillar will be written during 2006. In addition, coupled stress-flow laboratory tests will be conducted on large fracture samples from two boreholes, with the aim of improving already existing coupled hydro-mechanical fracture constitutive models. Analyses of data on inflow to e.g. the Prototype Repository in combination with numerical groundwater modelling are also planned.

The *Hydro Monitoring Programme* is an important part of the hydrogeological research and supports the experiments being undertaken at HRL. The programme started partly because a monitoring programme was required by the water-rights court in conjunction with permission being granted for construction of the tunnel. The computerised Hydro Monitoring System (HMS) collects on-line data on pressure, levels, flow and electrical conductivity of the groundwater at Äspö HRL and the nearby islands. The measured data are relayed to a central computer in the Äspö office. The activities during 2006 will comprise the operation, maintenance and documentation of the HMS system. A semi-automatic transfer of data to Sicada will be implemented and transducers for measurements of temperature, humidity and pressure of tunnel air will be installed.

The programme for *Monitoring of groundwater chemistry* is designed to provide information about where in the rock mass the hydrogeochemical changes are taking place and at what time stationary conditions are established. In 2005, some biogeochemical parameters were included in the programme and these data will be analysed during 2006. The last monitoring campaign gave a broad geochemical overview of the tunnel. Some areas with increased salinity were found in the Äspö-tunnel and one hypothesis for this effect is the up-coning of groundwater with high salinity. During 2006, the evolution of hydrogeochemical conditions will be studied further and will also take into account the interaction with sub-surface and surface groundwaters.

Rock Mechanic studies are performed in order to increase understanding of the mechanical properties of the rock. The studies include laboratory experiments and modelling at different scales. Another objective is to recommend methods for the measurement and analysis of mechanical properties. During 2006, work will mainly be performed within the Ä*spö Pillar Stability Experiment.*

The Äspö Pillar Stability Experiment was initiated to demonstrate the capability for prediction of spalling in a fractured rock mass and to demonstrate the effect of backfill (confining pressure) on the propagation of micro-cracks in the rock mass closest to the deposition hole. During 2003, a new drift was excavated to ensure that the experiment was carried out in a rock mass with a virgin stress field. Two vertical holes were drilled at a distance of one metre in the floor of the tunnel. When heaters were turned on, spalling was quickly initiated in the pillar wall. The pillar was sawn in blocks and removed from the experiment site during late 2004 and 2005, and the remaining rock walls and the blocks have been geologically mapped. An integrated analysis, which combines data on temperature, deformations and acoustic emissions during the heating phase of the experiment with data from the post characterisation, will be finalised and published during 2006. Back-calculations of the elastic deformations that occurred before spalling will also be presented.

Buffer and backfill materials and technology

A number of experiments which are being carried out at the Äspö HRL have confirmed that, at full scale, it is possible to place pre-pressed blocks and rings of bentonite around a canister under both ideal and more demanding conditions. Before building a final repository, where the operating conditions include the deposition of one canister per day, further studies of the behaviour of the buffer under different installation conditions are required. SKB has decided to build a Bentonite Laboratory at Äspö in order to study in detail how the phenomenon of channel formation can be controlled. This new laboratory will also be designed for studies of buffer materials in general. The Bentonite Laboratory will include two stations where the emplacement of buffer material at full scale can be tested under different conditions. The hall will also be used for continued testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

Natural barriers

At Äspö HRL, experiments are performed under the conditions that are expected to prevail at repository depth. The aim is to provide information about the long-term function of repository barriers. The natural barriers are the bedrock with its available fractures and fracture zones, its properties and the physical and chemical processes that occur in the rock and that affect the integrity of the engineered barriers and the transport of radionuclides. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The strategy for the current experiments is to focus on those of most importance for the site investigations. Tests of numerical models for groundwater flow, radionuclide migration and chemical/biological processes are one of the main purposes of the Äspö HRL. The programme includes projects which aim to evaluate the usefulness and reliability of different numerical models and to develop and test methods to determine parameters values that are required as input to the models.

A programme has been defined for tracer tests at different experimental scales, the so-called *Tracer Retention Understanding Experiments* (True). The overall objectives of the experiments are to gain a better understanding of the processes which govern the retention of radionuclides transported in crystalline rock, and to increase the credibility of models used for radionuclide transport calculations. At the moment, work is being performed in the projects: *True Block Scale Continuation* (BS2 and BS3), *True-1 Continuation* and *True-1 Completion*.

The objectives of the *True Block Scale Continuation Project* are to improve understanding of transport pathways at the block scale, including assessment of the effects of geometry, macro-structure and micro-structure. The *in situ* experiments with sorbing tracers were paralleled during 2005 by model predictions made with four different modelling approaches. Draft evaluation reports were produced by each modelling group and a review seminar was held in mid September. Completion of the evaluation reports and the BS2 final report during 2006 is planned. A second stage of the continuation the *True Block Scale Continuation (BS3)* has been discussed. This stage will not have specific experimental components, but will instead consolidate and integrate all the previous relevant True data and evaluations. During 2006 preparatory work will be carried out to sorting out the important issues and define a platform for the planned work.

One of the principal objectives of the *True-1 Continuation Project* is to map the porosity which provided the observed retention in the previously investigated Feature A at the True-1 site. Reports on the Fault rock zones characterisation project and the sorption characteristics of fault gouge material will be completed during 2006. In addition, scientific papers on the True team analysis of the True-1 experiments will be published. The planned injection of epoxy resin at the True-1 site will be preceded by complementary cross-hole hydraulic interference tests combined with tracer dilution tests. These tests, *True-1 Completion*, are intended to shed light on the possible three-dimensional aspects of transport at the site. The main tasks for 2006 are:
(a) complementary tracer tests, (b) epoxy injection and dismantling of the True-1 site and (c) over-coring the experimental boreholes after sufficient time of decay for the active Cs used in cation-exchange capacity test.

The *Long Term Diffusion Experiment* complements the diffusion and sorption experiments performed in the laboratory, and is a natural extension of the True-experiments. The difference is that the longer duration (approximately four years) of the experiment is expected to give an improved understanding of diffusion and sorption in the vicinity of a natural fracture surface. The experiment will be performed in a core stub with a natural fracture surface isolated at the bottom of a large diameter telescoped borehole. A functionality test with short lived radionuclides was performed during 2005 and overall, the system was found to work as expected. After the test, adjustment and modification of the test equipment during 2006, prior to the forthcoming diffusion and sorption test, was decided upon. Laboratory experiments performed at AECL, on core samples from the LTDE borehole, were completed in 2005 and a draft version of the final report was compiled. During 2006, diffusion and sorption test will be performed both *in situ* (five - seven months) and in the laboratory in order to evaluate whether or not laboratory scale sorption results are representative of larger scales.

The *Colloid Project* comprises studies of the stability and mobility of colloids, bentonite clay as a source for colloid generation, the potential of colloids to enhance radionuclide transport and the measurements of the colloid concentration in the groundwater at Äspö. The laboratory experiments, background measurements and borehole specific measurements are compiled in a final report that was sent for print in December 2005. Tracer tests with injections of conservative tracers will be performed at the True-1 site to determine whether the conditions are stable. Dipole colloid experiments, with injection of latex colloids and a colour tracer, will then start during 2006. These experiments will study the change in colloid content in the groundwater prior to and after its transport through a natural fracture. The data will be evaluated during 2006. Parallel to the colloid dipole experiment, actinide transport in the presence of colloids will be studied in a water bearing fracture when a suitable borehole has been selected.

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 future deep repository for spent fuel. These interactions are studied in the *Microbe Project*. The former stable conditions in the Microbe laboratory were dramatically changed in January 2005 as a result of the drilling of boreholes for the *in situ* corrosion testing of miniature canisters. Significant drainage has led to a completely new mixing situation with an increase in chloride concentration in the Microbe formation. A new complete characterisation will be performed in the beginning of 2006 to establish the new chemical conditions. In addition, three main activities are planned for 2006. Firstly, investigations will be performed of the influence of micro-organisms on the chemical situation in the groundwater. Secondly, *in situ* formation of complexing agents in the Microbe laboratory circulations will be investigated. Thirdly, bio-corrosion of copper canister will be investigated *in situ* by studying the result of microbial sulphide production in the surrounding bentonite.

The first phase of the *Matrix Fluid Chemistry* experiment (1998-2003) was published in 2004. The results from this phase gave information about matrix pore space fluids/groundwaters from crystalline rocks of low hydraulic conductivity, and complemented the hydrogeochemical studies already conducted at Äspö. The continuation phase focuses on the small-scale micro-fractures in the rock matrix which facilitate the migration of matrix waters. Understanding of the migration of ground-water, and its changing chemistry, is important for repository performance. A feasibility study, carried out during 2005, investigated the impact on hydrogeology and hydrochemistry of the tunnel construction at the Äspö Pillar Stability Experiment, in vicinity of the Matrix Fluid Experiment borehole. The impact of the excavation was found to be limited. Therefore initial hydrochemical and hydraulic characterisation of the presently isolated borehole sections containing microfractures was judged to be worthwhile. In addition hydraulic characterisation of the original fracture-free borehole sections sampled during the first phase of the matrix experiment will be carried out. Samples of waters from fracture-containing sections of the matrix boreholes are presently being chemically and isotopically analysed and hydraulic characterisation of the borehole is presently on-going and will continue in 2006. The scope of the work for 2006 will focus on completion of the hydraulic testing and analysis of sampled water.

Radionuclide Retention Experiments are carried out to confirm the results of laboratory experiments *in situ,* where the conditions with respect to groundwater properties are representative of those at repository depth. The experiments are carried out in special probes placed in boreholes. Radiolysis experiments, intended to investigate the influence of radiolysis on the migration of oxidised technetium, were performed with the Chemlab 1 probe. The field experiment and the evaluation of collected data are finished, and the final report is in print. Migration of actinides in a natural rock fracture in a drill core has been studied with the Chemlab 2 probe. The final report will be finished during spring 2006. The experiments on spent fuel leaching under relevant repository conditions have just been initiated and laboratory experiments which will preceding the *in situ* experiments in Chemlab 2 are being planned. Resistance to radionuclide transport at the buffer-rock interface will be studied in the laboratory after the Bentonite Erosion experiment, which now uses the experimental equipment, has been completed.

Padamot (Palaeohydrogeological Data Analysis and Model Testing) is an EC-project that is investigating specific processes that might link climate and groundwater in low permeability rocks and includes the development of analytical techniques and modelling tools to interpret data. The term palaeohydrogeology is used as a common name for information from fracture minerals that is used for interpretations of past hydrogeochemical and hydrogeological systems. The EC part of the project has been completed and published. During 2006, a paper will be presented on methodologies for palaeohydrogeological studies with emphasis on possible approaches to the Swedish site investigations. Methods such as bulk sample analyses and sequential leaching will be applied to a set of samples from Äspö and Laxemar to test the different techniques.

The basic idea behind the project *Fe-oxides in fractures* is to examine Fe-oxide fracture linings, in order to explore suitable palaeo-indicators and their formation conditions. At the same time, information about the behaviour of trace component uptake can be obtained from natural material as well as from studies in the laboratory under controlled conditions. A fast, effective and precise procedure has been developed to differentiate between several types of Fe-oxides found as fracture fillings in granite. During 2006, investigations into green rust stability and the potential mobility of green rust colloids will continue. Possibly, the next stage will be similar studies on selected samples from the site investigations at Oskarshamn and Forsmark. In addition, reactive transport modelling involving Fe(II)/Fe(III) species will be developed further at Enviros in Spain.

The general objective of the *Swiw-test with synthetic groundwater* (single well injection withdrawal) is better understanding of the dominating retention processes and the provision of new information on fracture aperture and diffusion. The Project constitutes a complement to tests and studies performed within the *True-1 and the True Block Scale* experiments. The tests will be performed with radon free synthetic groundwater and sorbing and non-sorbing tracers will be added during injection. The main part of 2006 will be devoted to detailed planning of the work.

Important goals of the activities at Äspö HRL are the evaluation of the usefulness and reliability of different models and the development and testing of methods to determine parameter values required as input to the models. An important part of this work is performed in the *Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes*. The work in the Task Force is closely tied to ongoing and planned experiments at the Äspö HRL. Specified tasks are defined in which several modelling groups work on the same set of field data. The modelling results are then compared to the experimental outcome and evaluated by the Task Force delegates. The ongoing Task 6, Performance assessment modelling, using site characterisation data, was initiated in 2001 and is planned to be completed during 2006. The Issue Evaluation table, which intends to provide a basis for the identification and evaluation of key issues in performance assessment of a deep geological repository, will be updated in 2006. The plans for 2006 also include modelling within Task 7, which aims to simulate the hydraulic responses detected during a long-term pumping test at the underground facility Onkalo at the Olkiluoto site in Finland.

Engineered barriers

At Äspö HRL, the goals are to demonstrate technology for and the 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 an appropriate scale. A number of large-scale field experiments and supporting activities are therefore carried out at Äspö HRL. The experiments focus on different aspects of engineering technology and performance testing, and will together form a major experimental programme.

The *Prototype Repository* is a demonstration of the integrated function of the repository and provides a full-scale reference for tests of predictive models concerning individual components as well as the complete repository system. It has also been a demonstration of the execution and function of the deposition sequence with state-of-the-art technology in full-scale. The layout involves altogether six deposition holes, four in an inner section and two in an outer. The tunnel is backfilled with a mixture of bentonite and crushed rock. In 2001 the inner section was installed and the monitoring of processes started. The installation of the outer section took place during 2003 and the surface between the outer plug and the rock was grouted in 2004. During 2005 the instrument readings in the two sections started. During 2006 the instrument readings will continue together with chemical measurements in buffer, backfill and surrounding rock. Modelling teams will also continue the comparison of measured data with predictions.

The *Long Term Test of Buffer Material* aims at validating models and hypotheses concerning physical properties in a bentonite buffer material and of related processes regarding microbiology, radionuclide transport, copper corrosion, and gas transport under conditions similar to those in a KBS-3 repository. The testing principle is to emplace parcels containing heater, central copper tube, pre-compacted clay buffer, instruments, and parameter controlling equipment in vertical boreholes with a diameter of 300 mm and a depth of around four meters. The parcels are extracted and the water distribution in the clay is determined and subsequent well-defined chemical and mineralogical analyses as well as physical tests are performed. Two pilot tests are finalised and reported, one parcel from the main test has been extracted and analysed and one parcel has been terminated. The remaining three parcels are functioning well and only minor service was needed during the past year. The hourly measurement of water pressure, total pressure, temperature, and moisture will continue and the data will be carefully analysed and reported in April and October 2006. The parcel that is terminated will be lifted up at the beginning of 2006 and bentonite material will be sent to the laboratories involved in the project. The analyses are planned to be completed during the summer and reported in September. In addition, minor maintenance and improvement work on the remaining parcels is planned for 2006.

The *Backfill and Plug Test* is a test of the hydraulic and mechanical function of different backfill materials, emplacement methods, and a full-scale plug. The 28 m long test region is located in the ZEDEX drift. The inner part of the drift is backfilled with a mixture of bentonite and crushed rock and the outer part is filled with crushed rock. The wetting of the backfill from the rock and filter mats supplying artificial water started at the end of 1999. The wetting continued until autumn 2003 when flow testing in the backfill started. The flow testing proceeded through 2004 and 2005. Measurement of hydraulic conductivity in single points, using pressurizing filter equipped tubes, and of water flow into the backfill began in late 2005. The excavation of the backfill materials was initially planned to start in autumn 2006. However, other priorities have led to a proposal to postpone the excavation. Presuming that no excavation will take place during 2006, the activities during the year will include continued measurements of hydraulic conductivity, water pressure and water flow, mechanical testing of compressibility of the back fill, and supplementary modelling that will complement the flow testing.

The *Canister Retrieval Test*, located in the main test area at the -420 m level, aims to demonstrate readiness for recovering emplaced canisters even after the time when the surrounding bentonite buffer is fully saturated. Bentonite rings and blocks, bentonite pellets, and a canister with a heater have been installed in a vertical deposition hole at full repository scale. The test has been running for a little more than five years. The bentonite between the rock and the canister is close to water saturation although the wetting seems to be somewhat uneven and the total pressure has not reached the expected values. Some clogging of the filter mats used for the artificial water supply may explain the inhomogeneous appearance. The measuring systems and transducers seem to work well with exception of several relative humidity sensors and all sensors inside the canister, which have failed. The retrieval of the canister is planned for early 2006, but the data collection will continue until the transducers are brought up from the buffer. The canister, heaters, and the bentonite buffer will be investigated and analysed after retrieval of the canister. The measurements in the rock will continue until the entire retrieval is finished and a final data report will be issued in April. The modelling of the THM-processes will continue during 2006.

The *Temperature Buffer Test* aims at improving the current understanding of the thermo-hydro-mechanical behaviour of buffers with a temperature around and above 100°C during the water saturation transient. This knowledge is needed in order to model the behaviour of the buffer. The French organisation Andra is running this test in co-operation with SKB. Two heater probes are installed in one deposition hole in the same test area as the Canister Retrieval Test. One of the probes is surrounded by an ordinary bentonite buffer and the other has a ring of sand as a thermal protection between the probe and the bentonite buffer. The operation phase, including heating, artificial pressurised saturation of the buffer and monitoring of temperature, humidity, pressure and displacement started in March 2003. Monitoring and sampling of experimental data are being carried out continuously and the information is transferred via a data link to Andra’s head office in France. The initial thermal shock caused local desaturation of the bentonite where the temperature exceeded 100°C. During 2006, the operation phase will continue and the experiment will be left without changes in boundary conditions. Three modelling tasks have been conducted during 2004 and 2005 and two modelling tasks are planned to be initiated during 2006: (a) predictive modelling of a mock-up test and (b) a field-test modelling task (including modelling of the present state and predictions of future conditions).

At the end of 2001, SKB published an R&D-Programme for the *KBS-3 method with horizontal emplacement* (KBS-3H). The programme, which is carried out by SKB and Posiva in co-operation, is divided into four parts: (1) Feasibility study, (2) Basic design, (3) Construction and testing at the Äspö HRL and (4) Evaluation. The outcome of the feasibility study was that the KBS-3H method is worth further development work. The Basic design study including, the development of technology for excavation of horizontal deposition holes and emplacement of Super containers, was finalised and reported in 2004. Preparations for the full scale demonstration at Äspö HRL are in progress. The demonstration comprises two deposition holes – one short hole (15 m), which will be used for construction and testing of a low-pH shotcrete plug, and one long hole (95 m) which will primarily be used for demonstration of the deposition equipment and for evaluation of the chosen excavation method. The excavation of the short hole was completed in 2004 and preparation for the installation of the low-pH plug started in 2005. The plug is now constructed and is hardening before the planned pressure test in 2006. The long hole was excavated and mapped during 2005 and in the niche, preparation for deposition equipment was performed and the docking- and gating flange mounted. The copper canisters, gamma gates and perforated steel sheets have been delivered, and assembly began in 2005. Two Super containers are now ready for tests of the deposition equipment. Activities planned for 2006 include design, manufacture and tests of different components in the KBS-3H concept, performance of a feasibility study of retrievability and preparations for the Safety Case. A report on the experimental study on the interaction between corroding iron and bentonite under anaerobic conditions will be completed in early 2006.

The aim of the *Large Scale Gas Injection Test* is to perform gas injection tests in a full-scale KBS-3 deposition hole. Our current understanding of the gas transport process through compacted bentonite indicates that the buffer would open for gas passage before any harmful pressures are reached. However, there are still large uncertainties around the gas migration process which have to be verified in large-scale experiments. The experiment is performed in a bored full-size deposition hole with a full-scale canister without heaters and a surrounding bentonite buffer. The installation phase, including the deposition of canister and buffer, was finalised in 2005. Water is artificially supplied and the evolution of the saturation of the buffer is continuously measured. The gas injection tests will start when the buffer is fully saturated, which is expected to take two years.

The objective of the project *In situ corrosion testing of miniature canisters* is to obtain a better understanding of the corrosion processes inside a failed canister. This information will form the basis for identification of the possible scenarios for radionuclide release from the canister. The process has been studied in the laboratory and by modelling. In Äspö HRL *in situ* experiments with miniature copper canisters with cast iron inserts will be performed. The canisters will be exposed to natural reducing groundwater and groundwater which has been conditioned by bentonite for several years. The design of the miniature canisters has been completed and the components of five canisters have been manufactured. Five boreholes have been drilled and under 2006 the plan is to complete the installations in the boreholes, emplace the five miniature canisters and finally start the monitoring.

In the project *Cleaning and sealing of investigation boreholes* the best available techniques are to be identified and demonstrated. In order to obtain data on the properties of the rock, investigation boreholes are drilled during site investigations and detailed characterisations are performed. These boreholes must be cleaned and sealed, no later than at the closure of the deep repository. The first phase of the project was a state-of-the-art review summarising the development of techniques during the last 10–15 years. A final report from the second phase, focussing on the development of a complete basic concept, has been prepared. The aim of the work during 2006 is to continue with the design and modelling of the performance of borehole plugs and to prepare and conduct tests of different plugging techniques in short and long boreholes. In addition, the evaluation of all stages in the plugging of Posiva´s borehole OL-KR-24 will be continued.

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS-3 concept, the bentonite buffer is required to serve as a mechanical support for the canister, to reduce the effects on the canister of a possible rock displacement, and to minimise water flow in the deposition holes. Within the project *Alternative buffer materials*, a large scale program to study the use of possible alternative buffer material has been initiated. The project aims at studying the long term stability of bentonites and the influence of accessory minerals in the materials. The project started in 2005. During 2006, all field activities related to the emplacement stage of the project will be carried out. This work includes experimental design, preparation of the test site, manufacturing of the clay blocks, assembly of the experiment parcels, emplacement of parcels, and finally, sealing of the boreholes and start of heaters. The testing principle to be used is that used in the *Long Term Test of Buffer Material* experiment.

The aim of the *Rock shear experiment* is to observe the forces that would act on a KBS-3 canister if a displacement of 100 mm were to take place in a horizontal fracture that crosses a deposition hole. Such a displacement could be caused by an earthquake. The test set-up is required to provide a shearing motion along the fracture that is equal to the expected shearing motion expected in reality. A feasibility study has been performed and reported. The main conclusion is that the test is feasible. The test set-up is planned to be installed at the *Äspö Pillar Stability Experiment* site when the rock mechanic tests have been completed. A preliminary decision to realise the plans has been taken but no time schedule is set. The activities during 2006 will mainly include planning of supplementary laboratory tests.

The *Task Force on Engineered Barrier Systems* was activated in 2004. The Task Force starts with a first phase that comprises four years. This phase addresses two tasks, THM processes and gas migration in buffer material. The work will produce a state-of-the-art report. The focus is on the use of codes for predictions of the conditions in the buffer during specified milestones in the repository evolution. During 2005 benchmark calculations for THM-processes and gas migration was performed. During 2006, the results regarding the THM-processes will be analysed. The possibility of and the requirement for further development of the codes will be evaluated. Comments on the capability of each participating code will be issued in a report. The results regarding gas migration will be reported by the modelling teams in April 2006. A suggested EC project named Theresa, which consists of six work packages, has also been presented.

Äspö facility

Important activities at the Äspö facility are the administration, operation and maintenance of instruments as well as the development of investigation methods. The main goal of the operation is to provide a safe and environmentally sound facility for everybody working or visiting the Äspö HRL. This includes preventative and remedial maintenance in order to maintain high availability in all the systems in the underground laboratory, such as drainage, electrical power, ventilation, alarm and communications.

The *Public Relations and Visitor Services* group located at Äspö HRL is responsible for presenting information about SKB and its facilities. They arrange visits to the facilities all year around as well as special events. The special events planned for 2006 are the same events that were successfully carried out during 2005 e.g. Underground 500.

Environmental research

The experiments performed in Äspö HRL are not exclusively focused on radionuclide related processes but also on non-radioactive environmental issues. The Kalmar University's Research School in Environmental Science at Äspö HRL (Äspö Research School) started in 2002. The school is the result of an agreement between SKB and Kalmar University. The activities foreseen for 2006 at Äspö HRL are, however, only minor. Initiatives will be taken to support the development of the Äspö Research School.

International co-operation

Nine organisations from eight countries will participate in the co-operation at Äspö HRL in 2006. Most of the organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several of the organisations are participating in the experimental work as well as in the Task Force on Modelling of Groundwater Flow and Transport of Solutes and the Task Force on Engineered Barrier Systems.

Contents

1 General

1.1 Background

The Äspö Hard Rock Laboratory (HRL), in the Simpevarp area in the municipality of Oskarshamn, constitutes an important part of SKB's work with design and construction of a deep geological repository for final disposal of spent nuclear fuel. This work includes the development and testing of methods for use in the 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. Most of the research is concerned with processes of importance for the long-term safety of a future final repository and the capability to model the processes taking place. Demonstration addresses the performance of the engineered barriers, and practical means of constructing a repository and emplacing the high-level nuclear waste.

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, see Figure 1-1. The total length of the tunnel is 3,600 m where the main part of the tunnel has been excavated by conventional drill and blast technique and the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts.

The work with Äspö HRL has been divided into three phases: Pre-Investigation phase, Construction phase and Operational phase.

During the *Pre-Investigation phase*, 1986–1990, studies were made to provide background material for the decision to locate the laboratory to a suitable site. The natural conditions of the bedrock were described and predictions made of geological, hydrogeological, geochemical and rock-mechanical conditions to be observed during excavation of the laboratory. This phase also included planning for the Construction and Operational phases.

During the *Construction phase*, 1990–1995, comprehensive investigations and experiments were performed in parallel with construction of the laboratory. The excavation of the main access tunnel to a depth of 450 m and the construction of the Äspö Research Village were completed.

The *Operational phase* began in 1995. A preliminary outline of the programme for this phase was given in SKB's Research, Development and Demonstration (RD&D) Programme 1992. Since then the programme has been revised every third year and the basis for the current programme is described in SKB's RD&D-Programme 2004 /SKB 2004/.

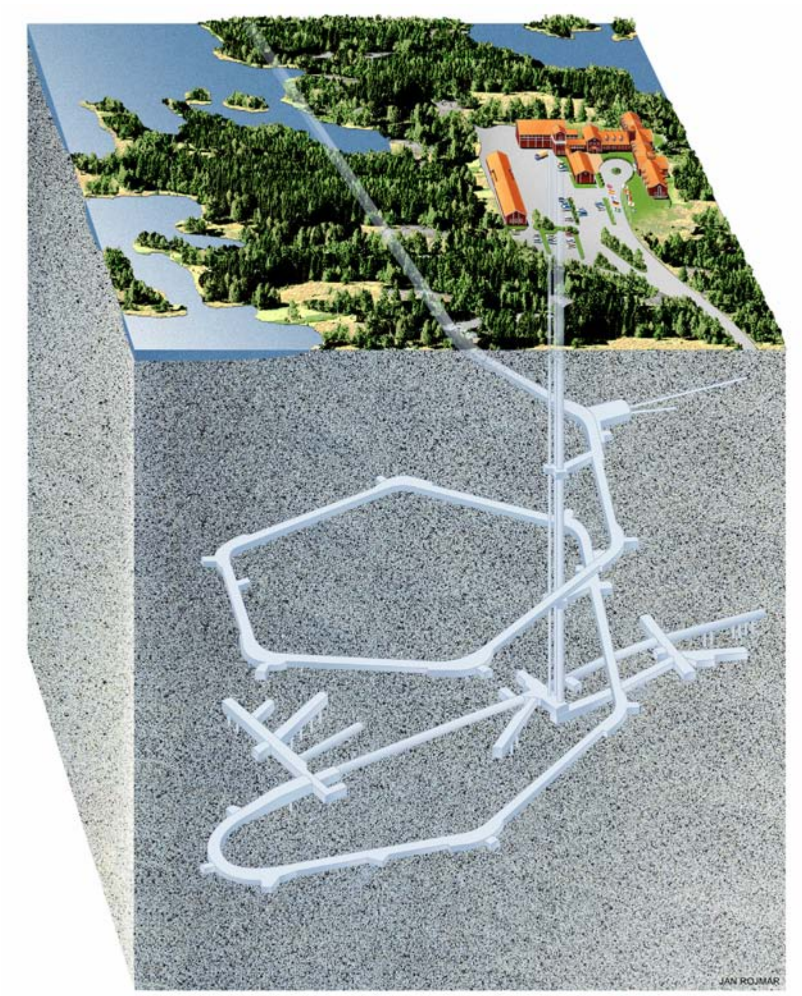

Figure 1-1 *Overview of the Äspö HRL facilities.*

1.2 Goals

To meet the overall time schedule for SKB's RD&D work, the following stage goals were initially defined for the work at the Äspö HRL:

1. *Verify pre-investigation methods*. Demonstrate that investigations on the ground surface and in boreholes provide sufficient data on essential safety-related properties of the rock at repository level.

2. *Finalise detailed investigation methodology*. Refine and verify the methods and the technology needed for characterisation of the rock in the detailed site investigations.

3. *Test models for description of the barrier functions at natural conditions*. Further develop and at repository depth test methods and models for description of groundwater flow, radionuclide migration and chemical conditions during operation of a repository and after closure.

4. *Demonstrate technology for and function of important parts of the repository system*. In full scale test, investigate and demonstrate the different components of importance for the long-term safety of a final repository and show that high quality can be achieved in design, construction and operation of repository components.

Stage goals 1 and 2 have been concluded at Äspö HRL and the tasks have been transferred to the Site Investigations Department of SKB which performs site investigations at Simpevarp/Laxemar in the municipality of Oskarshamn and at Forsmark in the municipality of Östhammar.

In order to reach present goals (3 and 4) the following important tasks are performed at the Äspö HRL:

- Develop, test, evaluate and demonstrate methods for repository design and construction as well as deposition of spent nuclear fuel and other long-lived waste.
- Develop and test alternative technology with the potential to reduce costs and simplify the repository concept without sacrificing quality and safety.
- Increase the scientific understanding of the final repository's safety margins and provide data for safety assessments of the long-term safety of the repository.
- Provide experience and train personnel for various tasks in the repository.
- Provide information to the general public on technology and methods that are being developed for the final repository.
- Participate in international co-operation through the Äspö International Joint Committee (IJC) as well as bi- and multilateral projects.

1.3 Organisation

SKB's work is organised into six departments: Technology, Nuclear Safety, Site Investigations, Operations, Environmental Impact Assessment (EIA) and Public Information and Business Support. The research, technical development and safety assessment work is organised into the Technology department, in order to facilitate co-ordination between the different activities.

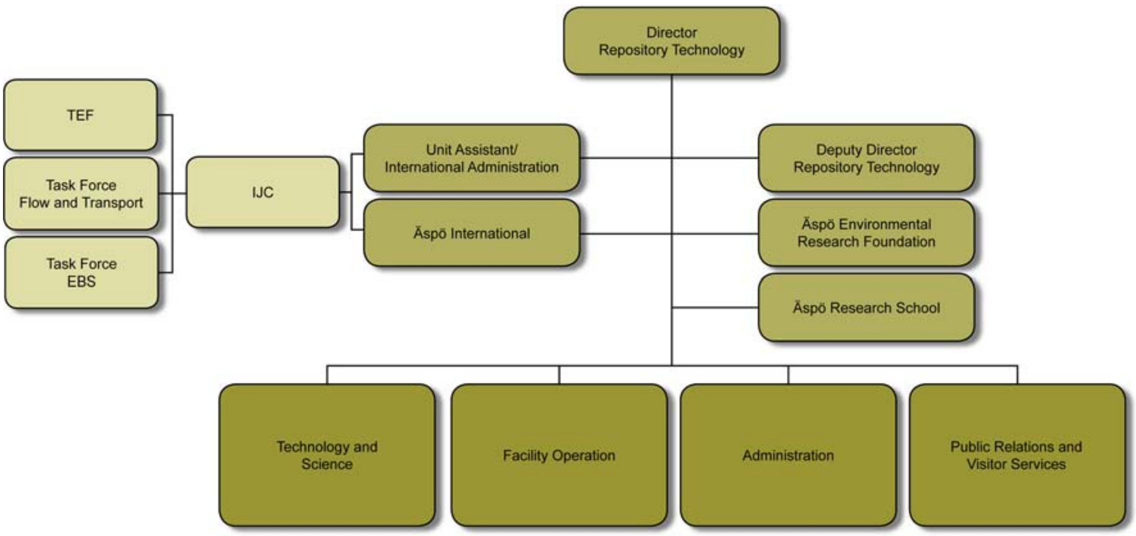

Figure 1-2 *Organisation of Repository Technology and Äspö HRL.*

Repository Technology (TD), one of five units organised under the Technology department, is responsible for development and testing of deep repository technology and *in situ* research on repository barriers at natural conditions. The unit is also responsible for the operation of the Äspö facility and the co-ordination of the research performed in international co-operation. The Repository Technology unit is organised in four operative groups, see Figure 1-2:

- *Technology and Science* is responsible for the co-ordination of projects undertaken at the Äspö HRL, for providing service (design, installations, measurements etc.) to the experiments, to manage the geo-scientific models of the "Äspö Rock Volume" and to maintain knowledge about the methods that have been used and the results that have been obtained from work at Äspö HRL.
- *Facility Operation* is responsible for operation and maintenance of the Äspö HRL offices, workshops and underground facilities and for operation and maintenance of monitoring systems and experimental equipment.
- *Administration* is responsible for providing administrative service and quality systems.
- *Public Relations and Visitor Services* is responsible for presenting information about SKB and its facilities with main focus on the Äspö HRL. The HRL and SKB's other research facilities are open to visitors throughout the year.

The Äspö HRL and the associated research, development and demonstration tasks are managed by the Director of Repository Technology. Each major research and development task is organised as a project that is led by a Project Manager who reports to the head of Technology and Science group. Each Project Manager will be 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.

1.4 International participation in Äspö HRL

The Äspö HRL has so far attracted considerable international interest. During 2006, nine organisations from eight countries will in addition to SKB participate in the Äspö HRL or in Äspö HRL-related activities. The participating organisations are:

- Agence Nationale pour la Gestion des Déchets Radioactifs (Andra), France.
- Bundesministerium für Wirtschaft und Technologie (BMWi), Germany.
- Central Research Institute of Electric Power Industry (CRIEPI), Japan.
- Japan Atomic Energy Agency (JAEA), Japan.
- Ontario Power Generation Inc. (OPG), Canada.
- Posiva Oy, Finland.
- Empresa Nacional de Residuos Radiactivos (Enresa), Spain.
- Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Nagra), Switzerland.
- Radioactive Waste Repository Authority (RAWRA), Czech Republic.

For each partner the co-operation is based on a separate agreement between SKB and the organisation in question.

Andra, BMWi, CRIEPI, JAEA, OPG and Posiva together with SKB form the Äspö International Joint Committee (IJC), which is responsible for the co-ordination of the experimental work arising from the international participation.

Task Forces are another form of organising the international work. Several of the international organisations in the Äspö co-operation participate in the two Äspö Task Forces on (a) Modelling of Groundwater Flow and Transport of Solutes and (b) THMC modelling of Engineered Barrier Systems.

SKB also takes part in several international EC-projects and participates in work within the IAEA framework.

1.5 Allocation of experimental sites

The rock volume and the available underground excavations have to be divided between the experiments performed at the Äspö HRL. It is essential that the experimental sites are allocated so that interference between different experiments is minimised. The allocation of experimental sites within the Äspö HRL is shown in Figure 1-3.

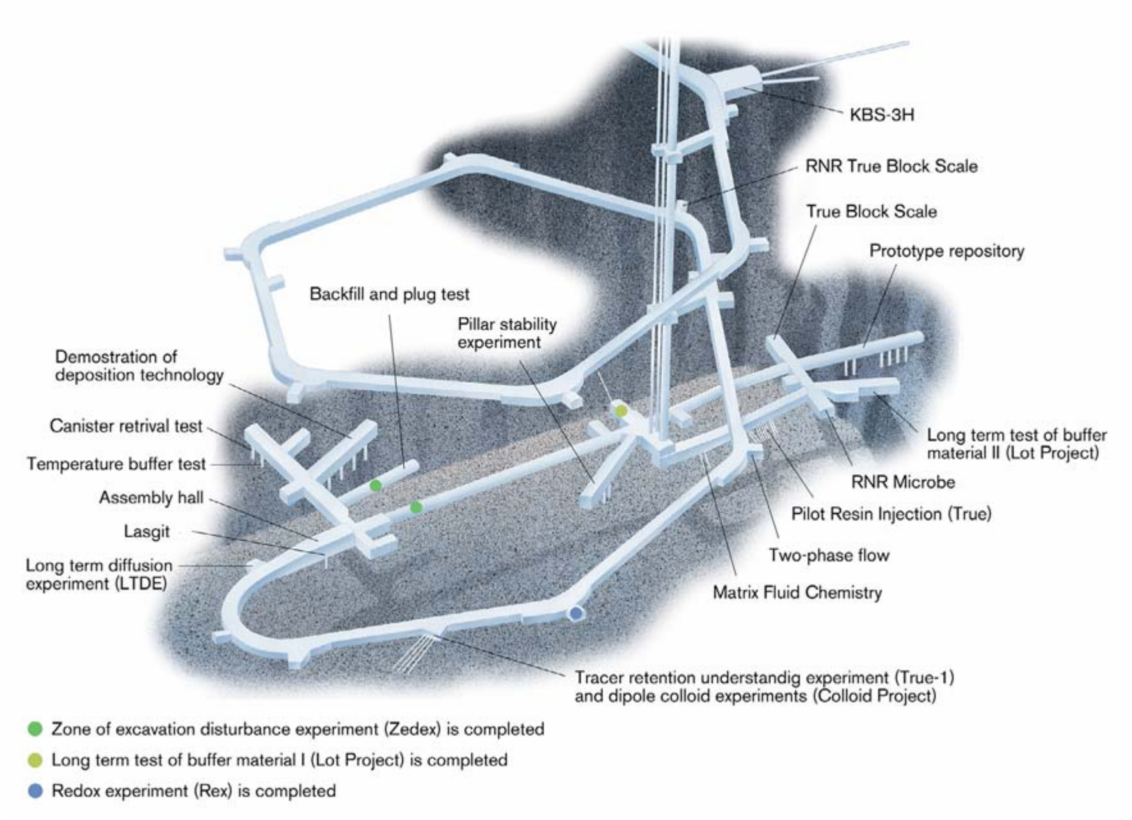

Figure 1-3 *Allocation of experimental sites from -220 m to -450 m level.*

1.6 Reporting

Äspö HRL is an important part of SKB's RD&D-Programme. The plans for research and development of technique during the period 2005–2010 are presented in SKB's RD&D-Programme 2004 /SKB 2004/. The information given in the RD&D-Programme related to Äspö HRL is detailed in the Äspö HRL Planning Report. This plan is revised annually and the current report gives an overview of the planned activities for the calendar year 2006. Detailed account of achievements to date for the Äspö HRL can be found in the Äspö HRL Annual Reports that are published in SKB's Technical Report series. In addition, Status Reports are prepared four times a year.

Joint international work at Äspö HRL, as well as data and evaluations for specific experiments and tasks, are reported in Äspö International Progress Report series. Information from Progress Reports is summarised in Technical Reports at times considered appropriate for each project. SKB also endorses publications of results in international scientific journals. Table 1-1 provides an overview of Äspö HRL related documents and the policy for review and approval.

Data collected from experiments and measurements at Äspö HRL are mainly stored in SKB's site characterisation database, Sicada.

Table 1-1 Overview of Äspö HRL related documents.

Report	Reviewed by	Approved by
SKB RD&D-Programme – Äspö HRL related parts	Director Repository Technology	SKB
Planning Reports – Detailed plans covering each calendar year	Contributors	Director Repository Technology
Annual Reports – Summary of work covering each calendar year	Contributors	Director Repository Technology
Status Reports – Short summary of work covering each 3 month period	Principal Investigators or Project Managers	Director Repository Technology
Technical Reports (TR)	Project Manager	Director Repository Technology
International Progress Reports (IPR)	Project Manager	Director Repository Technology
Internal Technical Documents (ITD)	Case-by-case	Project Manager
Technical Documents (TD)	Case-by-case	Project Manager

1.7 Management system

SKB is since 2001 certified according to the Environmental Management System ISO 14001 as well as the Quality Management Standard ISO 9001. Since 2003 SKB is also certified according to the up-graded ISO standard 9001:2000.

The structure of the management system is based on procedures, handbooks, instructions, identification and traceability, quality audits etc. The overall guiding documents for issues related to management, quality and environment are written as routines. The documentation can be accessed via SKB's Intranet where policies, common routines for SKB (SD-documents) as well as specific routines for Äspö HRL

(SDTD-documents) can be found. Employees and contractors related to the SKB organisation are responsible that work is performed in accordance with SKB's management system.

SKB is constantly developing and enhancing the security, the environmental labours and the quality-control efforts to keep up with the company's development as well as with changes in circumstances. One of the cornerstones of both the existing operations and in the planning of new facilities is the efficient utilisation of available resources.

The guiding principles of all SKB's activities and each employer's work are expressed in three key words:

- Safety.
- Efficiency.
- Responsiveness.

Project Model

SKB has developed a project model for the implementation of projects. The aim of the model is to create an effective and uniform management of all projects. According to this model each project shall have a project owner and a project leader shall be appointed. A project decision describing the aim of the project and the resources as well as a project plan shall be prepared.

Environmental management

SKB manages Sweden's spent nuclear fuel and radioactive waste in order to safeguard the environment and people's health in both the short and long term. This task is a key element of the national environmental objective of a safe radiation environment.

SKB also makes every effort to minimise the impact of ongoing operations and activities on the environment. This environmental work is goal-oriented and the progress versus goals is assessed every three months. Key assessment parameters for the selection of suppliers include security, environmental aspects and quality.

1.8 Structure of this report

The work planned at Äspö HRL during 2006 is in this report described in six chapters:

- Geo-science – experiments, analysis and modelling to increase the knowledge of the surrounding rock.
- Natural barriers – experiments, analysis and modelling to increase the knowledge of the repository barriers under natural conditions.
- Engineered barriers – demonstration of technology for and function of important engineered parts of the repository barrier system.
- Äspö facility – operation, maintenance, data management, monitoring, public relations etc.
- Environmental research.
- International co-operation.

2 Geo-science

2.1 General

During the pre-investigations for the Äspö HRL in the late 1980's the first geoscientists came to Äspö. Most of them were consultants that mainly worked off-site. A new site organisation was developed when the HRL was taken into operation 1995. Posts as site geologist and site hydrogeologist were then established. These posts have been broadened with time, and today the responsibility of the holder involves maintaining and developing the knowledge and methods of the scientific field, as well as scientific support to various projects conducted at Äspö. Geoscientific research and activities are conducted in the fields of geology, hydrogeology, geochemistry (with emphasis on groundwater chemistry) and rock mechanics.

Geoscientific research is a part of the activities at Äspö HRL as a complement and an extension of the stage goals 3 and 4, see Section 1.2. Studies are performed in both laboratory and field experiments, as well as by modelling work. The overall aims are to:

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

The activities further aim to provide basic geoscientific data and to ensure high quality of experiments and measurements related to geosciences. From 2006 the work will follow a yearly geoscientific programme. An important part of the planned work is to start the development of the new Äspö site description. The integrated site description is planned to be published 2007 and to be updated every third year. The planned general geoscientific work during 2006 further involves developing a detailed hydro-structural model of the main experimental level (-450 m).

2.2 Geology

Geological work at Äspö HRL is focused on several main fields. Major responsibilities are mapping of tunnels, deposition holes and drill cores, as well as continuous updating of the geological three-dimensional model of the Äspö rock volume and contribution with input knowledge in projects and experiments conducted at Äspö HRL. Also, development of new methods in the field of geology is a major responsibility. As a part of the latter, the Rock Characterisation System (RoCS) feasibility study is being conducted, see Section 2.2.2.

2.2.1 Geological Mapping and Modelling

Background and objectives

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

Present status

At present no exposed rock surfaces or drill cores from Äspö rock volume are unmapped. There are, however, earlier mappings that have not been digitised or entered into the site characterisation database Sicada. Possibilities to catch up have, however, increased as one more TMS (Tunnel Mapping System) station is in operation since summer 2005 and Sicada operators are engaged to assist in data entering and quality control.

The geological 3D model of Äspö rock volume had a major revision in 2002, reported in the GeoMod report /Berglund *et al*. 2003/. Minor revisions are performed as new data are achieved. A detailed 3D structural geological and hydrogeological model of the -450 m level has been initiated which will be based on all available data from earlier investigations.

A project with the purpose to establish true width of deformation zones by using magnetic anisotropy (AMS) has been initiated and the major part of the sampling is completed.

Scope of work for 2006

The activities planned for 2006 are:

- Mapping of drill cores from a number of short drill holes that will be made in the TASQ in the beginning of 2006.
- The development of the TMS will proceed. Also, in order to increase the usability of the TMS, suggestions to make it compatible with RVS will be examined.
- The model of the -450 m level will continue and will be completed during the spring 2006.
- The AMS project will be completed during the spring 2006.
- Continued computer work with regard to “old” tunnel and deposition hole mappings not yet digitized and with geological data not entered into the TMS database.

2.2.2 Rock Characterisation System

Background and objectives

A feasibility study concerning geological mapping techniques is performed beside the regular mapping and modelling tasks. The project Rock Characterisation System (RoCS) is conducted as an SKB-Posiva joint-project. The purpose is to investigate if a new system for rock characterisation has to be adopted when constructing a future final repository. The major reasons for the RoCS 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. In this initial feasibility study-stage, the major objective is to establish a knowledge base concerning existing and possible future methods and techniques to be used for a mapping system suitable for SKB requirements.

Present status

The first part of the feasibility study, establishing of the technical state-of-the-art, will be completed and reported during the spring of 2006. Test of data collection methods has been performed using both digital photogrammetry and laser scanning. Also, several complementary techniques, like geophysical survey methods, have been investigated, as well as software applications.

Scope of work for 2006

The major task for 2006 will be to establish a detailed specification of requirements for a new rock characterisation system to be used in a future final repository. The requirements taken into consideration will be both external from public authorities, as well as internal from all user groups of a rock characterisation system.

2.3 Hydrogeology

The major aims of the hydrogeological activities are to:

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

One of the main tasks is the development of the integrated Äspö site description. The numerical groundwater flow and transport model is an important part of the site description. The groundwater model is to be continuously developed and calibrated. The intention is to develop the model to a tool that can be used for predictions, to support the experiments, and to test hydrogeological hypotheses.

Another task during 2006 is to develop the more detailed model of hydraulically conductive structures at the –450 m level. The purpose of this model is firstly to grasp the important hydraulic structures in an area with many active experiments, and secondly to develop the methodology of detailed hydro-structural modelling. The work during 2006 also comprises activities concerning the Seismic Influence on the Groundwater System (Section 2.3.1), Inflow Predictions (Section 2.3.2) and Hydrogeological Monitoring (Section 2.3.3).

2.3.1 Seismic Influence on the Groundwater System

Background and objectives

The Hydro Monitoring System (HMS) registers at the moment the groundwater pressure in about 275 positions in boreholes 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 events in Sweden but also abroad, dependent on the magnitude of the event, as well as the position of the epicentre. The seismic events also include blasting activities in and around Äspö HRL. By analysing the data on changes in the groundwater pressure at Äspö, connections to specific seismic events are expected to be established. The work is a reference for the understanding of dynamic influences on the groundwater around a future final repository.

Present status

Data from the HMS are stored in the database pending analyses. A special computer code has been developed that may be used to find rapid pressure changes in the HMS data. For example, the earthquake in the Indian Ocean on the 26th of December 2004 was registered by the HMS system after 23 minutes.

Scope of work for 2006

The software development for cross comparison of different databases will be finalised. The effects of blasts in and around the Äspö HRL and the impact of earthquakes in Sweden and abroad will be analysed and documented.

As a first step, any disturbances that can be coupled to the blasting of the TASQ-tunnel will be identified, and as a second step, possible effects of some blasts for the Clab-2 construction will be investigated. The effects of the earthquakes in Turkey 1999 and in the Indian Ocean on the 26th of December 2004 will also be examined.

2.3.2 Inflow Predictions

Background

SKB has conducted a number of large field tests where predictions of inflow into tunnels or depositions holes have been a component: (a) Site characterisation and validation test in Stripa /Olsson 1992/, (b) Prototype Repository /Rhén and Forsmark 2001/ and (c) Groundwater degassing and two-phase flow experiments in Äspö HRL /Jarsjö *et al.* 2001/. The results from these tests show that when going from a borehole to a larger diameter hole, the inflow into the larger hole is often less than predicted, and the explanation for this is not yet well understood. The ability of predicting inflow is of importance from several aspects:

- Evaluation of experimental results from Äspö HRL. A good understanding of the mechanisms controlling inflow would improve the possibilities for good experimental set-ups and accurate result interpretation.
- Evaluation and comparisons between potential repository sites. It is desirable to be able to predict the inflow conditions into the excavations, already before the construction work starts, based on hydraulic measurements made in small diameter boreholes.
- Evaluation of the expected bentonite buffer behaviour. The amount of inflow into deposition holes will influence the time needed for saturation and also the expected performance of the buffer.
- Design and optimisation of the repository layout. Poor prediction of inflow could lead to less optimal design alternatives.

Objectives

The main objectives for this project are to:

- Make better predictions of the inflow of groundwater into deposition holes and tunnels possible.
- Confirm (or refuse) previous observations of reduced inflow into deposition holes and tunnels compared with boreholes.
- Identify the different mechanisms determining the inflow, and quantify their importance.

Present status

So far, extensive numerical analyses using the three-dimensional distinct element code 3DEC /Itasca 2003/ have been conducted. The aim has been to improve the knowledge about the effect of the effective stress redistribution, caused by excavation, on the fracture inflow into deposition holes considering single-phase flow /Mas Ivars 2004/.

Besides the numerical study, a field experiment was performed in 2004 at the Äspö Pillar Stability Experiment (Apse) site. The field experiment, the hydro-mechanical (HM) acquisition project /Mas Ivars 2005/, was done due to the fact that two highly conductive sub-vertical fractures intersected one of the deposition holes and the inflow into the excavation reached values of around 30 l/min. The aim of the HM data acquisition project was to monitor the changes (normal and shear displacement) in the conductive fractures, and the evolution of the inflow into the excavation versus time, due to the stress drop when the pillar was de-stressed. Data regarding groundwater pressure changes was also gathered in other locations expected to be influenced by the de-stressing of the pillar, making use of the existing HMS monitoring system.

The de-stressing caused a number of coupled hydro-mechanical effects. The effective normal stress acting on the conductive fractures dropped and the aperture increased with the consequent increase in inflow. The data gathered have enhanced the understanding about the hydro-mechanical behaviour of fractured rocks, with special emphasis on processes influencing groundwater flow through single conductive fractures and inflow into excavations.

Scope of work for 2006

A comprehensive report will be written about the three dimensional discontinuum mechanical modelling study of the de-stressing of the Apse pillar using the computer code 3DEC.

For the next step, two 30 mm diameter boreholes have been drilled. These two boreholes intersected a very conductive fracture where flow and displacements were monitored during the de-stressing of the Apse pillar (fracture 08 in Figure 2-1). Coupled stress-flow laboratory tests will be conducted on large fracture samples from the mentioned boreholes. A 3D-laser scanner will scan the surfaces of the fracture walls so the geometrical properties of the fracture plane can be well characterised. The results of the laboratory tests will be studied with the objective of improving already existing coupled hydro-mechanical fracture constitutive models so they can better represent the type of conductive fractures present at Äspö HRL.

Further work related to predictions of inflow to deposition holes and tunnels will be conducted. Analyses of data on inflow to e.g., the Prototype Repository and the Backfill and Plug Test tunnel, in combination with numerical groundwater modelling is planned to be done.

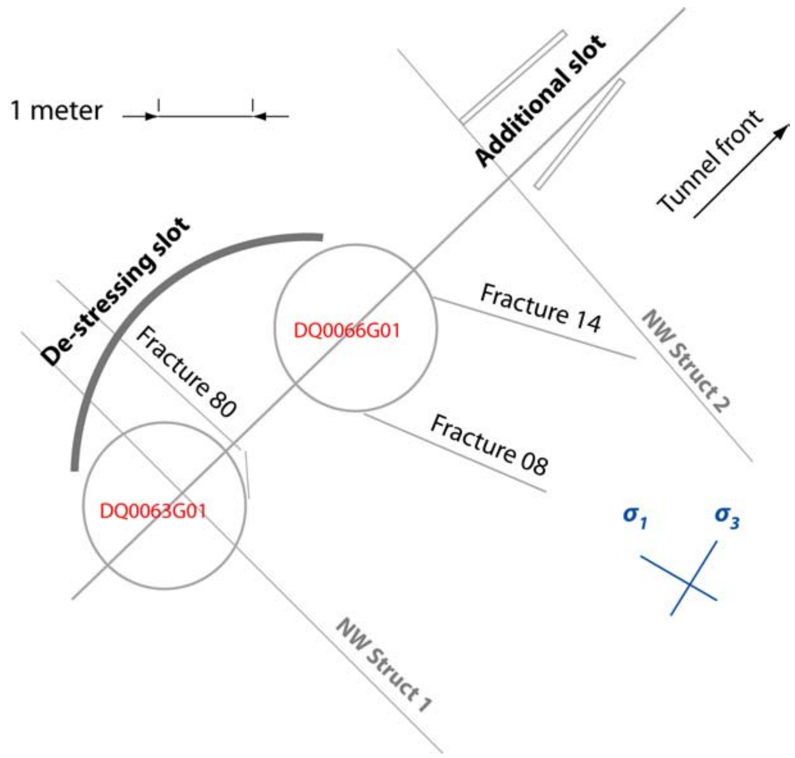

Figure 2-1 *Layout of the hydro-mechanical data acquisition experiment at the Äspö Pillar Stability Experiment site.*

2.3.3 Hydro Monitoring Programme

Background

The hydro monitoring programme is an important part of the hydrogeological research and a support to the experiments undertaken in the HRL. The programme had also had legal grounds. It was conditioned by the water rights court, when granting the permission to execute the construction works for the tunnel, that a monitoring programme should be put in place and that the groundwater head conditions should continue to be monitored until the year 2004.

The monitoring of water level in surface boreholes started in 1987 while the computerised Hydro Monitoring System (HMS) was introduced in 1992. The HMS implemented in the Äspö HRL and on the nearby islands collects data on-line of pressure, levels, flow and electrical conductivity of the groundwater. The data are recorded by numerous transducers installed in boreholes and in the tunnel. The number of boreholes included in the monitoring programme has gradually increased, and comprise boreholes in the tunnel in the Äspö HRL as well as surface boreholes on the islands of Äspö, Ävrö, Mjälen, Bockholmen, and some boreholes on the mainland at Laxemar. The tunnel construction started in October 1990 and the first pressure measurements from tunnel drilled boreholes were included in the HMS in March 1992. The tunnel excavation began to affect the groundwater level in many surface boreholes during the spring 1991.

Objectives

The scientific grounds of maintaining the hydro monitoring programme are:

- To establish a baseline of the groundwater head and groundwater flow situations.
- To provide information about the hydraulic boundary conditions for the experiments in the HRL.
- To provide data to various model validation exercises, including the comparison of predicted head with actual head.

Present status

The measuring system is at present working satisfactorily. To date the monitoring programme comprises a total of 143 boreholes (44 surface boreholes and 99 tunnel boreholes). Many boreholes are equipped with inflatable packers, dividing the borehole into different sections, and the pressure is measured by means of pressure transducers. During the last years a number of surface boreholes have been handed over to the Oskarshamn Site Investigation, and some malfunctioning packer systems in boreholes have been removed. The measured data is relayed to a central computer situated at the Äspö office through cables and radio-wave transmitters. Manual levelling is also obtained from the surface boreholes once a month. Weekly quality controls of preliminary groundwater head data are performed. Calibration of data is performed three to four times annually. This work involves comparison with the groundwater levels checked manually in boreholes. Once a year, the data is transferred to SKB's site characterisation database, Sicada. Water seeping through the tunnel walls is diverted to trenches and further to 25 weirs where the flow is measured.

Scope of work for 2006

The activities during 2006 comprise operation, maintenance and documentation of the HMS system. Equipment that is out of order will be exchanged or renovated, and the measuring points from the previous years will be maintained. At the moment, transducers for measurements of temperature, humidity and pressure of tunnel air are being installed. However, automatic monitoring in surface boreholes is successively replaced by monthly manual levelling. Semi-automatic transfer of data from HMS to Sicada three to four times annually will be implemented.

2.4 Geochemistry

Geochemistry is one of the fields included in the geoscientific programme for Äspö HRL. The main activities are related to the monitoring of changes in groundwater chemistry.

2.4.1 Monitoring of Groundwater Chemistry

Background

During the Äspö HRL construction phase, different types of 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 Äspö HRL operational phase, sampling was replaced by a groundwater chemistry monitoring programme, aiming at a sufficient cover of the hydrochemical conditions with respect to time and space within the Äspö HRL.

Objectives

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.

Present status

The monitoring campaign started in the end of August and was finalised in the middle of October 2005. The results from the latest monitoring campaign indicate that groundwater composition in the tunnel is within the range of groundwater compositions measured previous years.

The chloride concentration varied in general from 590 mg/l to around 9,700 mg/l from the shallower boreholes to the deepest ones. A few samples showed increased concentrations of chlorides, up to about 14,500 mg/l, as well as increased concentrations of other main components. In Figure 2-2 examples are given on the evolution of the chloride concentration in three boreholes located in the tunnel and in a KAS-borehole drilled from the surface. For the boreholes from the Äspö tunnel the level of the lower packer in the sampled section is given in brackets in the figure heading.

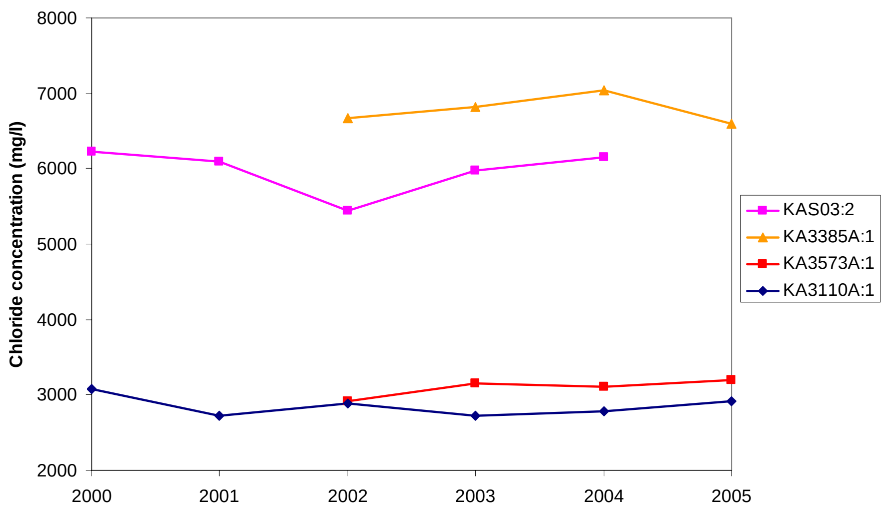

***Figure 2-2** Chloride concentrations (mg/l) in selected boreholes. The boreholes KA3110A (–416 m), KA3537A (-447m) and KA3385 (–449 m) are located in the Äspö tunnel and KAS03 is a borehole from the surface with a packed-off section at about –612 m.*

Scope of work for 2006

One hypothesis of the increased salinity in some areas in the Äspö-tunnel may be a possible effect of up-coning from deeper, much more saline, old waters of so called brine composition. This effect will be furthered studied also in combination with interactions from the sub-surface and surface hydrogeochemical groundwater composition.

During 2005 some biogeochemical parameters have been included in the monitoring programme. These will be evaluated during 2006.

2.5 Rock mechanics

Rock Mechanic studies are performed with the aims to increase the understanding of the mechanical properties of the rock but also to recommend methods for measurements and analyses. This is done by laboratory experiments and modelling at different scales and comprises:

- Natural conditions and dynamic processes in natural rock.
- Influences of mechanical, thermal, and hydraulic processes in the near-field rock including effects of the backfill.

During 2006 work will mainly be performed within the Äspö Pillar Stability Experiment, see Section 2.5.1.

2.5.1 Äspö Pillar Stability Experiment

Background

Very little research on the rock mass response in the transitional zone (accelerating frequency of micro-cracking) has been carried out. It is therefore important to gain knowledge in this field since the spacing of the canister holes gives an impact on the optimisation of the repository design.

A Pillar Stability Experiment was therefore initiated at Äspö HRL as a complement to an earlier study at URL performed by AECL in Canada. AECL's experiment was carried out during the period 1993–1996 in an almost unfractured rock mass with high *in situ* stresses and brittle behaviour. The major difference between the two sites is that the rock mass at Äspö is fractured and the rock mass response to loading is elastic. The conditions at Äspö HRL therefore make it appropriate to test a fractured rock mass response in the transitional zone.

Objectives

The Äspö Pillar Stability experiment is a rock mechanics experiment which can be summarised in the following three main objectives:

- Demonstrate the capability to predict spalling in a fractured rock mass.
- Demonstrate the effect of backfill (confining pressure) on the propagation of micro-cracks in the rock mass closest to the deposition hole.
- Comparison of 2D and 3D mechanical and thermal predicting capabilities.

Experimental concept

To achieve the objectives a new drift was excavated in Äspö HRL to ensure that the experiment was carried out in a rock mass with a virgin stress field. In the new drift a vertical pillar was constructed in the floor between two large boreholes, each with a diameter of 1.8 m. The pillar was designed in such a way that spalling will occur in the walls of the boreholes when the pillar is heated.

The two large vertical holes were drilled in the floor of the tunnel so that the distance between the holes is one metre. To simulate confining pressure in the backfill (0.7 MPa), one of the holes was subjected to an internal water pressure via a liner. Convergence measurements, linear variable displacement transducers (LVDT), thermistors and an acoustic emission system were used to monitor the experiment. The experiment drift has a rounded floor, se Figure 2-3, to concentrate the stresses in the centre of the drift.

Figure 2-3 *The Apse experimental drift shortly after the excavation.*

Present status

The experiment was carried out as planned during 2004. The pillar was sawn into five large blocks which were removed from the experiment site during late 2004 and early 2005, Figure 2-4. The remaining rock walls between the holes and the block themselves has been geologically mapped. The results were digitized in late 2005. The reporting of the field part of the experiment has been delayed but all reports have now left the draft stage and are about to be printed. /Andersson and Eng 2005/ describes the experiment's final design, the field work, observations, and results from the temperature and displacement monitoring. In /Eng and Andersson 2005/ the monitoring system for the temperature and displacement measurements are described in detail. The document includes specifications for the instruments and their mounting, calibration results and data handling. The experiment was also monitored by an acoustic emission system. The system and results are presented in /Haycox *et al.* 2005/. The temperature and stress development during the heating phase has been back calculated in /Fälth *et al.* 2005/.

The back calculated thermal induced stress has been added to the static stresses originating from the re-distribution of the *in situ* stresses around the created geometry. The observed failure times of the rock in the hole has been compared to the tangential stress acting at the hole wall which is defined as the spalling strength of the rock. The spalling strength varied very little when the failure of different parts of the pillar was compared.

Integrated analyses of the relation between the acoustic emissions and displacements and damage of the rock have started. The spalled volumes are compared to the relative energy releases registered by the acoustic system. The spalling volumes and displacements are also compared to variations in the geology. The development of the notch is also studied with help from the acoustic emission results. Preliminary results were presented in the proceedings of the 40th Rock Mechanics Meeting in Stockholm.

Figure 2-4 *Photography of the experimental site after removal of the five one metre high pillar blocks between the two large holes.*

Scope of work for 2006

The integrated analyses will be finalised and published in SKB reports. The analyses will also be condensed and submitted to the International Journal of Rock Mechanics and Mining Sciences for possible publication.

The objective with the analyses is to enhance the understanding of the failure process by further studying the spalling strength of rock and the relation between acoustic emission displacements and damage. Back calculation of the elastic deformations before the spalling occurred will also be presented.

3 Buffer and backfill materials and technology

3.1 Background

A number of experiments which are being carried out at the Äspö HRL (Canister Retrieval Test, Prototype Repository and Large Scale Gas Injection Test) have confirmed that, at full scale, it is possible to place pre-pressed blocks and rings of bentonite around a canister under both ideal and more demanding conditions. Conditions regarded as more demanding usually involve the inflow of groundwater in the deposition hole. Piping - usually flow channels between the rock wall and the buffer - arises when the inflow of groundwater in combination with the groundwater pressure are so great that the buffer is not able to swell quickly enough to counteract the pressures arising. When setting up the current experiments different solutions were applied to prevent flow channels forming or at least to stop them developing. Before building a final repository, where the operating conditions include the deposition of one canister per day, further studies of the behaviour of the buffer under different installation conditions are required.

3.2 Objectives

SKB has decided to build a Bentonite Laboratory at Äspö in order to study in detail how the phenomenon of channel formation can be controlled. This new laboratory will also be designed for studies of buffer materials in general. The Bentonite Laboratory, a hall with dimensions 15×30 m, will include two stations where the emplacement of buffer material at full scale can be tested under different conditions. The hall will also be used for continued testing of different types of backfill material and the further development of techniques for the backfilling of deposition tunnels.

This new initiative at Äspö HRL will be based on the current knowledge achieved until 2006 in the area of Buffer and Backfill Materials and Technology.

3.3 Scope of work for 2006

As well as the investment in the Bentonite Laboratory, a new group of young employees will be recruited to the Äspö Hard Rock Laboratory during 2006. The group will be composed of project leaders, industry-funded PhD students and materials specialists. The whole group will work with buffer materials and backfilling techniques. A number of qualified experts will also be involved with the group. This will enable the work of the group to develop as effectively as possible.

In combination with the planning of activities for 2007, an independent program for buffer material and backfilling techniques will be developed for the Bentonite Laboratory. The programme will be developed in cooperation with the unit Repository Engineering.

4 Natural barriers

4.1 General

To meet Stage goal 3, experiments are performed to further develop and test methods and models for description of groundwater flow, radionuclide migration, and chemical conditions at repository depth, see Figure 4-1.

The experiments are related to the rock, its properties and *in situ* environmental conditions. The programme includes projects with the aim to evaluate the usefulness and reliability of different conceptual and numerical models and to develop and test methods for determination of parameters required as input to the models.

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. The overall purposes are to:

- Improve the scientific understanding of the final repository's safety margins and provide input data for assessments of the repository's long-term safety.
- Obtain the special material needed to supplement data from the site investigations in support of an application for a siting permit for the final repository.
- Clearly present the role of the geosphere for the barrier functions: isolation, retardation and dilution.

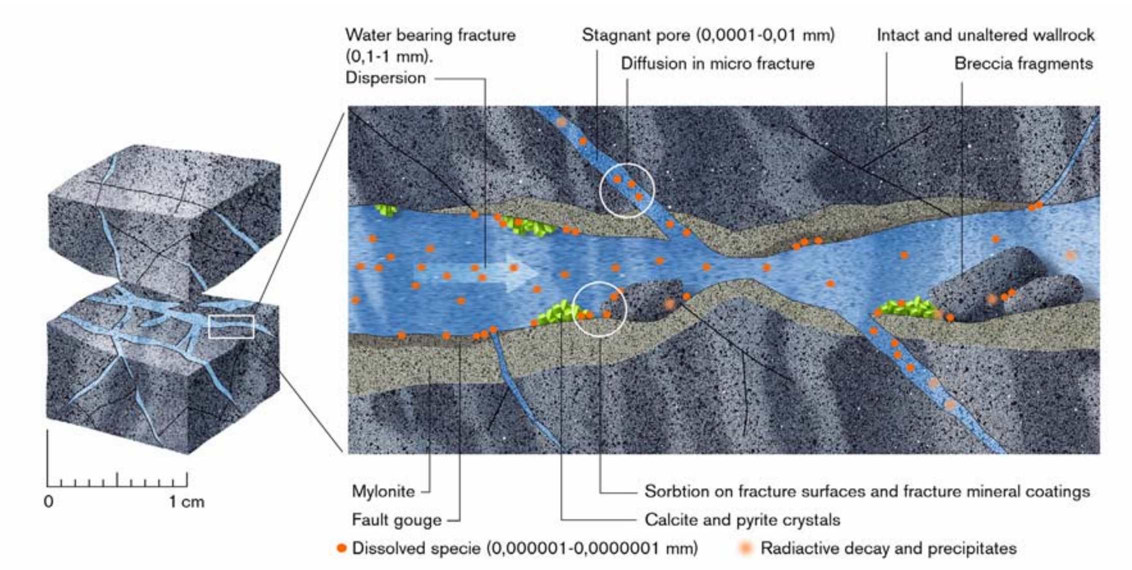

Figure 4-1 *Illustration of processes that influence migration of species along a natural rock fracture.*

The ongoing experiments and projects within the Natural Barriers at Äspö HRL are:

- Tracer Retention Understanding Experiments.
- Long Term Diffusion Experiment.
- Colloid Project.
- Microbe Project.
- Matrix Fluid Chemistry Continuation.
- Radionuclide Retention Experiments.
- Padamot.
- Fe-oxides in fractures.
- Swiw-test with Synthetic Groundwater.
- Äspö Task Force on Groundwater Flow and Transport of Solutes.

4.2 Tracer Retention Understanding Experiments

Background

A programme has been defined for tracer tests at different experimental scales, the so-called Tracer Retention Understanding Experiments (True) /Bäckblom and Olsson 1994/. The overall objective of the defined experiments is to increase the understanding of the processes which govern retention of radionuclides transported in crystalline rock, and to increase the credibility in models used for radionuclide transport calculations used in licensing of a repository.

Objectives

The True experiments should achieve the following general objectives:

- Improve understanding of radionuclide transport and retention in fractured crystalline rock.
- Evaluate to what extent concepts used in models are based on realistic descriptions of rock and whether adequate data can be collected during site characterisation.
- Evaluate the usefulness and feasibility of different approaches to modelling radionuclide migration and retention. Provide *in situ* data on radionuclide migration and retention.

During 2001, it was decided to collect all future True work in two separate projects: True Block Scale Continuation and True-1 Continuation. Although the experimental focus is placed on the respective True experimental sites developed at the Äspö HRL, integration and co-ordination of experimental activities at and between the sites is emphasised in the planned future work.

Experimental concept

The basic idea is to perform a series of *in situ* tracer tests with progressively increasing complexity. In principle, each tracer experiment will consist of a cycle of activities beginning with geological characterisation of the selected site, followed by hydraulic and tracer tests. An option is to characterise the tested pore space and analyse tracer fixation using epoxy resin injection. Subsequently, the tested rock volume will be excavated and analysed with regards to flow-path geometry and tracer concentration.

Together with supporting laboratory studies of diffusion and sorption characteristics made on core samples, the results of the *in situ* tests will provide a basis for integrating data on different scales, and testing of modelling capabilities for radionuclide transport up to a 100 m scale, see Figure 4-2**.** A test of the integration and modelling of data from different length scales and assessment of effects of longer time perspectives, partly based on True experimental results, is made as part of Task 6 in the Task Force on Modelling of Groundwater Flow and Transport of Solutes, see Section 3.11.

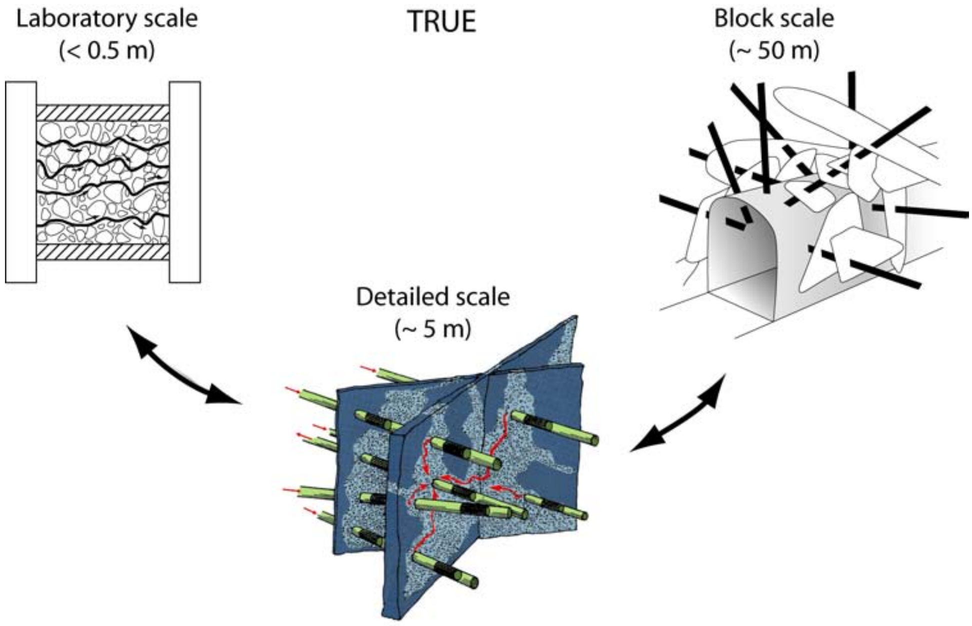

Figure 4-2 *Schematic representation of transport scales addressed in the True programme.*

4.2.1 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.

Objective

The overall objective of BS2 can be summarised as: “Improve understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure and micro-structure”. Special consideration is in this context put on the possibility to explore the role of more low-permeable parts of the studied fracture network, including background fractures, the latter without developed wall rock alteration and fault gouge signatures.

Present status

During the 2005 the four modelling teams involved carried out their individual evaluation and also produced individual draft evaluation reports. A review seminar was held in the Stockholm area in mid September. Using the input received at the review seminar, work on the final report of BS2 has progressed and an incomplete draft report was produced by the end of 2005. The performed joint evaluation emphasise the following results:

- Geological information (hydrostructural and microstructure models) is important for understanding sorbing tracer transport.
- Immobile zone retention material properties assigned to structure and background fracture flow paths have been verified by means of back-calculations, those of the structure flow path (Structure #19) being one order of magnitude higher than for the background fracture flow path.
- Overall retention in the background fracture flow path is found to be higher while the flow rate is significantly lower than the corresponding structure flow path of equitable length.

Scope of work for 2006

The scope of work for 2006 involves finalisation of and publication of individual evaluation reports and finalisation of the BS2 final report.

4.2.2 True Block Scale Continuation (BS3)

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

During 2006 preparatory work will be carried out sorting out the issues and defining a platform for the planned work.

4.2.3 True-1 Continuation

The True-1 Continuation project is a continuation of the True-1 experiments, and the experimental focus is primarily on the True-1 site. The continuation includes performance of the planned injection of epoxy resin in Feature A at the True-1 site and subsequent overcoring and analysis (True-1 Completion, see below). Additional activities include: (a) test of the developed epoxy resin technology to fault rock zones distributed in the access tunnel of the Äspö HRL (Fault Rock Zones Characterisation project), (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.

Objectives

The objectives of True-1 Continuation are:

- To obtain insight into the internal structure of the investigated Feature A, in order to allow evaluation of the pore space providing the observed retention in the experiments performed (see section on True-1 Completion below).
- To provide an improved understanding of the constitution, characteristics and properties of fault rock zones (including fault breccia and fault gouge) (Fault Rock Zones Characterisation).
- To provide quantitative estimates of the sorption characteristics of the altered rim zone and fault rock materials of fault rock zones.

The scope of work for the field and laboratory activities includes:

- Characterisation of a number of typical fault rock zones of variable thickness. Injection of epoxy resin and subsequent sampling. Assessment of pore space and quantification of *in situ* porosity of fault gouge material.
- Writing of three scientific papers accounting for the SKB True Project team analysis of the True-1 experiments.
- Batch sorption experiments on rim zone and fault gouge materials from the True Block Scale site and from other locations along the access tunnel.
- Injection of epoxy resin into the previously investigated Feature A, with subsequent excavation and analyses.

Present status

Ongoing activities in the Fault Rock Zones Characterisation include work in three areas: (a) image processing with the aim to get images with desired colour and contrast of the slices, (b) image analysis to find the desired parameters and (c) various types of visualisations to get the overall variability within and between rock slices. A draft report has been produced of the image analysis of the resin-impregnated rock material.

The laboratory sorption experiments have verified the values of Kd of fault gouge material estimated by /Andersson *et al.* 2002/ on the basis of hydrogeochemistry, cation exchange capacity, selectivity coefficient and mineralogy. Reporting is under way. A series of three scientific papers on the True team analysis of the True-1 experiments is now available in draft. Contact has been established with the editor of Water Resources Research and the first two in the series will be submitted early 2006. The papers will cover the following topics under the joint header of "Sorbing tracer experiments in a crystalline rock fracture at Äspö (Sweden):

Part 1 Experimental results, conceptual model and effective parameter estimation.

Part 2 Micro-scale characterisation of retention parameters.

Part 3 Effect of micro-scale heterogeneity.

Scope of work for 2006

- Finalisation of Fault Rock Zones Characterisation Project (Final report)
- Publication of at least 2 of the submitted papers. Possible strategic delay in submitting paper number 3.
- Finalisation of report on sorption characteristics of altered fracture wall rock and fault gouge.
- Starting up True-1 Completion.

4.2.4 True-1 Completion

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

The True-1 Completion project is collaborating with the Colloid Project in the planning and realisation of *in situ* tracer tests with latex collides in Feature A.

A complication for the scheduling of planned future work at the True-1 site lies in the fact that the True-1 and LTDE sites are hydraulically connected. In view of the urge for a relative hydraulic tranquillity on the part of LTDE, a priority for advancing LTDE has been set by SKB. 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.

Objectives

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 tracer 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 by mineralogical-chemical characterisation of the sorption sites for Cs.
- To update the conceptual micro structural and retention models of Feature A.

The scope of work for identified field and laboratory activities related to the True-1 site includes:

- Re-instrumentation of KXTT3 and KXTT4 in order to; a) ensure that the planned activities at the True-1 site do not in anyway interfere with the other projects at Äspö HRL in general and LTDE in particular and b) successfully perform the complementary tracer tests, the epoxy injection and the subsequent over coring of KXTT3 and KXTT4.
- Complementary tracer tests, Swiw- and CEC-tests.
- Epoxy injection, over coring of KXTT3 and KXTT4, and dismantling of infrastructure at the True-1 site.
- Analysis of core material using picture analysis, microscopy and chemical mineralogy aiming to improve the description of the inner structure of Feature A and possible identification of the immobile zones involved in the noted retention.

Present status

The re-instrumentation of KXTT3 and KXTT4 was successfully completed in November 2005. Newly constructed packers and dummies replaced some of the existing borehole equipment. The equipment was replaced in order to facilitate the complementary tracer tests, epoxy injection and the subsequent over-coring.

The complementary tracer tests were initiated with a non radioactive Swiw-test at the TRUE-1 site during November and December of 2005. The objectives of the Swiw-tests are to:

- Verify the performance of a Swiw-test at the TRUE-1 site without loosing tracer in the rock and also to provide vital information on the design of the Swiw-test with radioactive tracers.
- Verify the tracer distribution surrounding the Swiw-test borehole by passive sampling in the surrounding multi-borehole array intersecting Feature A.
- Evaluate the Swiw-test and to compare the results to previously performed tracer tests at the TRUE-1 site.

The result of the Swiw-test indicates a radial distribution of tracer solution from the injection borehole. Passive sampling in the surrounding multi-borehole array intersecting Feature A shows tracer breakthrough in the four sampled boreholes (Figure 4-3). It has, until now, not been possible in the ongoing SKB site investigations to monitor and verify the spread of tracer solution in the rock mass surrounding the injection borehole section. The results thus provide evidence that Swiw tests in Feature A propagate tracer over distances between 5 to 10 m. Support is hence provided that tracer indeed penetrate and sample a significant part of the tested conductive structure. General indirect support is also provided regarding tracer propagation in conductive structures/fractures currently being tested in deep cored boreholes in conjunction with the ongoing SKB site investigations where the possibility to conduct sampling in neighbouring boreholes is lacking.

The Swiw-test resulted in a very low tracer recovery, about 3%. This recovery stands in sharp contrast to the expected recovery of more than 80%. The low recovery may be the effect of a larger gradient than expected. In the case of a large gradient, the length of the tracer injection is most probably too long relative to the prevailing gradients at the site. The effect is that the tracer solution is pushed outside the influence radius of the withdrawal stage of the test, the result being the observed loss of tracer and hence a low tracer recovery.

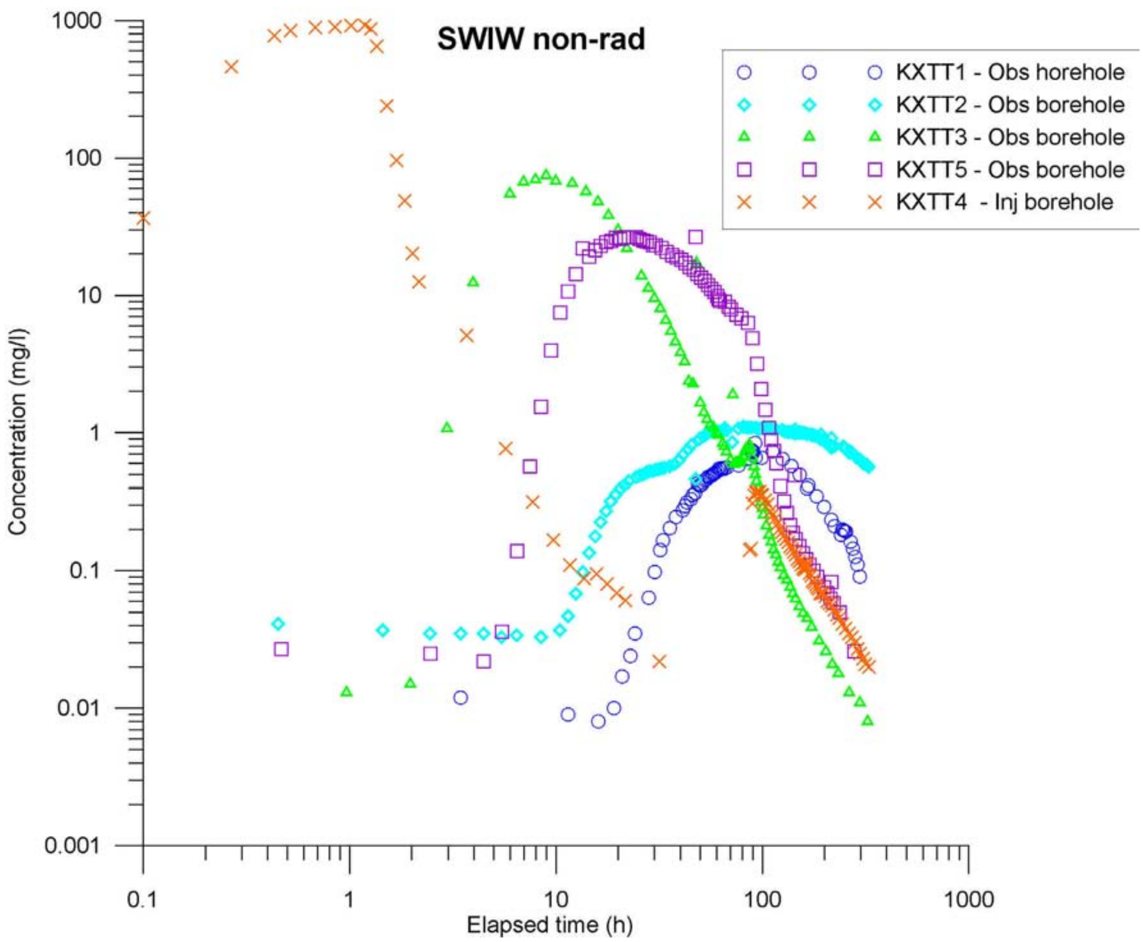

Figure 4-3 *Tracer injection and breakthrough curves for the non-radioactive Swiw-test with injection in KXTT4 and discrete sampling in KXTT1, KXTT2, KXTT3 and KXTT5.*

Scope of work for 2006

The main tasks for 2006 are:

- Complementary tracer tests, Swiw- and CEC-tests
- Epoxy injection and dismantling of the True-1 site after completion of the complementary tracer tests.
- Over-coring experimental boreholes after sufficient time of decay for the radioactive Cs used in CEC-test. Preparation of core samples and subsequent picture analysis, γ-spectroscopy, microscopy and chemical mineralogy.

4.3 Long Term Diffusion Experiment

Background

The Long Term Diffusion Experiment (LTDE) constitutes a complement to performed diffusion and sorption experiments in the laboratory, and is a natural extension of the performed *in situ* experiments, e.g. the True-1 and the True Block Scale experiments. The difference is that the longer duration (approximately 4 years) of the experiment is expected to enable an improved understanding of diffusion and sorption both in the vicinity of a natural fracture surface and in the matrix rock.

Matrix diffusion studies using radionuclides have been performed in several laboratory experiments. Some experimental conditions such as pressure and natural groundwater composition are however difficult to simulate with good stability in long-term laboratory experiments. Investigations of rock matrix diffusion at laboratory scale imply that one uses rock specimens in which damage due to drilling and unloading effects (rock stress redistribution) may have caused irreversible changes of the rock properties. Matrix diffusion in non-disturbed rock is therefore preferably investigated *in situ*. Through the proposed experimental technique one will also obtain some information of the adsorption behaviour of some radionuclides on exposed granitic rock surfaces.

Scoping calculations, for the planned experiment, have been performed /Haggerty 1999/ using the multi-rate diffusion concept which accounts for pore-scale heterogeneity. A test plan was drafted and presented at the combined True/LTDE review meeting in March 1999. The review and desires of SKB redirected the experiment towards an assessment of diffusion from a natural fracture surface, through the altered zone into the intact unaltered matrix rock. The new direction resulted in a revision of the test plan from its original form /Byegård *et al.* 1999/.

Objectives

The objectives of the Long Term Diffusion Experiment project are to:

- Investigate diffusion into matrix rock from a natural fracture *in situ* under natural rock stress conditions, natural hydraulic pressure and groundwater chemical conditions.
- Improve the understanding of sorption processes and obtain sorption data for some radionuclides on natural fracture surfaces.
- Compare laboratory derived diffusion constants and sorption coefficients for the investigated rock fracture system with the sorption behaviour observed *in situ* at natural conditions, and to evaluate if laboratory scale sorption results are representative also for larger scales.

Experimental concept

A core stub with a natural fracture surface is isolated in the bottom of a large diameter telescoped borehole. In addition a small diameter borehole is drilled through the core stub into the intact undisturbed rock beyond the end of the large diameter borehole. A cocktail of non-sorbing and sorbing tracers are circulated in the test section for a period of approximately 4 years after which the core stub is over-cored, and analysed for tracer content and tracer fixation, see Figure 4-4.

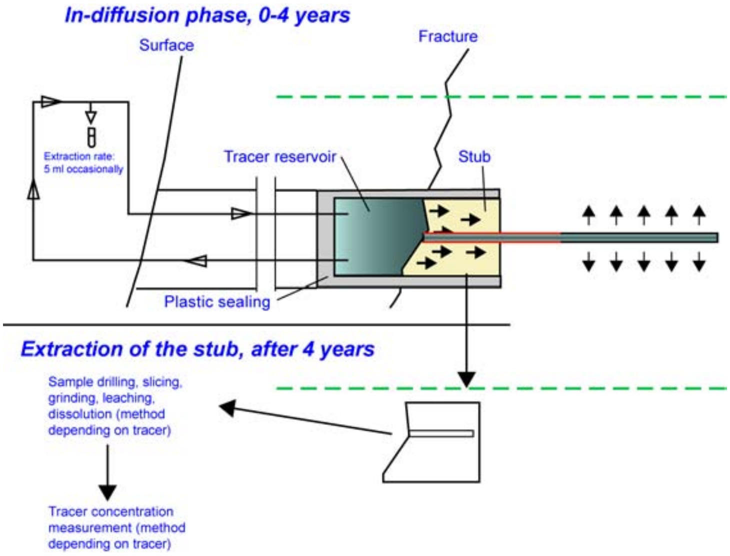

Figure 4-4 *LTDE experimental concept including injection borehole in contact with a fracture surface.*

The experiment is focussed on a typical conductive fracture identified in a pilot borehole (KA3065A02). A telescoped large diameter borehole (300/197 mm) (KA3065A03) is drilled sub-parallel to the pilot borehole in such a way that it intercepts the identified fracture some 10 m from the tunnel wall and with an approximate separation of 0.3 m between the mantel surfaces of the two boreholes.

The natural fracture as seen on the surface of the stub is sealed off with a polyurethane cylinder and a peek lid, which constitutes a “cup-like” packer. The remainder of the borehole will be packed off with a system of one mechanical and two inflatable packers. The small diameter (36 mm) extension is packed off using a double packer system leaving a 300 mm long section that will be exposed for the radionuclides. The system of packers and an intricate pressure regulating system will be used to eliminate the hydraulic gradient along the borehole, see Figure 4-5.

During the circulation of tracer, samples of water will be collected at various times over the duration of the experiment. The red-ox situation in the circulation loop will be monitored continuously with a flow through electrochemical cell, which will measure pH, Eh and temperature. Strategically positioned filter will ensure limited build-up of microbes in the water circulation loop. After completion of tracer circulation, the core stub is over-cored, sectioned and analysed for different radionuclide tracers.

The project also involves a variety of mineralogical, geochemical and petrophysical analyses. In addition, laboratory experiments with the core material from KA3065A03 (Ø 277, 177 and 22 mm) and the fracture “replica” material will be performed. Both “batch” sorption and through diffusion experiments are planned.

The drilling of the telescoped large diameter experimental borehole was performed with a high degree of interactivity between: careful iterative drilling in short uptakes (particularly in the inner part of the borehole), BIPS imaging, core examination and on-site structural modelling/updating of structural model. Despite these the resulting stub turned out three times longer (150 mm) than originally planned. The situation was analysed in a series of *in situ* and laboratory measurements and modelling, which showed that the core stub effectively is disturbed throughout its entire length.

A 36 mm borehole was drilled in 2001 as an extension of KA3065A03 into the intact matrix rock. Characterisation of the experimental borehole KA3065A03 and a structural model of the LTDE site based on boreholes KA3065A02 and KA3065A03 is presented in a separate report /Winberg *et al.* 2003/.

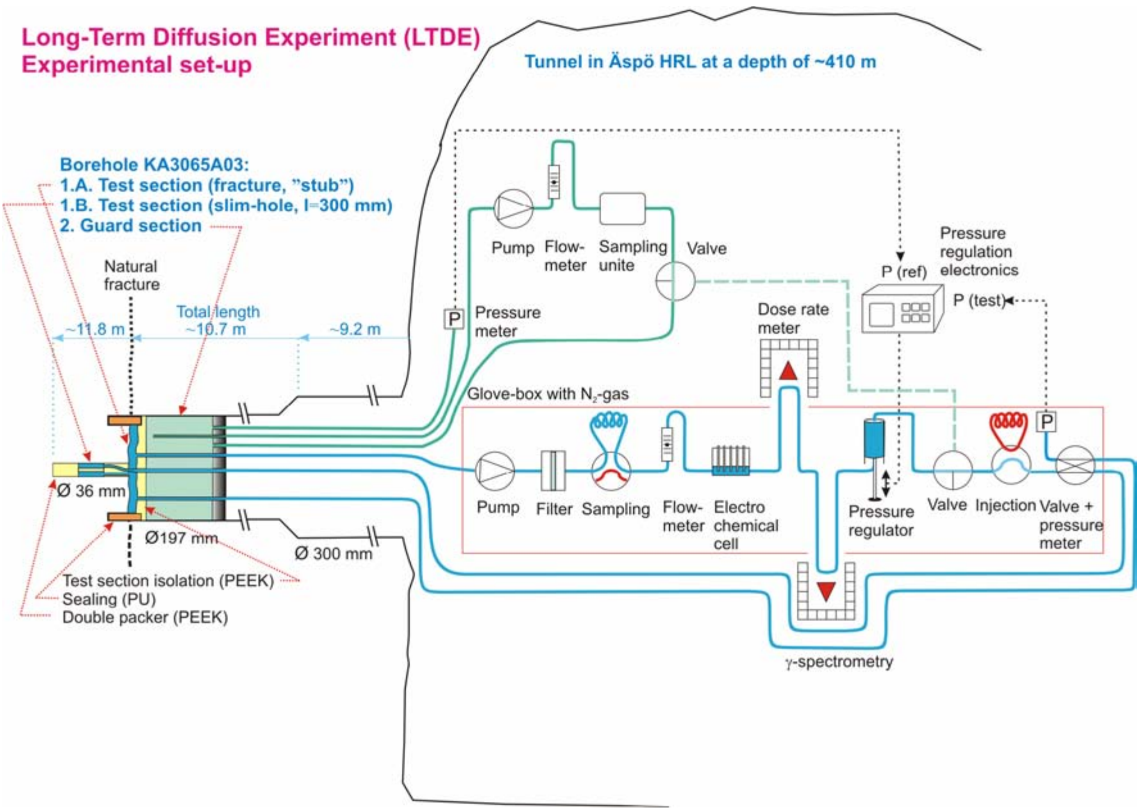

Figure 4-5 LTDE experimental set-up in the experimental borehole including the water circulation system to the test-section and the hydraulic pressure control system.

Present status

A functionality test with short lived radionuclides was started in September 2005 and terminated according to plan after five weeks. The objectives of the test were to:

- Test the complete experimental set up with respect to functionality and safety.
- Optimise circulation flow rate and injection and sampling procedures.
- Investigate if sorption processes on the stub-surface and on the matrix rock surface in the small-diameter borehole can be monitored with the present experimental set up, i.e. measurement of the decrease of tracer concentration in the test section volume.

It could be concluded from the functionality test that all systems worked overall as expected. Also, the injection and sampling procedures concerning both non-sorbing and sorbing tracers functioned as planned. However, some adjustments and modifications are proposed to increase the functionality prior to the forthcoming long term test, i.e. automatic alarm functions and complementary electrical control in the system. At the end of the functionality test, after seven months continuous operation, a small leakage was observed in the circulation and pressure regulating equipment in container 1. Rearrangement of the placement of the electrochemical flow cell in the glove box is also proposed in order to improve the practical work in the glove box and to reduce disturbances in the measurements. Furthermore, the experiment container needs cooling in order to reduce the temperature from 30 to 20 ^{o}C.

The functionality test was followed by a decision to adjust and modify the test equipment and run the forthcoming experiment based on a slightly up-dated project plan. The new plan emphasizes *in situ* sorption measurements with shorter experimental time frames than the original plan which had more focus on obtaining diffusion data.

The supporting laboratory experiments on core samples from LTDE borehole KA3065A03, performed by AECL´s Whiteshell Research Laboratories within the framework of collaboration between SKB and OPG, were completed in December. The experimental programme consisted of porosity measurements, diffusion cell experiments, permeability measurements and radial diffusion experiments. A status report was published in February /Vilks and Miller 2005/ and a draft version of the final report was compiled in December.

Scope of work for 2006

The main tasks for 2006 are:

- Adjustments and modifications of the test equipment prior to the forthcoming diffusion and sorption test, as consequence of the functionality test results.
- Start and complete a 5 -7 months duration diffusion and sorption *in situ* experiment with non-sorbing and sorbing radionuclides, including both the fracture surface on the core stub and matrix rock in the small diameter extension borehole.
- Over-coring experimental borehole after completion of diffusion and sorption test. Initiate the procedure to section and analyse tracer content and fixation in removed core stub and rock core encompassing the small diameter borehole.
- Initiate laboratory diffusion and sorption measurements on core samples from the small diameter extension borehole. It is planned to use the same radionuclides as in the *in situ* experiment.
- The results from the laboratory experiments above and the experiments performed at AECL 2005, will be used to compare laboratory derived diffusion and sorption coefficients for the investigated rock fracture system with the sorption behaviour observed from the *in situ* experiment. In addition, the representativeness of laboratory scale sorption results also for larger scales will be evaluated.

4.4 Colloid Project

Background

Colloids are small particles in the size range 10^{-6} to 10^{-3} mm. The colloidal particles are of interest for the safety of a repository for spent nuclear fuel because of their potential to transport radionuclides from a defect waste canister to the biosphere. SKB has for more than 10 years conducted field measurements of colloids. The outcome of the studies performed nationally and internationally concluded that the colloids in the Swedish granitic bedrock consist mainly of clay, silica and iron hydroxide particles and that the mean concentration is around 20–45 ppb which is considered to be a low value /Laaksoharju *et al.* 1995/. The low colloid concentration is controlled by the attachment to the rock, which reduces both the stability of the colloids and their mobility in aquifers.

It has been argued that e.g. plutonium is immobile owing to its low solubility in groundwater and strong sorption onto rocks. Field experiments at the Nevada Test Site, where hundreds of underground nuclear tests were conducted, indicate however that plutonium is transported as colloids in the groundwater. The $^{240}Pu/^{239}Pu$ isotope ratio of the samples established that an underground nuclear test 1.3 km north of the sample site is the origin of the plutonium /Kersting *et al.* 1999/.

The findings of potential transport of solutes by colloids and access to more sensitive instruments for colloid measurements motivated a Colloid Project at Äspö HRL. The project was initiated by SKB in 2000 and is planed to continue until the end of 2006.

Objectives

The aims and objectives of the Colloid Project are to study:

- The stability and mobility of colloids.
- Measure colloid concentration in the groundwater at Äspö.
- Bentonite clay as a source for colloid generation.
- The potential of colloids to enhance radionuclide transport.

The results from the project will be used mainly in the future development of safety assessment modelling of radionuclide migration.

Experimental concept

The Colloid Project comprises laboratory experiments as well as field experiments – Background measurements, Borehole specific measurements and Dipole colloid experiment. The Dipole colloid experiment is on going and all the others are finalised and reported:

- The **laboratory experiments** were performed to investigate in detail the chemical changes, size distribution and the effects from Na versus Ca rich bentonite associated with colloid generation /Wold and Eriksen 2002, Karnland 2002/.
- **Background measurements** were performed to measure the natural background colloid concentrations in eight different boreholes during 2002, representing groundwater with different ionic strength, along the Äspö HRL-tunnel. The colloid content at Äspö was found to be less than 300 ppb and at repository level it is less than 50 ppb /Laaksoharju and Wold 2005/.

- **Borehole specific measurements**, with the aim to measure the colloid generation properties of bentonite clay in contact with groundwater prevailing at repository depth, were made in 4 boreholes along the Äspö tunnel and 2 boreholes at Olkiluoto in Finland. The results indicate that the colloid release from the bentonite clay at prevailing groundwater conditions is small and an increased water flow did not increase the colloid release from the bentonite /Laaksoharju and Wold 2005/.

Dipole Colloid Experiment

The Dipole Colloid Experiment is a fracture specific experiment to be performed within the Colloid Project during the time period 2004–2007. According to present plans, two nearby boreholes having the same basic geological properties, KXTT3 and KXTT4 intersecting Feature A at the True-site, are selected for the dipole colloid experiment at Äspö HRL. One of the boreholes will be used as an injection borehole and the downstream borehole will be used for monitoring. Since bentonite colloids are not stable in the saline groundwaters at Äspö, fluorescent latex colloids will be used. A cocktail containing three different latex with 50, 100 and 200 nm mean sizes plus a colour tracer will be injected into the injection borehole, see Figure 4-6. The colloidal content will be measured with a flourospectrophotometer and a Single Particle Counter (SPC). The result of major interest is the changes in colloid content prior and after the transport through the fracture, i.e. to get the filtration factors (α) for colloids. The outcome of the experiment will be used to check performed model calculations and to develop future colloid transport modelling.

In addition, the actinide transport will be studied in the presence of colloids in a water bearing fracture. A core will be placed in a glove box and connected to a borehole in Äspö HRL, which one is not yet decided.

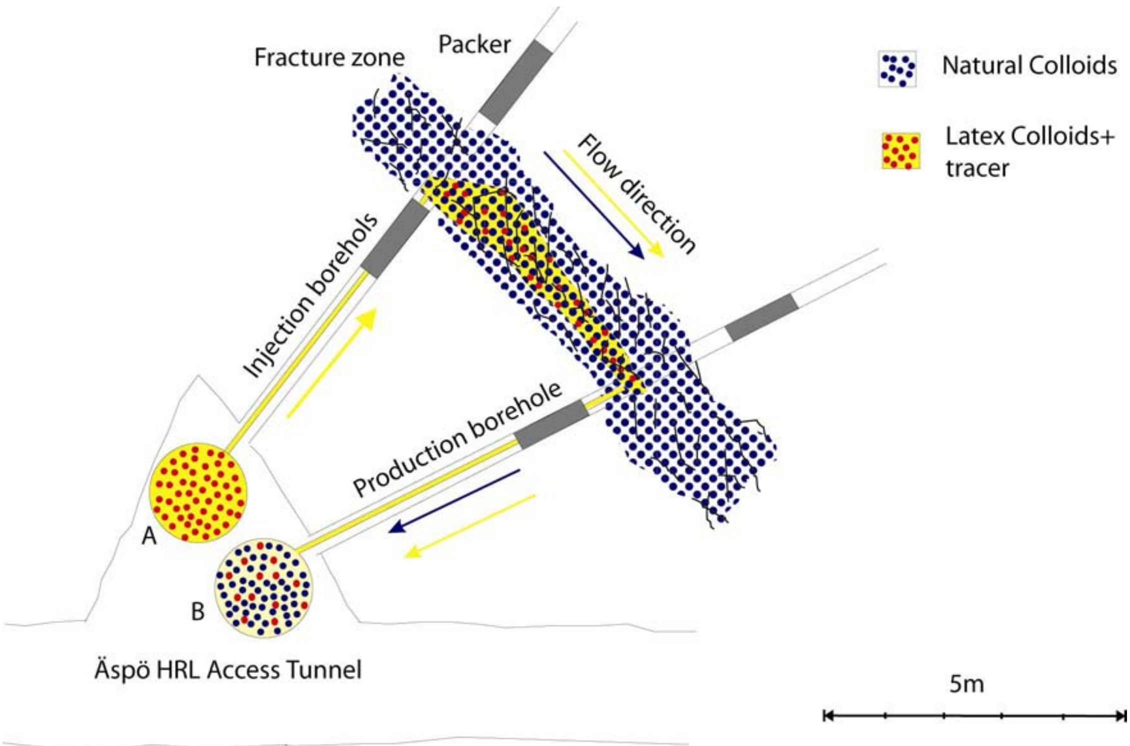

Figure 4-6 *Dipole colloid experiments – injection of latex colloids and monitoring of the injected and natural colloids in the production borehole.*

Present status

Scoping calculations has been performed to get realistic start conditions for the Colloid Dipole Experiments and the final planning for the *in situ* experiments is ongoing. Stability tests on bentonite and latex colloids have been performed in the laboratory as well as testing of the analyse equipment. The effect of salinity and temperature on colloid stability has been tested. Experiments with bentonite colloid transport in a fracture in a granite block, in dilute water, are ongoing at AECL, Canada. The final report for the activities in the Colloid project 2000-2004 is now printed /Laaksoharju and Wold 2005/.

An inventory is made of boreholes suitable for an actinide-colloid experiment and a decision will be taken in the beginning of 2006. A borehole with a low ionic strength and high DOC will be chosen to give conditions for colloidal stability.

Scope of work for 2006

The Colloid Dipole Experiment will start in March 2006 with an injection of a cocktail of latex colloids and a colour tracer. The colloid transport will be tested and different flow rates will be used. The data from these experiments will be evaluated during 2006.

The Actinide-Colloid Experiment will start parallel to the Colloid Dipole Experiments, but first a suitable borehole has to be selected.

4.5 Microbe Project

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 final repository for spent fuel /Pedersen 2002/. The study of microbial processes in the laboratory gives valuable contributions to our knowledge about microbial processes in repository environments. However, the concepts suggested by laboratory studies 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 microbiology 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 depend, 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/.

4.5.1 Microbe laboratory

Background

The university laboratory is best suited for pure cultures and therefore the effect from consortia of many participating species in natural ecosystems cannot easily be investigated there. The limitations of university laboratory investigations arrayed above 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.

There are presently four specific microbial process areas identified that are of importance for proper repository functions and that are best studied at the Microbe laboratory. 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.

Objectives

The major objectives for the Microbe laboratory are:

- 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 offer proper circumstances for research on the effect of microbial activity on the long term chemical stability of the repository environment.
- To enable investigations of bio-corrosion of copper under conditions relevant for a final repository for spent fuel.

Experimental concept

The Microbe laboratory is situated at the -450 m level in the F-tunnel (Figure 4-7). A laboratory container has been installed with laboratory benches, an anaerobic gas box and a climate control system. Three core drilled boreholes, KJ0050F01, KJ0052F01 and KJ0052F03, intersect water conducting fractures at 12.7, 43.5 and 9.3 m, respectively. They are connected to the Microbe laboratory via 1/8" PEEK tubing. The boreholes are equipped with metal free packer systems that allow controlled circulation of groundwater via respective fracture /Pedersen 2000/. Each borehole has been equipped with a circulation system offering a total of 2,112 cm^2 of test surface in each circulation flow cell set up (four flow cells) for biofilm formation at *in situ* pressure, temperature and chemistry conditions. The systems operate at the pressures 26, 32 and 26 bars in KJ0050F01, KJ0052F01 and KJ0052F03, respectively. The flow through the flow cells is adjusted to 25-30 ml per minute, which corresponds to a flow rate over the surfaces of about 1 mm per second. Temperature is controlled and kept close to the *in situ* temperature at around 15-16°C. Remote alarms have been installed for high/low pressure, flow rate and temperature. A detailed description of the Microbe laboratory can be found in a recent International Progress Report (IPR) /Pedersen 2005/.

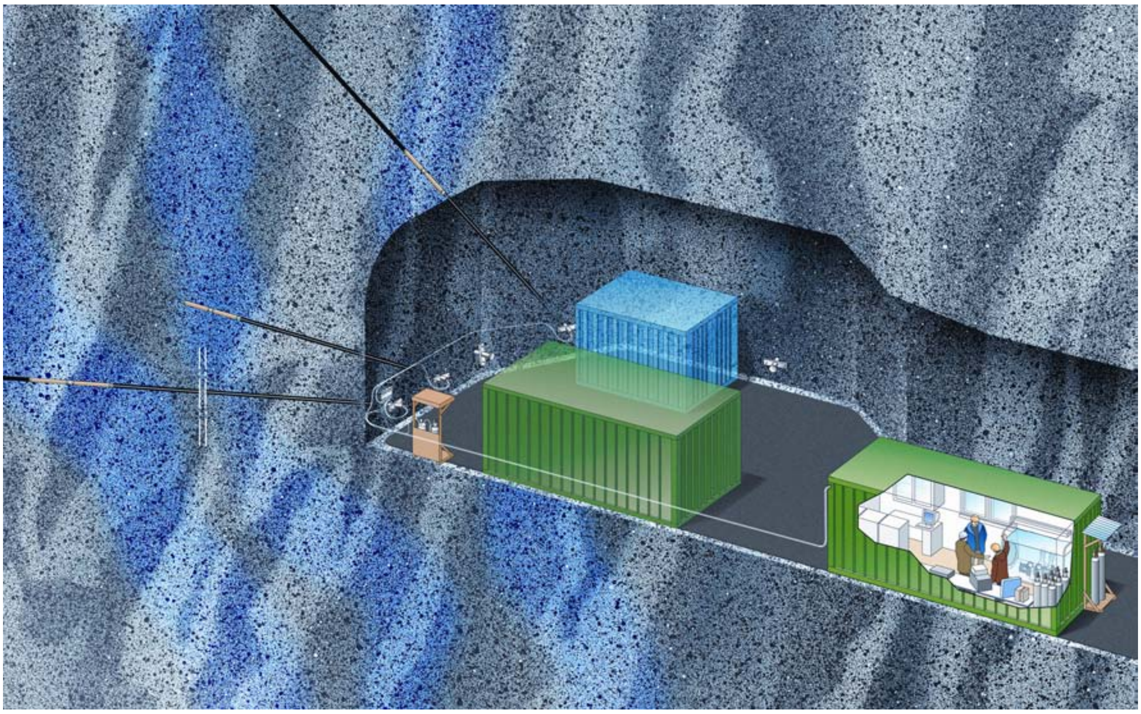

***Figure 4-7** The artists view of the Microbe 450 m site and the metal free packer configuration. The laboratory is situated in a steel container and connected to three discrete fractures in the rock matrix.*

Present status

The Microbe laboratory is working very well with respect to installed equipment /Pedersen 2005/. The site selection of the Microbe laboratory in the F-tunnel of Äspö has, until January 2005, assured stable conditions. However, the situation has changed dramatically since the drilling of boreholes in January 2005 at the -450 m level for the *in situ* corrosion testing of miniature canisters (Minican). This drilling caused a significant drainage of the formation from which Microbe takes its groundwater. During 2005 more than 15 000 m^3 groundwater have been drained via the Minican boreholes from a borehole denoted KA3386A01. This is a very significant drainage. A completely new mixing situation has developed in the Microbe formation during 2005. The drainage was eventually blocked in the beginning of December 2005.

Scope of work for 2006

Significant increases in chloride concentrations indicate that deeper and saltier water is moving up from large depths towards the Microbe formation as a result of the Minican drainage. A new complete characterisation must be performed. Complete class 5 analyses must be performed in the beginning of 2006, to establish the new chemical conditions that have evolved as a result of the Minican drainage. An analysis of the new mixing situation that has evolved during the 2005 must be performed. M3 modelling will be applied when the pressure and drainage conditions have been restored and the new chemical situation has been analysed. Finally, new analyses of microbes must be performed once the conditions have returned to those prevailing before the Minican disturbance. It is expected that a totally new situation will be found, because of the introduction of large amounts of new, deeper and saltier water to the Microbe formation.

4.5.2 Micored

Background

Microorganisms can have an important influence on the chemical situation in groundwater /Haveman and Pedersen 2002/. Especially, they may execute reactions that stabilise the redox potential in groundwater at a low and, therefore, beneficial level for the repository. It is hypothesised that hydrogen from deep geological processes contributes to the redox stability of deep groundwater via microbial turnover of this gas. Hydrogen, and possibly also carbon monoxide and methane energy metabolisms will generate secondary metabolites such as ferrous iron, sulphide, acetate and complex organic carbon compounds. These species buffer towards a low redox potential and will help to reduce possibly introduced oxygen. The circulations in the Microbe laboratory have microbial populations that are reproducible in numbers and species distribution over time as exemplified in Figure 4-8. All groups execute influence on the redox situation from left to right. Iron and manganese reducing bacteria are active at higher redox potentials (approximately -100 to -200 mV) than the methanogens and acetogens (approximately -300 to -400 mV). Sulphate reducing bacteria are most active between the optimal redox potentials for those groups (approximately -200 to -300 mV). Anaerobic microbial ecosystems generally force the redox potential towards more negative values when they are active. In other words, the Microbe laboratory is very well suited for research on the influence of microorganisms on the evolution and stability of redox potential in groundwater.

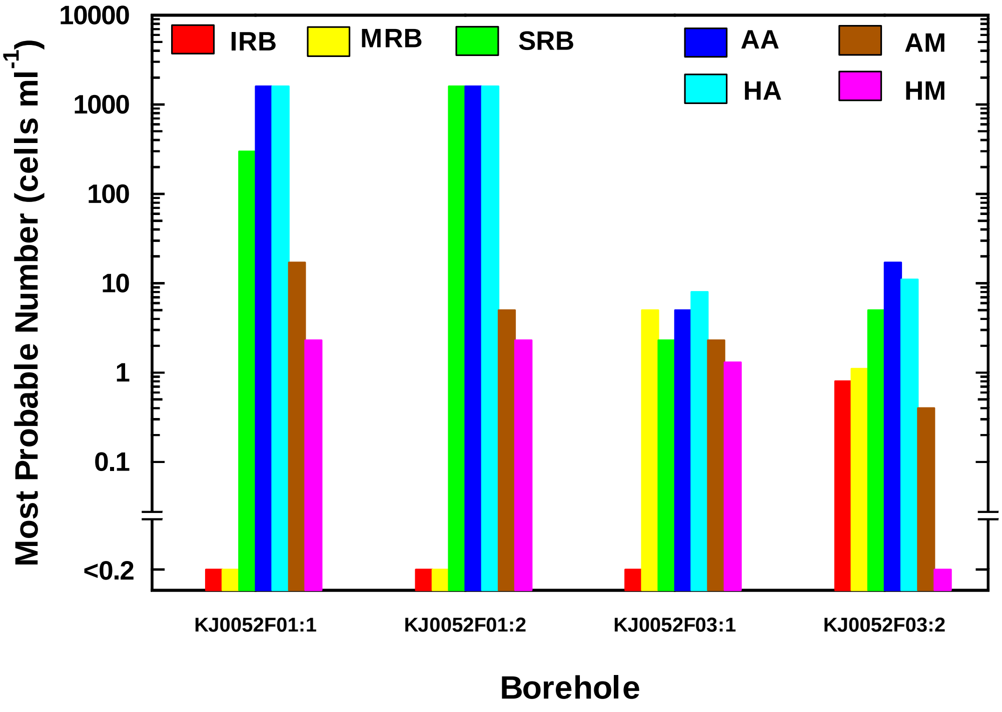

Figure 4-8 MPN of analysed physiological groups in two boreholes at the Microbe site at two different occasions, 2004-10-26 (1) and 2005-02-09 (2). Abbreviations: MRB (Manganese Reducing Bacteria), SRB (Sulphate Reducing Bacteria, AA (Autotrophic Acetogens), AM (Autotrophic Metanogens), IRB (Iron Reducing Bacteria), HA (Heterotrophic Acetogens), HM (Heterotrophic Metanogens).

Objectives

The major objectives for the Micored are:

- To clarify the contribution from microorganisms to stable and low redox potentials in near-and far-field groundwater.
- To demonstrate and quantify the ability of microorganisms to consume oxygen in the near- and far-field areas.
- To explore the relation between content and distribution of gas and microorganisms in deep groundwater.
- To create clear connections between investigations of microorganisms in the site investigations for a future repository and research on microbial processes at Äspö hard rock laboratory.

Experimental concept

Pressure resistant electrodes for redox potential and dissolved oxygen will be adapted and installed in the circulations in the Microbe laboratory. The circulations will be run with biofilms under various conditions with additions of the variables hydrogen, acetate, methane and oxygen. There are three circulations that will be coupled in series. This will allow simultaneous testing of two variables with one control at the time.

Present status

The work will commence mid spring 2006.

Scope of work for 2006

Pressure resistant electrodes for redox potential and dissolved oxygen will be adapted and installed in the circulations in the Microbe laboratory. The consumption of hydrogen, methane, acetate and oxygen will be monitored as a function of present microorganisms. The production of carbon dioxide, sulphide, acetate and microbial biomass will be analysed. This work is planned to be continued during 2007.

4.5.3 Micomig

Background

It is well known that microbes can mobilise trace elements /Pedersen 2002/. Firstly, unattached microbes may act as large colloids, transporting radionuclides on their cell surfaces with the groundwater flow. Secondly, microbes are known to produce ligands that can mobilise soluble trace elements and that can inhibit trace element sorption to solid phases.

A large group of microbes catalyse the formation of iron oxides from dissolved ferrous iron in groundwater that reaches an oxidising environment /Ferris *et al*. 1999, 2000/. Such biological iron oxide systems (Bios) will have a retardation effect on many radionuclides. Typically, microbes form stalks and sheaths that increase the volume of the iron oxides from densely packed inorganic oxides to a fluffy, rust-like material with water contents of up to 99%. The microbes contribute to the exposure of a large oxide area to trace elements flowing by with the groundwater and the organic biological material adds a strong retention capacity in addition to iron oxides /Anderson and Pedersen 2003/.

Biofilms in aquifers will influence the retention processes of radionuclides in groundwater. Recent work /Anderson *et al.* 2005/ indicate that these surfaces adsorb up to 50 % of these radionuclides in natural conditions with K_a (m) approaching 10^5 and 10^6 for Co and Pm respectively. The formation of colloids accounted for a further 20 % to 40 % of aqueous Co and Pm complexation. The anaerobic biofilms and rock surfaces share similar adsorption capacities for Pm but not for Co (Figure 4-9). The biofilms seemed to isolate the rock surface from the groundwater as diffusion to the rock surface must first proceed through the biofilms. The possible suppression of adsorption by biofilms needs further research. So far this has been observed only with one biofilm type in one Microbe laboratory circulation.

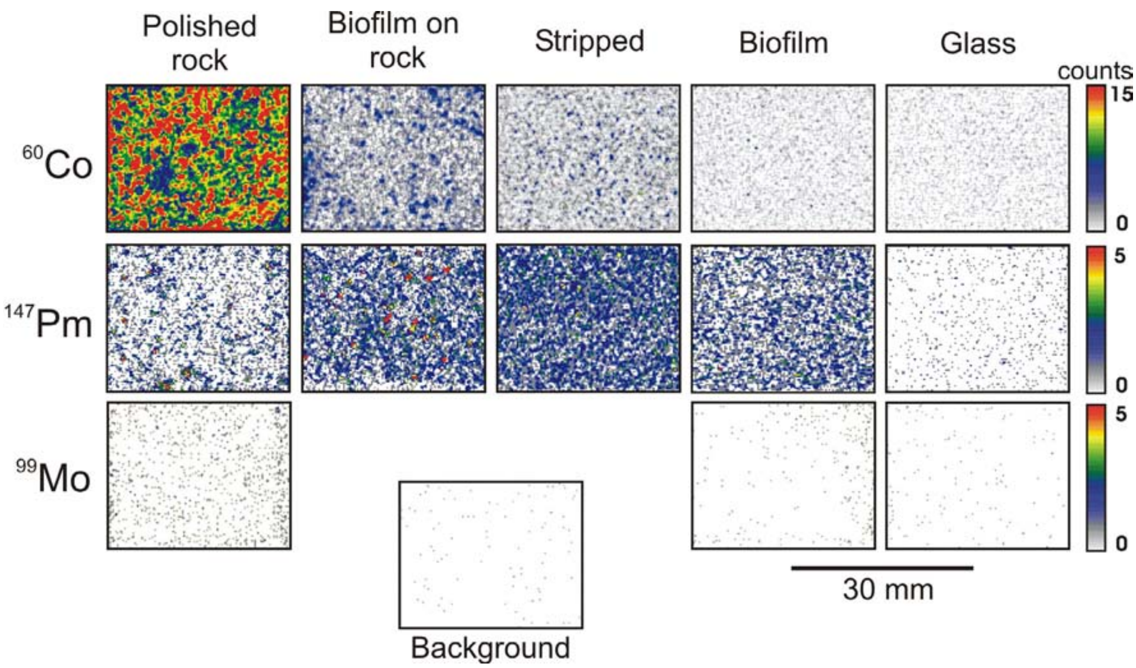

Figure 4-9 *Five sorption surfaces were tested for each radionuclide. The sorption surfaces were as follows: polished granite rock slides (Polished rock), biofilms attached to rock slides (Biofilm on rock), biofilms attached to glass slides partially stripped of metals (Stripped), biofilms attached to glass slides (Biofilm),and glass slides (Glass).*

Objectives

The major objectives for the Micomig are:

- To evaluate the influence from microbial complexing agents on radionuclide migration.
- To explore the influence of microbial biofilms on radionuclide sorption and matrix diffusion.

Experimental concept

In situ formation of complexing agents in the Microbe laboratory circulations will be investigated. We will adapt the experimental concept from laboratory work /Arlinger *et al.* 2004/ to the field. Pressure safe containers will be amended with radionuclide cocktails and groundwater from closed and active Microbe laboratory circulations will be added under ambient pressure, pH and redox potential. The distribution of the radionuclides between solid and liquid phases will be analysed as previously done in the laboratory.

New experiments with biofilm effects on radionuclide migration will utilise the tested and recently published experimental concept /Anderson *et al.* 2005/. Different circulations will be analysed. The types of biofilm microorganisms will be analysed.

Present status

The work will commence mid spring 2006.

Scope of work for 2006

One of the circulations at the Microbe laboratory will be adapted for assessment of complexing agent formation. Pressure containers will be tested and adapted. Pilot experiments will be run.

Biofilms from the ongoing Micored project will be utilised for further research on microbial effects on radionuclide migration.

4.5.4 Bio-corrosion

Background

Bio-corrosion of the copper canisters, if any, can be the result of microbial sulphide production. Two important questions have been identified and studied: Can sulphide-producing microbes survive and produce sulphide in the bentonite surrounding the canisters? Can microbial sulphide production in the surrounding rock exceed a performance safety limit? A series of laboratory and field experiments have indicated that this is not the case /Pedersen *et al.* 2000a, 2000b/. However, the results have been criticised for not accounting for natural conditions such as high pressure and the natural population of sulphate reducing bacteria in deep groundwater. This issue must, therefore, be further investigated under *in situ* conditions at repository depth.

Objectives

The major objective for the Bio-corrosion is:

- To establish parameters, i.e. swelling pressure and connected variables such as water activity and diffusivity that must be fulfilled to avoid excessive sulphide production in the buffer.

Experimental concept

The technical concept will follow earlier published procedures /Masurat and Pedersen 2004/. Pressure safe stainless steel containers with bentonite compacted to a range of swelling pressures will be connected to one of the circulations in the Microbe laboratory with large populations of naturally occurring microorganisms. Bio-corrosion of copper plates by sulphide produced by sulphate reducing bacteria will be analysed as previously done with $^{35}SO_4$ and lactate using 2-D autoradiography to detect copper sulphide.

Present status

The oedometers from earlier work (Figure 4-10) are being upgraded to allow continuous flow over the bentonite surface. Design and construction of the experimental equipment is ongoing.

Figure 4-10 *Steel oedometers with compacted bentonite were connected to KJ0052F03 in two series. All experiments were performed inside an anaerobic box at the -450 m level in the Microbe laboratory /Masurat and Pedersen 2004/.*

Scope of work for 2006

Three series of six oedometers with varying swelling pressures will be installed early spring 2006. They will be connected to groundwater from KJ0050F01 or KJ0052F01 depending on the results from the characterisations after the Minican disturbance. Sulphate diffusion, sulphide production and sulphide copper corrosion will be followed as a function of time, swelling status and swelling pressure.

4.6 Matrix Fluid Chemistry Continuation

Background

The first phase of the Matrix Fluid Chemistry experiment (1998–2003) increased the knowledge of matrix pore space fluids/groundwaters from crystalline rocks of low hydraulic conductivity ($K<10^{-10}$ ms^{-1}), and this complemented the hydrogeochemical studies already conducted at Äspö. The results of this first phase were published in early 2004 /Smellie *et al.* 2003/.

The continuation phase (2004–2006) is presently focussed on areas of uncertainty which remain to be addressed. These are:

- The nature and extent of the connected pore waters in the Äspö bedrock (chemical, hydraulic and transport properties).
- The nature and extent of the microfracture groundwaters which penetrate the rock matrix (chemical, hydraulic and transport properties) and the influence of these groundwaters (by in- and out-diffusion) on the chemistry of the pore waters.
- The confirmation of rock porosity values previously measured in the earlier studies.

This continuation phase also saw the completion of a feasibility study to assess the effects on the matrix borehole and its surroundings due to the untimely excavation of a new tunnel for the Äspö Pillar Stability Experiment carried out in April/May, 2003. There was concern that repercussions from this excavation may have influenced the hydraulic (and therefore the hydrochemical) character of the matrix borehole and the host rock vicinity.

Objectives

Because of the possibility that the hydraulic and hydrochemical character of the matrix borehole and the host rock vicinity has been disturbed, the following objectives were identified:

- To establish the impact of tunnel construction on the matrix borehole by evaluating the monitored pressure profiles (HMS) registered on the isolated borehole sections during the period of construction (small-scale).
- To establish the impact of tunnel construction on boreholes located in the near-vicinity of the matrix borehole in “Tunnel F” by similar means (large-scale).
- If the evaluation indicates that the rock hosting the matrix borehole has been unaffected by tunnel construction, the experiment will proceed first to hydrochemically and hydraulically characterise the presently isolated borehole sections containing microfractures and, secondly, to hydrochemically and hydraulically characterise the original fracture-free borehole sections.
- To carry out additional porosity measurements on drillcore samples to confirm or otherwise those values already measured.

Experimental concept

The first phase of the Matrix Fluid Chemistry Experiment was designed to sample matrix pore water from predetermined, isolated borehole sections. The borehole was selected on the basis of: (a) rock type, (b) mineral and geochemical homogeneity, (c) major rock foliation, (d) depth in the tunnel, (e) presence and absence of fractures, and (f) existing groundwater data from other completed and ongoing experiments at Äspö HRL.

Special downhole equipment, see Figure 4-11, was constructed ensuring: (a) an anaerobic environment, (b) minimal contamination from the installation, (c) minimal dead space in the sample section, (d) the possibility to control the hydraulic head differential between the sampling section and the surrounding bedrock, (e) in-line monitoring of electrical conductivity and drilling water content, (f) the collection of pore waters (and gases) under pressure and (g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

This experimental equipment, with some modifications, is being used in the continuation phase to sample groundwaters from the microfractures, to measure the hydraulic parameters of the microfractures and the rock matrix, and finally to conduct the long term *in situ* diffusion experiment.

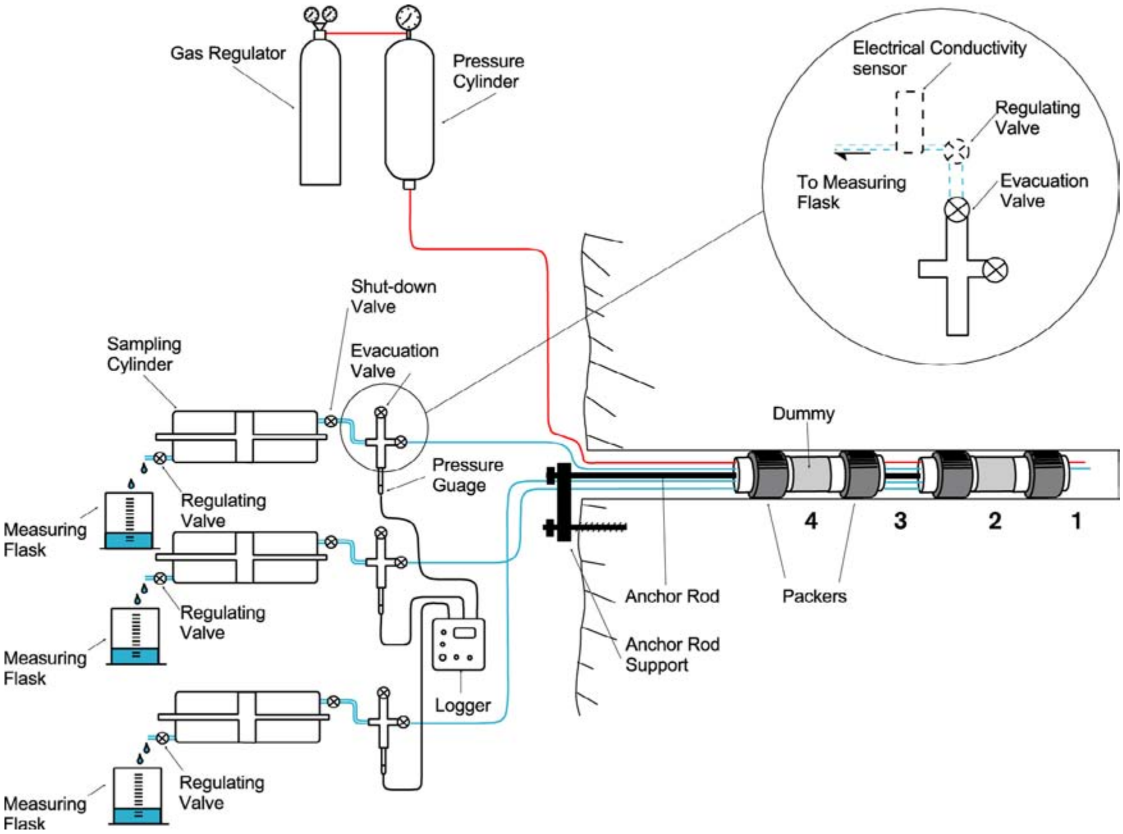

Figure 4-11 *Matrix Fluid Chemistry experimental set-up. Borehole sections 2 and 4 were selected to collect matrix fluid, sections 1-4 were continuously monitored for pressure.*

Present status

The feasibility study focussing on the impact of tunnel construction (i.e. Äspö Pillar Stability Experiment) on the hydrogeology and hydrochemistry in the vicinity of the experimental matrix borehole KF0051A01 was carried out during the period March-August, 2005. The impact of the tunnel construction was judged to have had little effect on the hydraulic properties of the rock mass which hosts the Matrix Fluid Chemistry Experiment borehole (cf. Geosigma Memorandum: 2005-08-30). It was therefore deemed worthwhile to initially hydrochemically and hydraulically characterise the presently isolated borehole sections containing microfractures and, secondly, to hydraulically characterise the original fracture-free borehole sections sampled during the first phase of the matrix experiment.

Sampling of waters from fracture-containing sections of the matrix borehole was carried out in April and November 2005; these waters are presently being chemically and isotopically analysed to complement earlier data from the fracture-free borehole lengths /Smellie *et al.* 2003/.

Preparation for the hydraulic characterisation of matrix borehole was successfully completed in November 29th, 2005. Hydraulic characterisation of the borehole is presently on-going and is expected to continue to the spring of 2006.

With respect to the final objective, porosity measurements on drillcore material (borehole KA2599G01) to supplement data from the Matrix Fluid Chemistry Experiment borehole have been carried out successfully and a draft report is available. The report is presently being reviewed prior to being published as an internal TD early in 2006. A parallel article has been submitted and accepted for publication in Engineering Geology in 2006.

Scope of work for 2006

The scope of the work for 2006 will concentrate on completion of the hydraulic testing, scheduled for the spring of 2006, and completion of the sampled water analysis around the same time. These data will be tabulated, interpreted and reported by the autumn of 2006 as a Technical Document (TD). With respect to the additional porosity data, these have been completed and will be available as a TD in the spring. No further programme of research is planned for the Matrix Fluid Chemistry Experiment borehole.

4.7 Radionuclide Retention Experiments

Background

The retention of radionuclides in the rock is the most effective protection mechanism when the engineered barriers fail and radionuclides are released from the waste form. The retention is mainly due to the chemical properties of the radionuclides, the chemical composition of the groundwater, and to some extent also by the conditions of the water conducting fractures and the groundwater flow.

Laboratory studies of radionuclide retention under natural conditions are extremely difficult to conduct. Even though the experiences from different scientists are uniform it is of great value to be able to demonstrate the results of the laboratory studies *in situ*, where the natural contents of colloids, organic matter, bacteria etc. are present in the groundwater used in the experiments. A special borehole probe, Chemlab, has been designed for different kinds of *in situ* experiments where data, representative for the properties of groundwater at repository depth, can be obtained.

The results of experiments in Chemlab will be used to validate models and check constants used to describe radionuclide dissolution in groundwater, the influence of radiolysis, fuel corrosion, sorption on mineral surfaces, diffusion in the rock matrix, diffusion in buffer material, transport out of a damaged canister and transport in an individual fracture. In addition, the influence of naturally reducing conditions on solubility and sorption of radionuclides will be studied.

Objectives

The objectives of the radionuclide retention experiments are to:

- Validate the radionuclide retention data and fuel dissolution data which have been measured in laboratories by data from *in situ* experiments.

- Demonstrate that the laboratory data are reliable and correct also at the conditions prevailing in the rock.
- Decrease the uncertainty in the retention properties of relevant radionuclides.

Experimental concept – Chemlab

Chemlab 1 and 2 are borehole laboratories built into probes, in which *in situ* experiments can be carried out under ambient conditions with respect to pressure and temperature, and with the use of natural groundwater from the surrounding rock, see Figure 4-12. Initially one "all purpose" unit, Chemlab 1, was constructed in order to meet any possible experimental requirement. At a later stage, a simplified version, the Chemlab 2 unit, was designed to meet the requirements by experiments where highly sorbing nuclides are involved. In Figure 4-13 the principles of the borehole laboratories are given. In already completed or almost completed experiments the following have been studied:

- Diffusion of cations (Cs^{+}, Sr^{2+}, and Co^{2+}) and anions (I^{-} and TcO^{4-}) in bentonite.
- The influence of primary and secondary formed water radiolysis products on the migration of the redox-sensitive element technetium. The final report is in print.
- Migration of actinides (americium, neptunium, and plutonium) in a rock fracture. The final report will be finished during spring 2006.

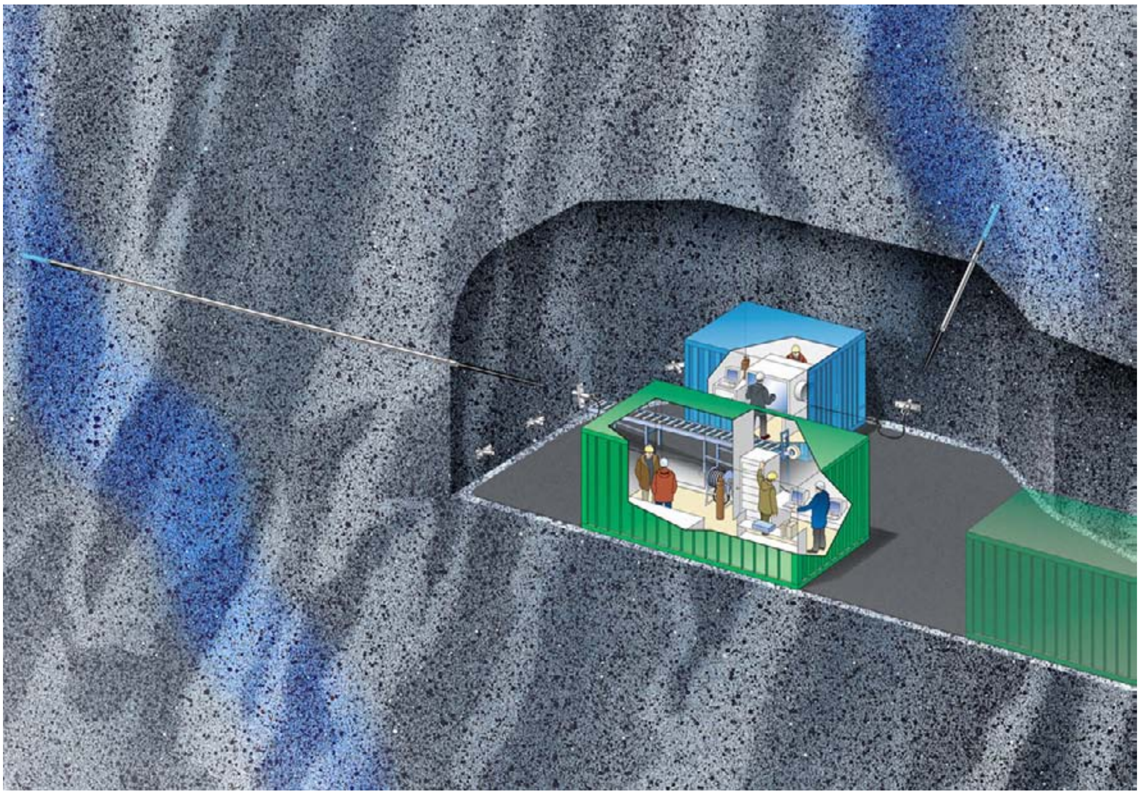

Figure 4-12 *Illustration of the experimental set-up of the Radionuclide Retention Experiments.*

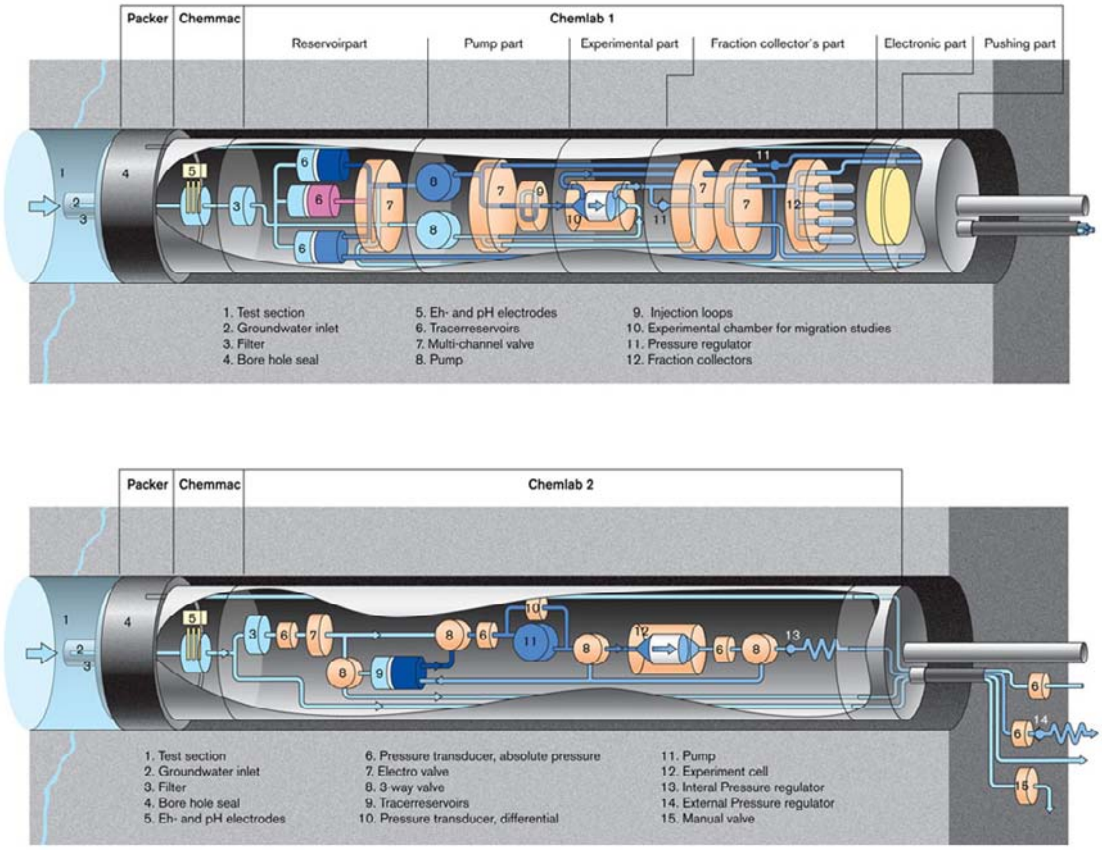

Figure 4-13 *Schematic illustration of Chemlab 1 and 2 borehole laboratories.*

4.7.1 Spent Fuel Leaching

Background and objectives

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

The objectives of the experiments are to:

- Investigate the leaching of spent fuel in laboratory batch experiments and at *in situ* conditions.
- Validate laboratory data by experimental retardation data from *in situ* experiments.
- Demonstrate that the laboratory data are reliable and correct for the conditions prevailing in the rock.
- Reduce the uncertainties in the retardation properties of Am, Pu and Np.

Experimental concept

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).

Present status

The experiment has just been initiated and the planning of laboratory experiments is in progress.

Scope of work for 2006

The spent fuel leaching experiments are planned to start in the middle of 2006.

4.7.2 Transport Resistance at the Buffer-Rock Interface

Background and objectives

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

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

Experimental concept

The experiment will be performed in the laboratory, where a fracture is simulated as a 1 mm space between two plexiglas plates, see Figure 4-14. The equipment includes a water pump for very low flow rates.

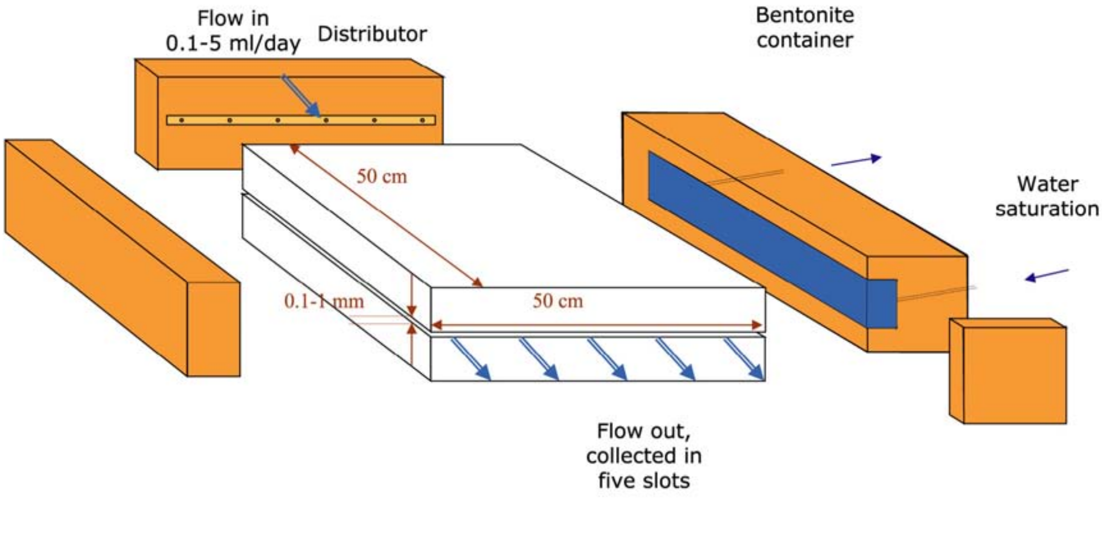

Figure 4-14 *Illustration of experimental set-up.*

Present status

The laboratory equipment that will be used to study the phenomenon is being manufactured and is expected to be finished in February 2006. The experimental equipment will, however, first be used by another SKB-project (Bentonite Erosion) and the above experiments has been postponed.

Scope of work for 2006

When the experiments on Bentonite Erosion are finished the experiments for the project Transport Resistance at the Rock-Bentonite Interface will start.

4.8 Padamot

Background

Palaeohydrogeology is a relatively new term used as a common name for information from fracture minerals that is used for interpretations of past hydrogeochemical and hydrogeological systems. The need for such interpretations has become evident in the geological/hydrogeological modelling of sites within the radwaste programmes of several countries. An EC founded 3 year project with the name Equip (Evidences from Quaternary Infills for Palaeohydrogeology) was therefore started in 1997. When the Equip project ended in 2000 /Bath *et al.* 2000/ there was a need for continued fracture mineral investigations and model testing of the obtained results. A new EC-project called Padamot (Palaeohydrogeological Data Analysis and Model Testing) was therefore initiated in the beginning of 2002.

Objectives

The objectives for the Padamot project include:

- Further developments of analytical techniques that exploit the rapid advances in instrumental capabilities, especially for quantitative microanalyses of trace elements and isotopes for dating.
- Development of modelling tools to interpret data quantitatively and to relate it to both water-rock reactions at the scale of mineral crystals and to evolution of the groundwater systems at larger scales.
- Focus of further research to investigate specific processes that might link climate and groundwater in low permeability rocks.

The Swedish part of the Padamot study concentrates on the two work packages:
WP2 (Palaeohydrogeological characterisation of sites) involving applications of several analytical techniques on fracture filling calcites dominantly from KLX01, and WP5 that deals with performance assessment applications of palaeohydrogeological data and modelling.

Present status

The EC part of the project is finished and was reported in EC series of reports in 2005. The methodology for performing palaeohydrogeological studies will be applied within SKB's now ongoing site investigations in Laxemar/Simpevarp and Forsmark.

Scope of work for 2006

A paper for the open literature presenting a methodology for palaeohydrogeological studies with the focus on possible approaches to be used for the Swedish sites (Äspö/Laxemar/Simpevarp and Forsmark) is planned. The Uranium series measurements were originally planned within the Padamot EC-project but were later removed from the common part of WP2. Natural uranium decay series analyses have been used previously on smaller sets of samples from Äspö /Tullborg *et al.* 2003, Landström *et al.* 2001/. Different methods can be used including bulk samples analyses and sequential leaching. The plan for 2006 is to apply this type of analyses to a set of samples from Äspö and Laxemar, in order to test the different techniques.

4.9 Fe-oxides in fractures

Background

Uptake of radioactive elements in solid phases can lead to immobilisation, thus minimising the release to the environment. Uptake extent depends on solution conditions such as concentration, pH, Eh, temperature, pressure and the presence of other species. Transition metals, lanthanides and actinides are often incorporated by identical processes, consequently better understanding of the behaviour of the two first groups mentioned strengthens understanding also of the actinides, which are difficult to study. Moreover, presence of trace components in minerals can provide information about a mineral's genesis conditions and history.

Fractures lined with Fe-oxides are found in the Äspö bedrock and they are present as minor components nearly everywhere at the Earth's surface. Their affinity for multivalent species is high but Fe-oxide uptake of lanthanides and actinides has not been studied to any great extent. Fe(II)-oxihydroxides, known as "green rust", form in Fe-bearing solutions under reducing conditions and are associated with the early stages of corrosion. Their uptake capacity during formation and transition to Fe(III)-oxides is essentially unknown at present. These minerals could be an important sink for radioactive species where Fe is abundant in the natural fractures or in materials brought into the repository. Fe itself can be an indicator of redox state. Fe-isotope fractionation, a very new topic of research, might give clues about redox conditions during Fe-mineral formation or as a result of its inclusion in other secondary fracture minerals.

There are three questions relevant for radioactive waste disposal in fractured granite:

- How extensive is the capacity for Fe(III)-oxides, in fracture linings, to take up and retain radionuclides or other toxicants from solutions, and what happens during transformation of the oxides to more stable phases?
- What capacity do the reduced Fe(II)-oxides have for uptake and retention?
- Does the suite of trace components and isotopes measured in minerals from fracture linings provide information about conditions of the water that passed through them in the past?

These questions can be rephrased more specifically, for direct application to problems for Swedish waste disposal, as:

- Can more detailed information about the uptake of higher valent elements such as Eu^{3+} provide a model for actinide behaviour and Cr^{3+} as a palaeo-redox-indicator?
- Can stable Fe-isotopes from Fe-oxides or from other minerals tell us anything about solution conditions during genesis?
- What is the uptake and retention capacity of green rust under solution conditions relevant for Äspö?
- Is it possible to find evidence to support or dispute the hypothesis that, at the time of glacier retreat, oxidising water might have penetrated to or below the depth of the planned final repository?
- How might secondary Fe-minerals affect the migration of radionuclides released from a repository?

Objectives and experimental concept

The basic idea of the project is to examine Fe-oxide fracture linings, in order to explore suitable palaeo-indicators and their formation conditions. At the same time knowledge about the behaviour of trace component uptake can be obtained from natural material as well as through studies in the laboratory under controlled conditions.

A glove-box set-up, where Atomic Force Microscopy is possible *in situ*, will be used to investigate green rust under a stable atmosphere at reducing conditions. More possibilities for extracting chemical information from the secondary Fe-oxides will be tested and the merits of stable Fe- and O-isotope fractionation as well as Mössbauer (MS) and energy dispersive X-ray (EDS) spectroscopy will be examined.

Present status

A fast, effective and precise procedure has been developed to differentiate between several types of Fe-oxides found as fracture fillings in granite. Together with data from Mössbauer spectroscopy, X-ray diffraction (XRD) and rare Earth element (REE) analysis, three genetic environments for Fe-oxide formation have been demonstrated.

The natural, low-temperature, recent Fe-oxides likely formed from weathering of chlorite fracture linings. Very recent, X-ray amorphous ($\leq$ ~ 10 nm), low temperature Fe-oxides have resulted from drilling at Oskarshamn and Forsmark. The studies showed that metallic iron and maghemite, a common corrosion product of steel, were also present in minor amounts. From the samples studied, no evidence was found to indicate penetration of oxidising, low temperature solutions below a depth of about 100 m below current ground level.

Investigations of green rust (GR) have shown that existing literature data for structure and composition are incorrect. Revised data, which are required for PA modelling, have been produced and more are coming.

Methods for investigating GR reactivity have been developed by using Cr(VI) reduction to Cr(III) as a model redox active compound. Preliminary studies with Np(V) and Se(VI) show the same behaviour.

Reactive transport modelling involving Fe(II)/Fe(III) species has commenced recently, driven by Enviros (Spain).

Scope of work for 2006

On present fracture material investigations will continue to determine GR stability in natural conditions and the potential mobility of green rust colloids. In addition, the reactive transport modelling involving Fe(II)/Fe(III) species will be further developed at Enviros (Spain). However, now that new methodologies have been developed and tested to identify and to understand further the behaviour of different Fe-oxide phases in crystalline rock, the next logical stage in the Fe-Oxide study is to conduct similar studies on other reliable and carefully selected sample sets. One attractive possibility is to select samples from the Oskarshamn and Forsmark characterisation sites where triple-tube methods have been used, thus ensuring better drillcore samples for study. Data from such cores will be very helpful to:

- Better understand the situation at Äspö where sample quality is less reliable and sample selection less systematic.
- Further demonstrate developed methodologies using strategically sampled material, thus providing useful input to on-going mineralogical and solute transport studies (i.e. transfer of experience and knowledge from the Äspö studies).

4.10 Swiw-test with Synthetic Groundwater

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

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

Objectives

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.

Experimental concept

The basic idea is to perform Swiw-tests with radon free synthetic groundwater with a somewhat altered composition, e.g. replacement of chloride with nitrate and the exclusion of potassium and strontium, compared to the natural groundwater at the True Block Scale site. Sorbing as well as non-sorbing tracers are added during the injection phase of the tests. In the withdrawal phase of the tests the contents of the "natural" tracers, radon, chloride, potassium and strontium, as well as the added tracers in the pumping water is monitored. The breakthrough curves contain the desired information on diffusion.

Scope of work for 2006

The main part of 2006 will be devoted to a feasibility study, determination of scope and planning of the work ahead.

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

Background

The work within Äspö Task Force constitutes an important part of the international co-operation within the Äspö HRL. The group was initiated by SKB in 1992 and is a forum for the organisations to interact in the area of conceptual and numerical modelling of groundwater flow and transport. A Task Force delegate represents each participating organisation and the modelling work is performed by modelling groups. The Task Force meets regularly about once to twice a year.

Different experiments at the Äspö HRL are utilised to support the Modelling Tasks. To date modelling issues and their status are as follow:

Task 1: Long term pumping and tracer experiments (completed).

Task 2: Scooping calculations for some of the planned detailed scale experiments at the Äspö site (completed).

Task 3: The hydraulic impact of the Äspö tunnel excavation (completed).

Task 4: The Tracer Retention and Understanding Experiment, 1st stage (completed).

Task 5: Coupling between hydrochemistry and hydrogeology (completed).

Task 6: Performance assessment modelling using site characterisation data (ongoing).

Task 7: Long-term pumping experiment (ongoing).

Occasionally, there is work done in so-called Meta Tasks, which are normally not directly coupled to a specific modelling task, but have an overview perspective. Such a task has been initiated. It is dedicated to updating the Issue Evaluation Table, which is intended to provide a basis for identification and evaluation of key issues in performance assessment of a final geological repository /Ström, 1998/.

Objectives

The Äspö Task Force is a forum for the organisations supporting the Äspö HRL project to interact in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock. In particular, the Task Force shall propose, review, evaluate, and contribute to such work in the project. The Task Force shall interact with the principal investigators responsible for carrying out experimental and modelling work for Äspö HRL of particular interest for the members of the Task Force.

Much emphasis is put on building of confidence in the approaches and methods in use for modelling of groundwater flow and migration in order to demonstrate their use for performance and safety assessments.

The ongoing Task 6 was initiated in 2001. Task 6 does not contain experimental work but it uses experimental results of the former Task 4 and True Block Scale project. Task 4 included a series of tracer tests performed in a single feature over transport distances of about 5 m using simple flow geometry and both conservative and sorbing tracers. In True Block Scale, a series of tracer tests was performed in a fracture network over tens of metre distances. The main objectives of Task 6 are to:

- Assess simplifications used in performance assessment (PA) models.
- Assess the constraining power of tracer experiments for PA models.
- Provide input for site characterisations programme from PA perspective.
- Understand the site-specific flow and transport at different scales using site characterisation models.

These sub-tasks have been defined within Task 6:

6A Model and reproduce selected True-1 tests with a PA model and/or a site characterisation (SC) model to provide a common reference.

6B Model selected PA cases at the True-1 site with new PA relevant (long term/base case) boundary conditions and temporal scales.

6B2 Similar to Task 6B, but uses a different boundary condition, a linear source term and the tracers are analysed at a fracture intersecting Feature A.

6C Develop semi-synthetic, fractured granite hydrostructural models. Two scales are supported (200 m block scale and 2,000 m site-scale).

6D This modelling task is similar to sub-task 6A, and is using the semi-synthetic structural model in addition to a 50 to 100 m scale True Block Scale tracer experiment.

6E This modelling task extends the sub-task 6D transport calculations to a reference set of PA time scales and boundary conditions.

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.

6F2 The purpose of the Task 6F2 Sensitivity study is to exploit the model setup within Task 6E and 6F to perform additional studies evaluating specific topics of concern for the modelling of transport in fractured rock.

Task 7 was presented at the 19th International Task Force meeting in Finland, 2004. Hydraulic responses during construction of a final repository are of great interest because they may provide information for characterisation of hydraulic properties of the bedrock and for estimation of possible hydraulic disturbances caused by the construction. Task 7 will focus on the underground facility Onkalo at the Olkiluoto site in Finland, and is aimed at simulating the hydraulic responses detected during a long-term pumping test carried out in borehole KR24.

Present status

One Task Force meeting and one workshop have been held during year 2005. The 20th International Task Force meeting, hosted by SKB was held in May at Äspö HRL. At this meeting, the modelling groups presented results of sub-task 6D, and 6E and 6F. The venue for the workshop was Riddersviks Gård outside Stockholm in September. At this workshop, initial modelling for Task 7 was presented and discussed.

The work within the Task Force has been in progress after the meeting and workshop. Minutes from the meetings are published on Member Area of the Task Force Website (www.skb.se/taskforce). In the planning group, telephone meetings are held on a regular basis. Modelling reports of sub-task 6A, 6B and 6B2 have been printed. The external review process for Task 6 is ongoing, and review reports of Task 6A, 6B and 6B2, and 6C have been printed. The modelling groups are working on reporting of Task 6D, 6E, 6F and F2 in integrated reports.

A specification on Task 7 has been sent out to the Task Force members, which has been followed by a task definition. Data for Task 7 are published on the Member Area mentioned above.

Scope of work for 2006

The main activities targeted to be accomplished during 2006 are summarised below:

- Organise the 21st International Task Force meeting in March, hosted by Andra in France.
- Finalisation of Task 6
    - Print modelling reports of sub-task 6D, 6E, 6F and 6F2.
    - Finalise the external review process of Task 6.
    - Publish the review of the Task 6 in a scientific journal.
- Perform modelling within Task 7.
- Update the Issue Evaluation Table

5 Engineered barriers

5.1 General

To meet stage goal 4, to demonstrate technology for and function of important parts of the repository barrier system, work is performed at Äspö HRL. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a future 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 and performance testing, and will together form a major experimental programme.

With respect to technology demonstration important overall objectives of this programme are:

- To furnish methods, equipment and procedures required for excavation of tunnels and deposition holes, near-field characterisation, canister handling and deposition, backfill, sealing, plugging, monitoring and also canister retrieval.
- To integrate these methods and procedures into a disposal sequence, that can be demonstrated to meet requirements of quality in relation to relevant standards, as well as practicality.

With respect to repository function, the objectives are to test and demonstrate the function of the engineered barriers as well as the function of the integrated repository system.

The main experiments that are installed in Äspö HRL or under way are:

- Prototype Repository.
- Long Term Test of Buffer Material.
- Backfill and Plug Test.
- Canister Retrieval Test.
- Temperature Buffer Test.
- KBS-3 method with Horizontal Emplacement.
- Large Scale Gas Injection Test.
- In Situ Testing of Miniature Canisters
- Rock Shear Experiment

5.2 Prototype Repository

Background

Many aspects of the KBS-3 repository concept have been tested in a number of *in situ* and laboratory tests. Models have been developed that are able to describe and predict the behaviour of both individual components of the repository, and the entire system. However, processes have not been studied in the complete sequence, as they will occur in connection to repository construction and operation. There is a need to test and demonstrate the execution and function of the deposition sequence with state-of-the-art technology in full-scale. In addition, it is needed to demonstrate that it is possible to understand and qualify the processes that take place in the engineered barriers and the surrounding host rock. This technology was developed and is tested and demonstrated in the Prototype Repository.

The execution of the Prototype Repository is a dress rehearsal of the actions needed to construct a final repository from detailed characterisation to resaturation of deposition holes and backfill of tunnels. The Prototype Repository provides a demonstration of the integrated function of the repository and provides a full-scale reference for test of predictive models concerning individual components as well as the complete repository system. The Prototype Repository should demonstrate that the important processes that take place in the engineered barriers and the host rock are sufficiently well understood.

The installation of the Prototype Repository has been co-funded by the European Commission with SKB as co-ordinator. The EC-project started in September 2000 and ended in February 2004. The continuing operation of the Prototype Repository is funded by SKB.

Objectives

The main objectives for the Prototype Repository are to:

- Test and demonstrate the integrated function of the final repository components under realistic conditions in full-scale and to compare results with model predictions and assumptions.
- Develop, test and demonstrate appropriate engineering standards and quality assurance methods.
- Simulate appropriate parts of the repository design and construction processes.

The evolution of the Prototype Repository should be followed for a long time, possible up to 20 years. This is made to provide long term experience on repository performance to be used in the evaluation that will be made after the initial operational stage in the real deep repository.

Experimental concept

The test location chosen is the innermost section of the TBM-tunnel at the -450 m level. The layout involves altogether six deposition holes, four in an inner section and two in an outer, see Figure 5-1. The tunnels are backfilled with a mixture of bentonite and crushed rock (30/70). A massive concrete plug designed to withstand full water and swelling pressures separates the test area from the open tunnel system and a second plug separates the two sections. This layout provides two more or less independent test sections. Canisters with dimension and weight according to the current plans for the final repository and with heaters to simulate the thermal energy output from the waste have been positioned in the holes and surrounded by bentonite buffer. The deposition holes are placed with a centre distance of 6 m. This distance was evaluated considering the thermal diffusivity of the rock mass and the maximum acceptable surface temperature of the canister.

The decision when to stop and decommission the test will be influenced by several factors including performance of monitoring instrumentation, results successively gained, and the overall progress of the deep repository project. It is envisaged that the outer test section will be decommissioned after approximately five years to obtain interim data on buffer and backfill performance. Instrumentation is used to monitor processes and evolution of properties in canister, buffer material, backfill and near-field rock. Examples of processes that are studied include:

- Water uptake in buffer and backfill.
- Temperature distribution in canisters, buffer, backfill and rock.
- Displacements of canisters.
- Swelling pressure and displacement in buffer and backfill.
- Stresses and displacements in the near-field rock.
- Water pressure build up and pressure distribution in rock.
- Gas pressure in buffer and backfill.
- Chemical processes in rock, buffer and backfill.
- Bacterial growth and migration in buffer and backfill.

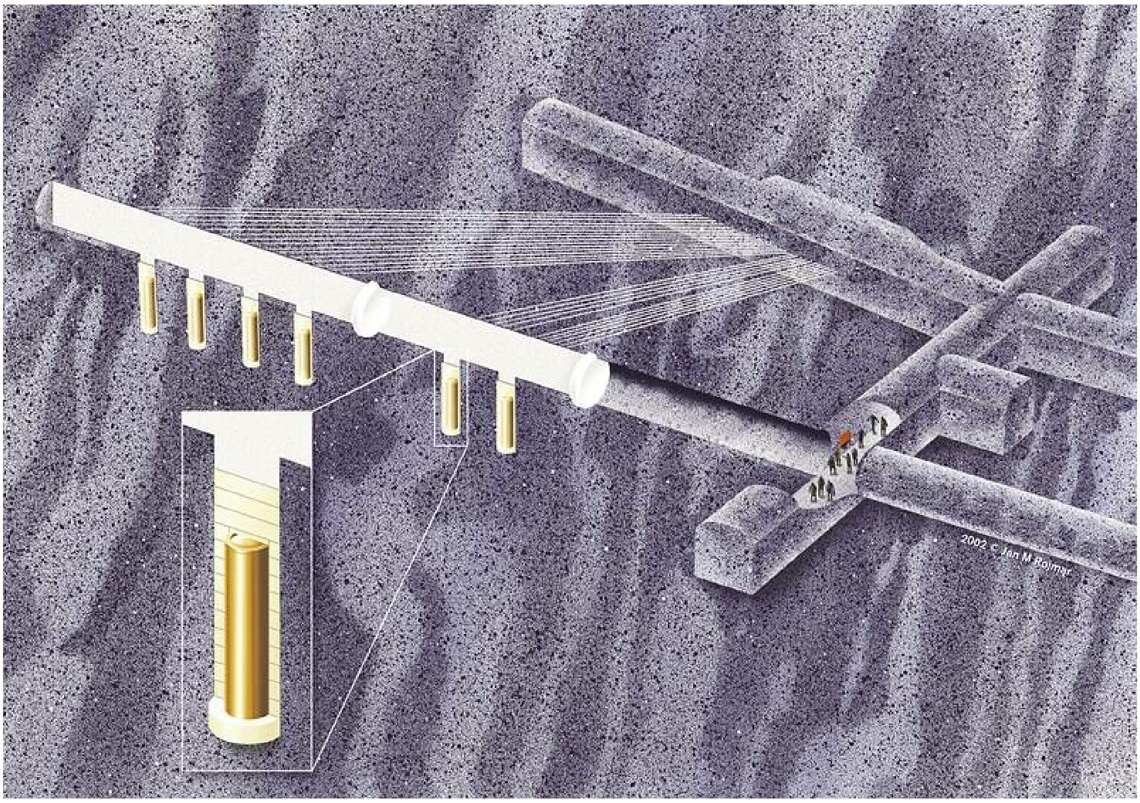

Figure 5-1 *Schematic view of the layout of the Prototype Repository (not to scale).*

Present status

The inner section was installed and the plug cast in 2001. Heaters were turned on one by one during September–October 2001 and the monitoring of processes was started and has yielded the expected data flow since then. The buffer and the canisters in the outer section were installed at the beginning of 2003. Immediately after the installation of the buffer, the tunnel section was backfilled and the heaters were turned on. This work was finished at the end of June 2003. At these stages the monitoring of processes in section two was started. The construction and casting of the outer plug started in August and were finished in September 2003. 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 2004. Subsequent the pore pressure in the backfill and the buffer increased and about one month after the closing of the drainage, damages of the heaters in two of the canisters were observed. The power to all of the heaters was then switched off, the drainage of the tunnel was opened again and an investigation of the damaged canisters started. The power to all the canisters except for canister #2 was switched on and the drainage of the tunnel was kept open. At the beginning of September 2005 new damages of the heaters in canister #6 was observed. The power to this canister was then switched off but at the beginning of November 2005 the power was switched on again. New damages on canister #6 were observed at the beginning of August 2005 and the power to this canister was switched off during two months but is now switched on again.

Chemical measurements in buffer, backfill and surrounding rock are ongoing. Tests for evaluating the ground water pressure and ground water flow in the rock have also been performed.

Scope of work for 2006

The instrument readings in the two sections and the chemical measurements in buffer, backfill and surrounding rock will continue. In addition, new tests for evaluation of the hydraulic conditions in the rock will be made and the modelling teams will continue the comparison of measured data with predictions. THM modelling of the buffer and the backfill will continue.

5.3 Long Term Test of Buffer Material

Background

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS-3 concept the demands on the bentonite buffer are to serve as a mechanical support for the canister, reduce the effects on the canister of a possible rock displacement, and minimise water flow over the deposition holes.

The decaying power from the spent fuel in the HLW canisters will give rise to a thermal gradient over the bentonite buffer by which original water will be redistributed parallel to an uptake of water from the surrounding rock. A number of laboratory test series, made by different research groups, have resulted in various buffer alterations models. According to these models no significant alteration of the buffer is expected to take place at the prevailing physico-chemical conditions in a KBS-3 repository, neither during nor after water saturation. The models may to a certain degree be validated in long-term field tests. Former large-scale field tests in Sweden, Canada, Switzerland and

Japan have in some respects deviated from possible KBS-3 repository conditions and the testing periods have generally been dominated by initial processes, i.e. water uptake and temperature increase.

Objectives

The present test series aims at validating models and hypotheses concerning the evolution of bentonite buffer properties. In the tests related processes regarding microbiology, radionuclide transport, copper corrosion and gas transport under conditions similar to those expected in a KBS-3 repository are studied. The expression "long-term" refers to a time span long enough to study the buffer performance at full water saturation, but obviously not "long-term" compared to the lifetime of a repository. The objectives may be summarised in the following items:

- Collect data for validation of models concerning buffer performance under quasi-steady state conditions after water saturation, e.g. swelling pressure, cation exchange capacity and hydraulic conductivity.
- Check of existing models on buffer-degrading processes, e.g. illitisation and salt enrichment.
- Collect data concerning survival, activity and migration of bacteria in the buffer.
- Check of calculation results concerning copper corrosion, and information regarding type of corrosion.
- Check existing models for diffusive transport of cations.
- Collect information, which may facilitate the realisation of the full-scale test series, with respect to clay preparation, instrumentation, data handling and evaluation.

Experimental concept

The testing principle for all tests is to emplace parcels containing heater, central tube, pre-compacted clay buffer, instruments and parameter controlling equipment in vertical boreholes with a diameter of 300 mm and a depth of around 4 m, see Figure 5-2. The test series, given in Table 5-1, concern realistic repository conditions except for the scale and the controlled adverse conditions in three tests.

Table 5-1 Buffer material test series.

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

A = adverse conditions S = standard conditions

T = temperature [K^+] = potassium concentration

pH = high pH from cement am = accessory minerals added

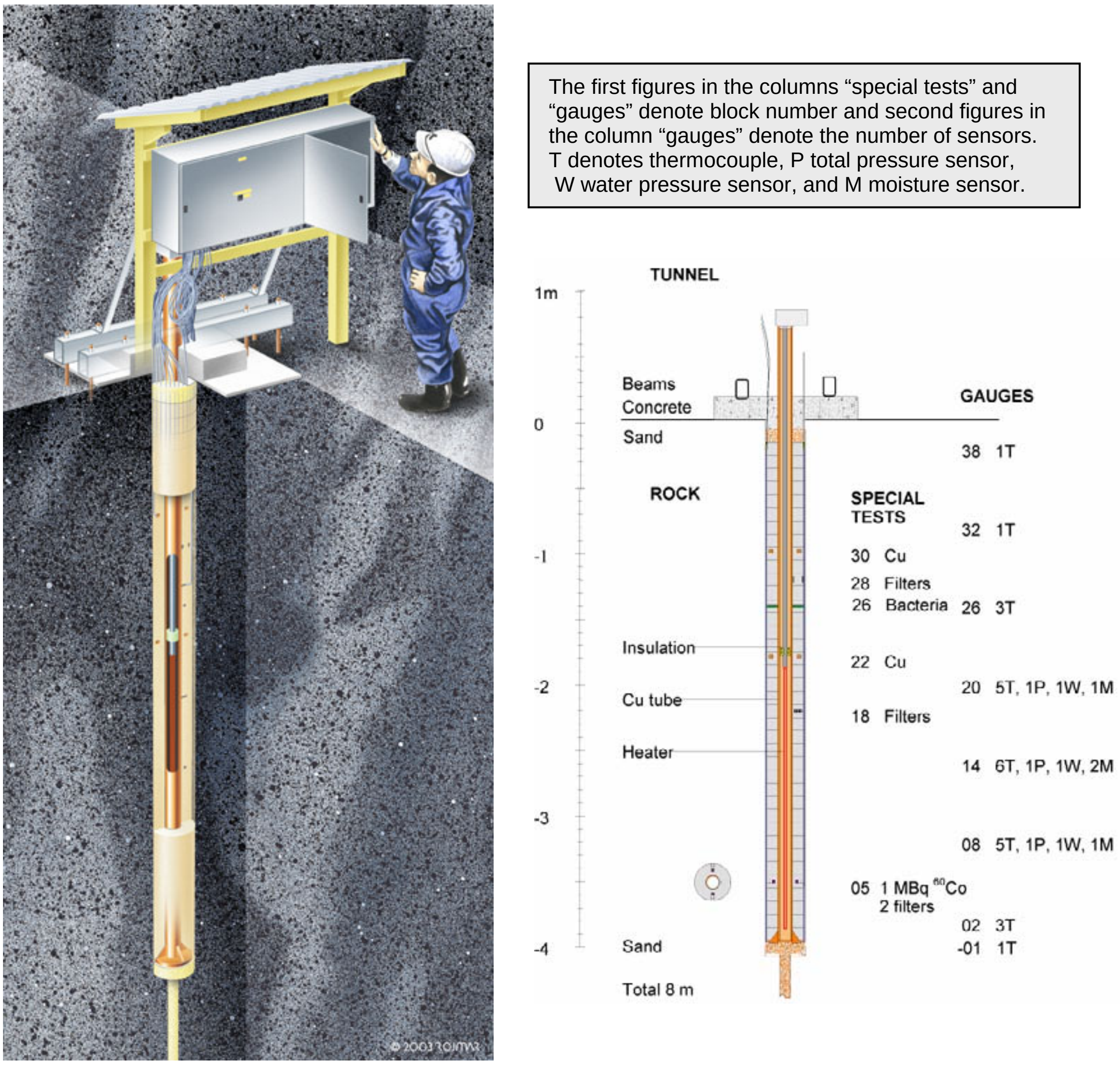

Figure 5-2 *Illustration of the experimental set-up in the Long Term Test of Buffer Material (left) and a cross-section view of one S-type parcel (right).*

Adverse conditions in this context refer to high temperatures, high temperature gradients over the buffer, and additional accessory minerals leading to i.e. high pH and high potassium concentration in clay pore water. The central copper tubes are equipped with heaters in order to simulate the decay power from spent nuclear fuel. The heater effect are regulated or kept constant at values calculated to give a maximum clay temperature of 90°C in the standard tests and in the range of 120 to 150°C in the adverse condition tests.

Each parcel contains 25 thermocouples, 3 total pressure gauges, 3 water pressure gauges, 4 relative humidity sensors, 7 filter tubes, and 12 water sampling cups. The power is controlled and temperature, total pressure, water pressure and water content are continuously being measured.

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 chemical, mineralogical analyses and physical testing is performed.

Present status

The A1 and S1 parcels are finalised and reported, the A0 parcel have been analysed and the A2 parcel have been terminated. The remaining three parcels are functioning well and only minor service was needed during the past year.

Scope of work for 2006

Water pressure, total pressure, temperature and moisture in the three remaining parcels will be continuously measured and stored every hour. The data are being checked monthly, and the results are analysed more carefully in April and October. Minor maintenance and improvement work will be made on the running parcels.

Parcel A2 will be uplifted in January and bentonite material will be sent to the involved laboratories in Sweden, Finland, Switzerland and France. The examinations of the bentonite physical properties involve a general determination of water content, buffer density and degree of saturation. Triaxial and unconfined compression tests on positions representing a radial distribution from the copper tube to the rock will be made in order to detect potential rheological changes. The same positions will be examined with respect to potential changes in swelling pressure and hydraulic conductivity. Mineralogical analyses including mineral composition (powder X-ray), swelling properties (oriented sample X-ray), cation exchange capacity and element distribution will be made in five radial positions from the copper tube to the rock both in hot and cold areas. Special analyses will be made with respect to i.e. bacterial activity, copper corrosion and redistribution of tracer elements. The analyses are planned to be finalised during summer and a report will be delivered in September.

5.4 Backfill and Plug Test

Background

The Backfill and Plug Test include tests of backfill materials and emplacement methods and a test of a full-scale plug. It is a test of the integrated function of the backfill material and the near-field rock in a deposition tunnel excavated by blasting. It is also a test of the hydraulic and mechanical functions of a plug. The test was partly a preparation for the Prototype Repository.

Objectives

The main objectives of the Backfill and Plug Test are to:

- Develop and test different materials and compaction techniques for backfilling of tunnels excavated by blasting.
- Test the function of the backfill and its interaction with the surrounding rock in full-scale in a tunnel excavated by blasting.
- Develop technique for building tunnel plugs and to test the function.

Experimental concept

The test region for the Backfill and Plug Test is located in the old part of the Zedex drift. Figure 5-3 shows a 3D visualisation of the experimental set-up. The test region, which is about 30 m long, is divided into the following three test parts:

- The inner part filled with a mixture of bentonite and crushed rock (six sections).
- The outer part filled with crushed rock and bentonite blocks and pellets at the roof (four sections).
- The concrete plug.

The backfill sections were applied layer wise and compacted with vibrating plates that were developed and built for this purpose. It was concluded from preparatory tests that inclined compaction should be used in the entire cross section from the floor to the roof and that the inclination should be about 35 degrees.

The inner test part is filled with a mixture of bentonite and crushed rock with a bentonite content of 30%. The composition is based on results from laboratory tests and field compaction tests. The outer part is filled with crushed rock with no bentonite additive. Since the crushed rock has no swelling potential, but may instead settle with time, a slot of a few decimetres was left between the backfill and the roof. The slot was filled with a row of highly compacted blocks, with 100% bentonite content, in order to ensure a good contact between the backfill and the rock. The remaining irregularities between these blocks and the roof were filled with bentonite pellets.

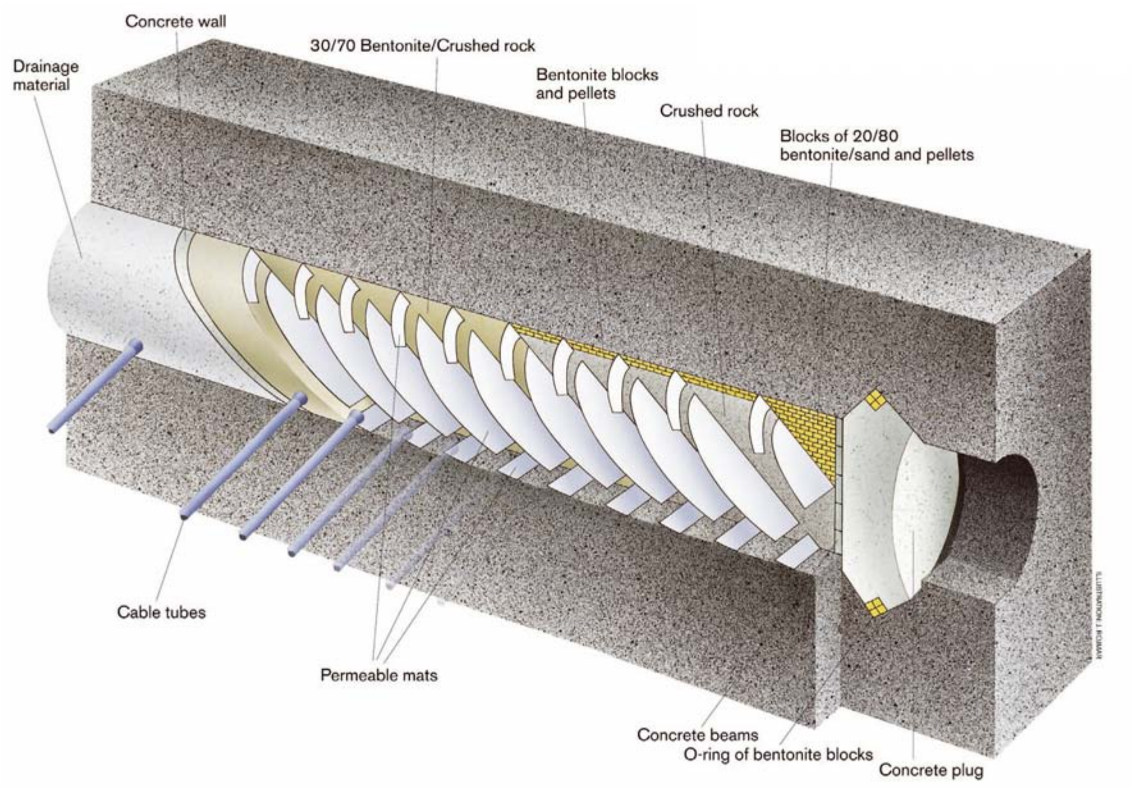

Figure 5-3 *Illustration of the experimental set-up of the Backfill and Plug Test.*

Each one of the two test parts are divided by drainage layers of permeable mats in order to apply hydraulic gradients between the layers and to study the flow of water in the backfill and near-field rock. The mats are also used for the water saturation of the backfill. The mats were installed in both test parts with the individual distance of 2.2 m. Each mat section was divided in three units in order to be able to separate the flow close to the roof from the flow close to the floor and also in order to separate the flow close to the rock surface from the flow in the central part of the backfill.

The outer test part ends with a wall made of prefabricated concrete beams for temporary support of the backfill before casting of the plug. Since *in situ* compaction of the backfill cannot be made in the upper corner, this triangle was instead filled with blocks of bentonite/sand mixture with 20% bentonite content.

The plug is designed to resist water and swelling pressures that can be developed. It is equipped with a filter on the inside and a 1.5 m deep triangular slot with an ”O-ring” of highly compacted bentonite blocks at the inner rock contact.

The backfill and rock are instrumented with piezometers, total pressure cells, thermocouples, moisture gauges, and gauges for measuring the local hydraulic conductivity. The axial conductivity of the backfill and the near-field rock is after water saturation tested by applying a water pressure gradient along the tunnel between the mats and measuring the water flow. All cables from the instruments are enclosed in Tecalan tubes in order to prevent leakage through the cables. The cables are led through the rock in boreholes drilled between the test tunnel and the neighbouring demonstration tunnel hosting the data collection room.

Present status

The entire test set-up with backfill, instrumentation and building 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 November 1999. Wetting of the backfill from the filter mats and the rock has continued during the years 2000 to 2003 and data from transducers has been collected and reported. In order to increase the rate of water saturation the water pressure in the mats was increased to 500 kPa at the turn of the year 2001/2002. At the end of 2002 the moisture measurements indicated that the entire backfill of both backfill types was completely water saturated and during 2003 preparations and rebuilding of the wetting system for adapting it to the flow testing were done.

During 2004 and 2005 the flow testing of the bentonite/crushed rock mixture has been running. Evaluation of the results shows that the field hydraulic conductivity is in the same range as expected from the laboratory tests. The results also show that the hydraulic conductivity is rather high close to the roof due to poor compaction and close to the floor, probably due to the blast disturbed zone in the rock. In late 2005 measurements of hydraulic conductivity in single points by pressurising filter equipped tubes and measure the water flow into the backfill started.

Scope of work for 2006

According to the time schedule, the Backfill and Plug Test was planned to be interrupted and the backfill excavated in autumn 2006. However, work prioritisation has entailed a proposal to postpone the excavation.

The following activities will be accomplished presuming that no excavation will take place during 2006:

- Continued measurements of hydraulic conductivity in single points.
- Start of mechanical testing of the compressibility of the backfill with the four pressure cylinders. Two of them are placed in the roof and two on the floor.
- Continued data collection and reporting of measured water pressure, water flow and total pressure.
- Maintenance of equipment and supervision of the test.
- Supplementary modelling of the flow testing and evaluation of results.
- Supplementary laboratory testing for modelling and understanding of the hydro-mechanical properties of the backfill materials.

5.5 Canister Retrieval Test

Background

The stepwise approach to safe disposal of spent nuclear fuel implies that if the evaluation of the deposition after the initial stage is not judged to give a satisfactory result the canisters may need to be retrieved and handled in another way. The evaluation can very well take place so long after deposition that the bentonite has swollen and applies a firm grip around the canister. The canister, however, is not designed with a mechanical strength that allows it to be just pulled out of the deposition hole. The canister has to be made free from the grip of the bentonite before it can be taken up.

The Canister Retrieval Test is aiming at demonstrating the readiness for recovering of emplaced canisters also after the time when the bentonite is fully saturated and has its maximum swelling pressure.

Objectives

The overall aim of the Canister Retrieval Test (CRT) is to demonstrate to specialists and to the public that retrieval of canisters is technically feasible during any phase of operation. The following was defined to fulfil the aim of the Canister Retrieval Test:

- Two vertically bored test holes in full repository scale, which fulfil the quality requirements deemed necessary for the real repository.
- Careful and documented characterisation of the properties of these holes including the boring disturbed zone.
- Emplacement of bentonite blocks, bentonite pellets and canisters with heaters, and artificial addition of water. However, only one of these deposition holes has been used for implementation of the Canister Retrieval Test.
- Saturation and swelling of the buffer are monitored under controlled conditions.
- Preparations for testing of canister retrieval.

Boring of full-scale deposition holes and geometrical/geotechnical characterisation of holes as well as emplacement of bentonite and canister with heaters were made within sub-projects that concern also other tests in the Äspö HRL. In addition to the retrieval test, the results from monitoring of the buffer and the laboratory testing of excavated parts of the buffer will be used to increase the understanding of the THM processes in a deposition hole.

Experimental concept

The Canister Retrieval Test is located in the main test area at the -420 m level. The tunnel is excavated by conventional drill and blast techniques and is 6 m wide and 6 m high. The test period is separated into three stages:

Stage I Boring of deposition holes and installation of instrumented bentonite blocks and canister with heaters in one hole. This hole is covered in the top with a lid of concrete and steel.

Stage II Saturation of the bentonite and evolution of the thermal regime with measurement of thermal, hydraulic and mechanical processes.

Stage III Test of freeing the canister from the bentonite, docking the gripping device to the canister lid and lifting of the canister up to the tunnel floor and into the radiation shield on the deposition machine (reversed deposition sequence).

The buffer was installed in the form of blocks of highly compacted Na-bentonite, with a full diameter of 1.65 m and a nominal height of 0.5 m. Instruments for measuring temperature, relative humidity, total pressure and pore pressure were installed in the bentonite in many of the blocks. When the stack of blocks was 6 m high the canister equipped with electrical heaters was lowered down in the centre. Cables to heaters, thermocouples in the rock and strain gauges in the rock were connected, and additional blocks were emplaced until the hole was filled up to 1 m from the tunnel floor. On top the hole was sealed with a plug made of concrete and a steel plate as cover. The plug was secured against heave caused by the swelling clay with 9 cables anchored to the rock. The tunnel will be left open for access and inspections of the plug support. The experimental set-up is shown in Figure 5-4.

Artificial addition of water is provided evenly around the bentonite blocks by means of permeable mats attached to the rock wall. The design of the mats was done so that they are not disturbing the future test of retrieval.

Predicted saturation time for the test is 2–3 years in the 350 mm thick buffer along the canister and 5–10 years in the buffer below and above the canister. Decision on when to start the retrieval tests is dependent on the degree of saturation in the buffer. The instrumentation in the buffer is similar to the instrumentation in the Prototype Repository and yield comparable information during the saturation period.

Based on the information regarding saturation of the buffer and the problems with the heaters it was decided that stage III (Retrieval of the canister) will take place in the beginning of January 2006.

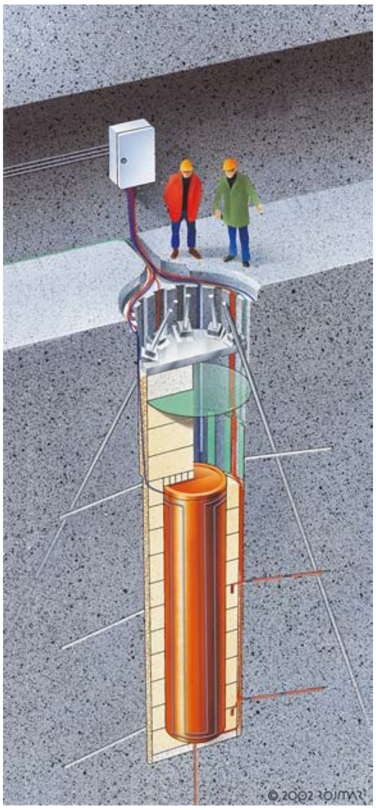

Figure 5-4 *Illustration of the experimental set-up of the Canister Retrieval Test.*

Present status

CRT Saturation Phase

The installation of the buffer material and the canister with instrumentation and heaters started mid September 2000 and was completed during October 2000 including the *in situ* casting of the concrete plug on top of the bentonite buffer. The heaters were turned on and the artificial watering of the buffer material started in October 2000. The test has thus been running for a little more than 5 years with continuous measurement of the wetting process, temperature, stresses and strains. The general conclusion is that the measuring systems and transducers seem to work well with exception of several relative humidity sensors that have failed due to water saturation and the sensors inside the canister, which all have failed. Data reports are produced twice a year.

In order to increase the rate of saturation, the water pressure in the mats was increased in steps to 800 kPa during the autumn 2002 and in order to reduce the risk of heater failure the power of the canister was reduced from 2600 to 2100 W in September 2002. Back flushing of the mats has been done in order to avoid clogging. In December 2003 the power was further reduced to 1600 W. During 2005 additional heater failure made it necessary to reduce the power to 1200 W in March. The excess water pressure was also closed. In order to reduce the temperature and prepare for the excavation and retrieval the power of the heaters were switched off in October.

The relative humidity sensors indicate that the bentonite between the rock and the canister is close to water saturation although the wetting seems to be somewhat uneven and the total pressure has not reached the expected values. Some clogging of the filters may explain the inhomogeneous appearance.

CRT Retrieval Phase

Due to the partial failure of the heaters, retrieval of the canister is planned to begin early 2006. The canister will be examined and the heaters analysed. The analysis will bring clarity to the problems causing the malfunction. This knowledge is vital to other projects experiencing the same issues with heater elements.

Scope of work for 2006

CRT Saturation Phase

Although the excavation and retrieval will start in January 2006, the data collection will continue until the transducers are brought up from the buffer. The measurements in the rock will continue until the entire retrieval is finished. A final data report will be issued in April. Modelling of the THM-processes will continue.

CRT Retrieval Phase

Retrieval of the canister will start in January 2006. The buffer will be manually excavated down to half the canister height. This allows buffer samples to be analysed. Both bentonite chemistry and biology will be analysed. The remaining buffer will be disintegrated and pumped out of the deposit hole freeing the canister. Once lifted the canister will be analysed in order to document effects from the deposit period. The field activities will be finished in the first half of 2006. The analysis of the buffer material is expected to be done at the end of 2006.

Analysis of the heaters will start with a gas test from the canister as soon as the canister lid is reached during buffer excavation. This is expected to be done during the first quarter of 2006. The power cables will also be tested as soon as possible. Further heater investigation will be done when the canister is retrieved from the deposition hole.

5.6 Temperature Buffer Test

Background

The aim of the Temperature Buffer Test (TBT) is to evaluate the benefits of extending the current understanding of the behaviour of bentonite buffer to include high temperatures (above 100°C). The French organisation Andra is running the test in Äspö HRL in co-operation with SKB.

The scientific background to the project relies on results from large-scale field tests on engineered barrier systems carried out in underground laboratories: the Buffer Mass Test (Stripa), the Buffer/Container Experiment (URL in Canada), Febex (Grimsel Test Site), Canister Retrieval Test and Prototype Repository (Äspö HRL).

Objectives

The Temperature Buffer Test aims at improving the current understanding of the thermo-hydro-mechanical behaviour of clay buffers at temperatures around and above 100°C during the water saturation transient, in order to be able to model this behaviour.

Experimental concept

TBT is located in the same test area as the Canister Retrieval Test (CRT) at the -420 m level. Two identical heater probes, each 3 m long and 0.6 m in diameter, are stacked in a vertical 1.8 m diameter deposition hole. The principle design of the test and the experimental set-up are shown in Figure 5-5.

Two buffer arrangements are being investigated:

- One probe is surrounded by bentonite in the usual way, allowing the temperature of the bentonite to exceed 100°C locally.
- The other probe has a ring of sand between the probe and the bentonite, as thermal protection for the bentonite, the temperature of which is kept below 100°C.

The principle of the TBT test is to observe, understand and model the behaviour of the deposition hole components, starting from an initial unsaturated state under thermal transient and ending with a final saturated state with a stable heat gradient.

Heat transfer comes into play from the start of the test, possibly redistributing water being present in the buffers, with partial desaturation of very hot zones (>100°C). Inflow of water then causes saturation and consequent swelling of the bentonite.

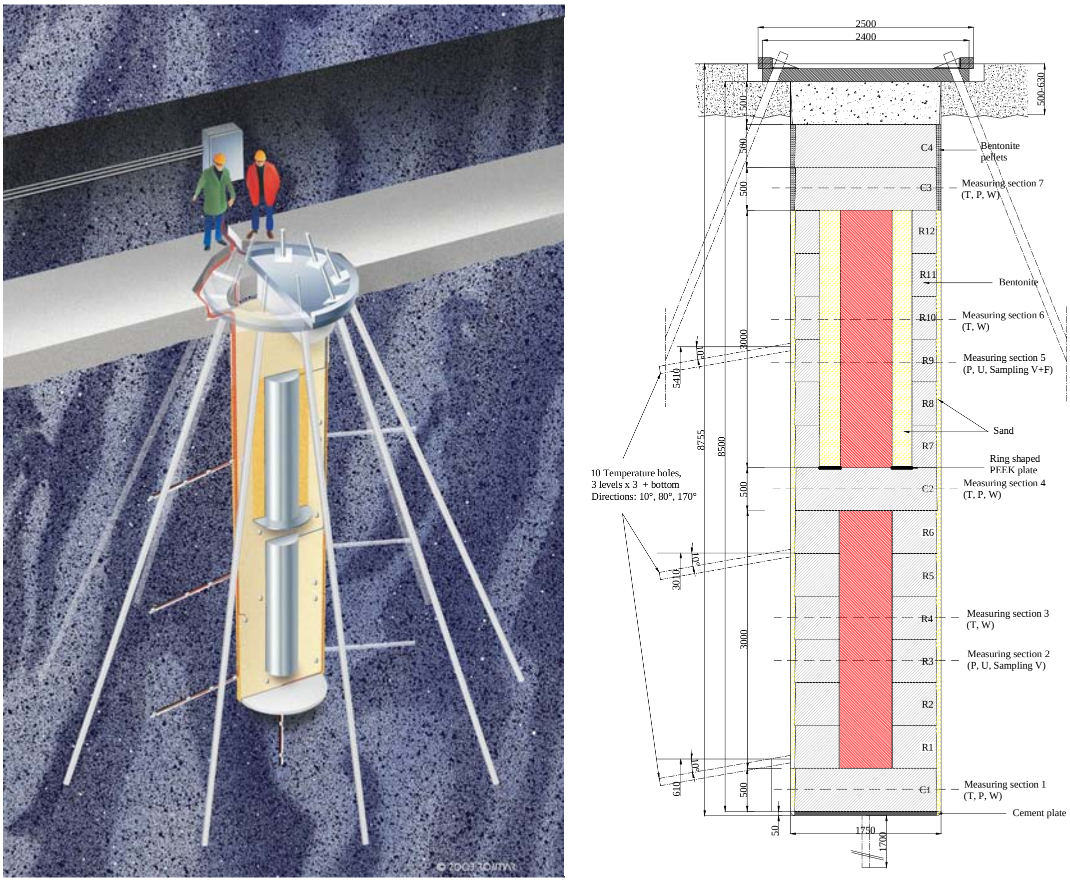

Figure 5-5 *Principle design and experimental set-up of the Temperature Buffer Test.*

The effects of a bentonite desaturation/resaturation cycle on the confinement properties are not well known. An open question which TBT is designed to answer is whether the mechanical effects of desaturation (cracking of the material) are reversible.

The similar geometries of CRT and TBT, the similar artificial water saturation systems, and the use of MX-80 bentonite buffer will facilitate interpretation of data and comparisons of results.

Present status

During 2002, TBT design modelling, procurement of instruments, fabrication of bentonite blocks were carried out by Clay Technology and heater probes built by Aitemin. Early 2003, the experiment was installed in Äspö HRL. The operation phase started late March 2003. Artificial water pressure and heater power have been set according to plan. The initial thermal shock has produced its effect showing local desaturation of the bentonite in place where temperature exceeded 100°C. No fluid pressure was measured in the sand of the composite buffer. Monitoring and sampling of experimental data are continuously ongoing. The data link from Äspö to Andra's head office in France has been functioning well.

A modelling group, formed with Swedish, Spanish and French teams, issued a preliminary predictive modelling report mid 2003. The predictions were compared with the first experimental results and presented in November 2003 at Sitges /Hökmark 2003/.

Two modelling tasks were conducted during 2004. The first one was predictive, and addressed the effect of increasing the output from the upper heater. From the results it was decided not to change the heat load. The second one emphasised on the evaluation of the development of stresses in Ring 9 and 10 around the upper heater. A predictive modelling task was conducted during 2005. This concentrated on a mock-up test, conducted by CEA, designed to mimic the conditions at the interior of the buffer around the lower heater. The aim of the task was to determine the relationship between temperature gradients and levels on one hand, and extent of desaturation on the other.

Scope of work for 2006

The operation phase continues and the experiment should be left without changes in boundary conditions in order to be reasonably confident about the conditions in the barriers at the time of dismantling and final interpretation.

Two modelling tasks are planned to be initiated during 2006:

- *Predictive modelling of mock-up test*. This task will be similar to the previous one, with simultaneous blind predictive modelling and experimental work. This test will follow a simpler and more efficient thermal protocol. The experimental setup will also be improved. An aim of this exercise is that it will provide input data to the following task.
- *Field-test modelling task*. The current ambition is that this will encompass both a reproduction of the evolution up to the present state, as well as a prediction of the time-scales to reach full saturation in the buffer.

The final evaluation of the test will to a significant extent be based on the outcome from the future dismantling. Relevant issues to be decided upon in the planning of the dismantling are: (1) objectives, (2) target end-states and (3) target time-frames for dismantling. Suggestions for the first two points will be compiled and evaluated during 2006. The current ambition is that the last point will rely on the outcome of the field-test modelling task, mentioned above.

5.7 KBS-3 Method with Horizontal Emplacement

Background

The KBS-3 method based on the multi-barrier principle is accepted by the Swedish authorities and the government as base for the planning of the final disposal of the spent nuclear fuel. The possibility to modify the reference method and make serial deposition of canisters in long horizontal holes (KBS-3H) instead of vertical emplacement of single canisters in the deposition hole (KBS-3V), see Figure 5-6, has been considered since early nineties. The deposition process requires that each copper canister and its buffer material are assembled into a prefabricated so-called Super container.

Most of the positive effects of a repository based on horizontal emplacement are related to the smaller volume of excavated rock. Examples of positive effects are:

- Less environmental impact during construction.
- Reduced impact on the groundwater situation in the bedrock during construction and operation.
- Reduced cost for construction and backfilling of the repository compared to KBS-3V. However, great efforts are required developing the KBS-3H concept.

Late 2001 SKB published an R&D programme for the KBS-3 method with horizontal emplacement. The RD&D programme /SKB, 2001/ is divided into four parts: Feasibility study, Basic design, Demonstration of the concept at Äspö HRL and Evaluation. The RD&D programme is carried through by SKB in co-operation with Posiva.

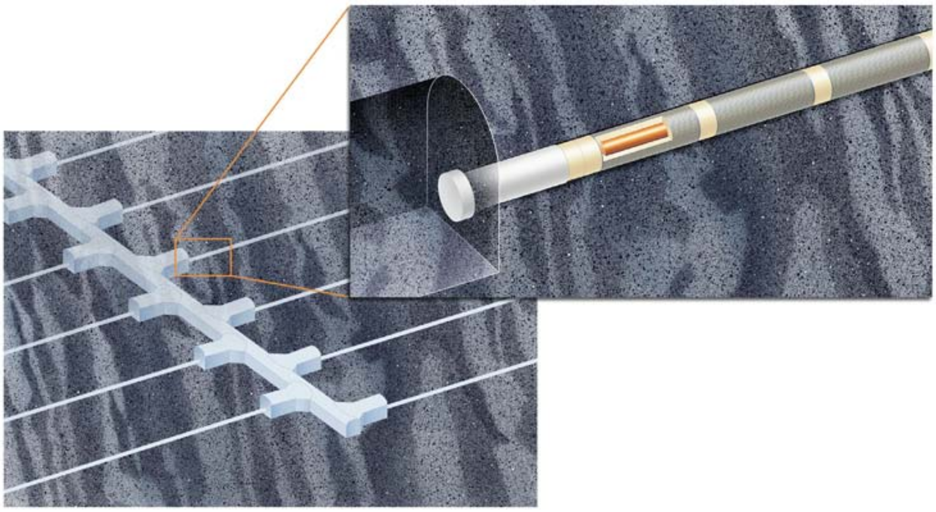

Figure 5-6 *Schematic illustrations of KBS-3H.*

Objectives

The objective of the first part of the project, the Feasibility study, was to evaluate whether horizontal emplacement is a realistic alternative, and if so, to give SKB and Posiva a basis for continued evaluation of KBS-3H. The feasibility study focused on differences compared to the reference concept KBS-3V. Highlighted tasks were excavation of the drifts, the deposition technique and the function of the buffer.

The second step, the Basic design study /Thorsager and Lindgren 2004/, focuses on technology for excavation of holes, emplacement of super containers, but also the design of the bentonite buffer inside the super container. In addition, an evaluation of the long term safety of the concept is carried out.

Demonstration site

A need for a demonstration of the KBS-3H concept was foreseen in the KBS-3H feasibility study and it was decided to investigate a suitable location and prepare a site at Äspö HRL. The demonstration site is located at the –220 m level in a niche, 15 times 25 meters. The niche is designed to accommodate vehicles, machinery and auxiliary equipment for drilling of the holes. Two horizontal holes with a diameter of 1.85 m have been excavated, one hole is 15 m long and the other is 95 m. The short hole will be used for construction and testing e.g. of a low-pH shotcrete plug and other design components, and the long hole will primarily be used for demonstration of the deposition equipment but also for evaluation of the chosen excavation method.

Present status

During 2005 work has been focused on the following parts:

- Excavation of the long hole for the full scale demonstration of the deposition equipment.
- Assembly of two Super containers.
- Design and manufacturing of the deposition equipment.
- Continued research regarding buffer design and design of the different components in the hole.
- Resolving of critical issues related to the long term safety of the concept and modelling.

Scope of work for 2006

The KBS-3H project will continue with the following main activities:

- Demonstration of the KBS-3H concept at the Äspö HRL.
- Design of repository layout and geological adaptation of the KBS-3H concept.
- Safety case.

Demonstration at the Äspö HRL

Year 2006 will start with the pressure test of the low-pH shotcrete plug in February/March. The Factory Acceptance Test (FAT) of the deposition equipment will be performed in CNIM's workshop in Toulon, France. The delivery of the equipment is expected in March and the Site Acceptance Test (SAT) shall be finished in April. After SAT is executed and verified, a one year test period of deposition machine and Super containers will be performed.

Design work

Different important components as steel plug, Mega Packer, etc. will be designed, manufactured and tested in the 15 m long hole at the -220 m level at Äspö.

The buffer design will continue during year 2006 with a number of experiments in different scales. The objective is to further verify the limitations of the system with respect to water inflow and pressure increase rate but also to give input to the design of the so called fixing ring which is a necessary part of the tight distance block design.

In order to evaluate the feasibility of the KBS-3H concept, an Olkiluoto specific layout adaptation will be carried out to assess the site utilisation degree of the concept and to provide basis for a safety assessment.

A feasibility study of the retrievability of the KBS-3H concept will be performed till end 2006.

Safety Case

Preparations for the KBS-3H Safety Case will continue with completion of a Process and Evolution as well as a Safety Case plan report. Work to resolve the critical issues highlighted in the review of the preliminary safety assessment will continue.

The report on the experimental study on the interaction between corroding iron under anaerobic conditions and bentonite will be finalised in early 2006.

5.8 Large Scale Gas Injection Test

Background

The bentonite buffer is an important barrier in the KBS-3 system. A key purpose of the buffer is to serve as a diffusion barrier between the canister and the groundwater in the rock. An important performance requirement on the buffer material is to not cause any harm to the other barriers. Gas build up from corrosion of the iron insert could potentially affect the buffer performance in three ways:

- Permanent pathways in the buffer could form at gas breakthrough. This could potentially lead to a loss of the diffusion barrier.
- If the buffer does not let the gas through, the pressure could lead to mechanical damage of the other barriers.
- The gas could de-hydrate the buffer.

Current knowledge pertaining to the movement of gas in initially saturated buffer bentonite is based on small-scale laboratory studies. While significant improvements in our understanding of the gas-buffer system have taken place, recent laboratory work has highlighted a number of uncertainties, notably the sensitivity of the gas migration process to experimental boundary conditions and possible scale-dependency of the measured responses. These issues are best addressed by undertaking large scale gas injection tests.

Objectives

The aim of the Large Scale Gas Injection Test (Lasgit) is to perform a gas injection test in a full-scale KBS-3 deposition hole. The objective of this experimental programme is to provide data to improve process understanding and test/validate modelling approaches which might be used in performance assessment. Specific objectives are:

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

The Lasgit project will end after two years of gas testing. At that stage a decision will be taken whether to dismantle the experiment or to continue with testing in a new project.

Experimental concept

Lasgit is a full-scale demonstration project conducted in the assembly hall area in Äspö HRL at a depth of -420 m. A deposition hole, 8.5m deep and 1.8m in diameter, has been drilled in to the gallery floor. A full-scale KBS-3 canister (without heater) has been emplaced in the hole. Thirteen circular filters of varying dimensions are located on the surface of the canister to provide point sources for the injection of gas to mimic canister defects. Pre-compacted bentonite blocks with a high initial water saturation have been installed in the deposition hole. The hole has been capped by a conical concrete plug retained by a reinforced steel lid capable of withstanding over 5000 tonnes of force (Figure 5-7).

In the field laboratory instruments continually monitor variations in the relative humidity of the clay, the total stress and porewater pressure at the borehole wall, the temperature, any upward displacement of the lid and the restraining forces on the rock anchors. The experiment is a "mock-up test" which does not use any radioactive materials.

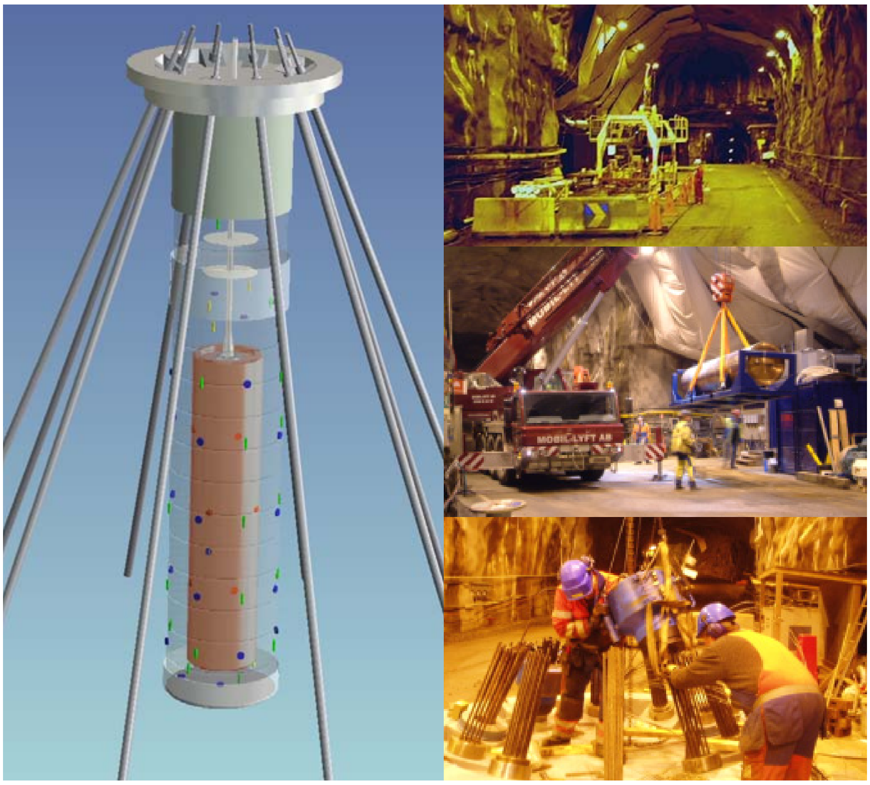

Figure 5-7 *Layout of the Lasgit experiment showing the copper canister, the bentonite buffer, the location of some of the instrumentation, the plug and rock anchors. From top to bottom the photographs on the right-hand side show the Assembly Hall area, the movement of the copper canister prior to installation and the pre-tensioning of the steel lid.*

The *installation phase* consists of the design, construction and emplacement of the experiment and it includes mainly:

- Characterisation of the deposition hole, hydraulic measurements and instrumentation of the wall.
- Development of a technique for the manufacturing of buffer blocks with exceptional high water content. Manufacturing of a set of blocks. Preliminary modelling of the hydration of the buffer.
- Preparation of a full-scale canister with gas injection equipment. Design and construction of a lid, which will seal the deposition hole and simulate the tunnel backfill.
- Design and construction of a gas injection and measurement field laboratory. Installation and testing of the equipment before deposition of the canister.
- Installation of canister, buffer, lid, and sealing of the deposition hole.

The aim of the *hydration phase* is to fully saturate and equilibrate the buffer. This will be done by:

- Water uptake from natural groundwater in the deposition hole.
- Artificial saturation by water injection through the gas injection ports mounted on the surface of the canister.
- Artificial saturation by water injection through mats located at a number of positions within the buffer and around the walls of the emplacement borehole.

The saturation will be monitored by measuring pore pressure, total pressure and suction at both the buffer/rock interface and key locations within individual clay blocks.

The hydration phase will provide an additional set of data for (T)HM modelling of water uptake in a bentonite buffer. However, no such modelling is planned within the project at this stage.

The *gas injection phase* will start when the buffer is considered to be fully saturated. A series of detailed gas injection histories will be performed examining the processes and mechanisms governing gas flow in bentonite.

Present status

The Lasgit deposition hole was closed on 1st February 2005 signifying the start of the hydration phase. Groundwater inflow through a number of conductive discrete fractures resulted in elevated porewater pressures. This problem was addressed by drilling two pressure-relief holes in the surrounding rock mass. The artificial wetting of the buffer from the top and through the injection filters in the canister began on 18th May 2005 after 106 days of testing.

The monitored porewater pressures within the clay remain low, ranging from 15 kPa to 130 kPa. This is in contrast to the water pressure measured at the face of the deposition hole which ranges from 85 kPa to 600 kPa. Monitored radial stress around the clay continues to increase steadily ranging in value from 910 kPa to 2640 kPa, with an average value of 1935 kPa. The axial stress within the clay ranges from 2710 kPa to 3450 kPa (excluding sensor PB901). The axial stress is non-uniformly distributed across the major axis of the emplacement hole and generally exhibits only minor sensitivity to changes in porewater pressure. The axial force acting on the steel lid has reduced since the deposition hole was closed. The continuum axial swelling pressure within the bentonite is now greater than the initial pre-stress applied by the lid. The slight reduction in force during the latter stages of the test can be explained by convexing deformation of the steel lid in response to the uneven distribution in axial stress.

Since closure of the deposition hole there have been no instrumentation failures. The Lasgit experiment continues to yield data of the highest quality amenable to the development and validation of process models aimed at repository performance assessment.

Scope of work for 2006

Activities during 2006 will primarily focus on the monitoring and interpretation of the hydration phase of the experiment which is likely to continue for a number of years while the clay hydrates and swells, closing any engineered voids. Detailed analysis of the data will be used to guide future experimental activities, in particular, the artificial hydration of the clay.

In addition to this core function, a software revision to the main data acquisition code will also be performed to include a number of new pressure transducers which will be used to continuously monitor the evolution of porewater pressure within the rock mass adjacent to the Lasgit deposition hole. Processed data from the Lasgit experiment will be regularly uploaded to a secure member’s web site for access by the project partners.

5.9 In Situ Corrosion Testing of Miniature Canisters

Background

The evolution inside a copper canister with a cast iron insert after failure is of great importance for the release of radionuclides from the canister. After failure of the outer copper shell, the course of the subsequent corrosion in the gap between the copper shell and the cast iron insert will determine the possible scenarios for radionuclide release from the canister. This has been studied experimentally and been modelled. The corrosion will take place under reducing, oxygen free conditions and such conditions are very difficult to create and maintain for longer periods of time in the laboratory. *In situ* experiments at Äspö HRL would be invaluable for understanding the development inside the canister after initial penetration of the outer copper shell.

Objectives

The objective of the project is to obtain a better understanding of the corrosion processes inside a failed canister. The results of the experiment will be used to support process descriptions and safety analyses.

Experimental concept

Miniature copper canisters, with a diameter of 150 mm, will be emplaced in boreholes, with a diameter of 300 mm. The canisters will be exposed to natural reducing groundwater during several years and the experiment will be monitored.

Present status

The planning of the project was finalised during 2004 and the components of the miniature canisters have been designed and manufactured. The components are currently being prepared for electron beam welding. The support cages to hold the model canisters have been designed and the first one is being manufactured. Long-term durability testing of the sensors is in progress and the sensors chosen have performed satisfactorily. The customised electrochemical monitoring kit is being manufactured. Five 76 mm holes 5 m deep have been drilled and these holes have been reamed to 350 mm down to a depth of 2.5 m, see Figure 5-8. Five casings have been installed and grouted in the right rock wall in the niche NASA 3384 A.

Scope of work for 2006

In the niche, the rock volume behind the right wall will be grouted to a depth of 1 m in order to get a higher groundwater pressure in the boreholes. The experiment will be installed and initiated during this year. The activities comprise e.g. reaming of the last part of the boreholes to 302 mm, emplacement of support cages with canisters and installation of instrumentation. The first phase of the experiment is planned to run during five years.

Figure 5-8 *One of the five drilled boreholes in the niche.*

5.10 Cleaning and Sealing of Investigation Boreholes Background

Investigation boreholes are drilled during site investigations and detailed characterised in order to obtain data on the properties of the rock. These boreholes must be sealed, no later than at the closure of the final repository, so that they do not constitute flow-paths from repository depth to the biosphere. Sealing of the borehole aims at receiving a conductivity in the borehole that is no higher than that of the surrounding rock. Cleaning of the boreholes means that instrumentation that has been used in the boreholes during long time-periods, in a sometimes aggressive environment, is removed.

Sealing of boreholes with cementitious materials is commonly used in construction work and can be performed with well-known techniques. Earlier studies, e.g. the Stripa project, have shown that sealing with cementitious material include a potential risk for degradation due to leaching and the sealing can not be guaranteed over time-periods longer than hundreds of years. Another opportunity is to use swelling clay materials, such as compacted bentonite blocks or bentonite pellets. Sealing with bentonite blocks has been tested in the framework of the Stripa project, in boreholes with a length of 200 m, with very promising results. A further development of this technique is, however, required to show that boreholes with lengths of up to 1,000 m can be sealed. Since most of the investigation boreholes are instrumented, reliable technique is also needed to clean boreholes so that they can be sealed.

Objectives

The main objective of this project is to identify and to demonstrate the best available techniques for cleaning and sealing of investigation boreholes. The project comprises three phases. Phase 1, mainly an inventory of available techniques, was finalised in

2003. Phase 2 aims to develop a complete cleaning and sealing concept "Basic concept". In phase 3, the techniques and handling will be tested and demonstrated in full scale. The work is divided in the four sub-projects described below.

Sub-project 1

This sub-project comprises the engineering of design solutions of borehole plugs of clay and cement, respectively. The development of design of the basic sealing concept, with highly compacted clay in perforated tubes primarily intended for use in boreholes longer than 100 m, comprises the following steps:

- Theoretical modelling of the hydration and maturation of clay components in perforated tubes, taking perforation geometry and clay density as main variables.
- Definition of most suitable density and water content of clay components according to the modelling.
- Lab and small-scale field testing of erodability of clay components in perforated tubes (Figure 5-9).
- Lab testing of the maturation rate for assessment of the theoretical model using different water salinities and perforation geometries.
- Manufacturing of clay components for plugging of short and long holes.
- Investigation and pretesting of alternative methods for plugging short holes by use of clay.

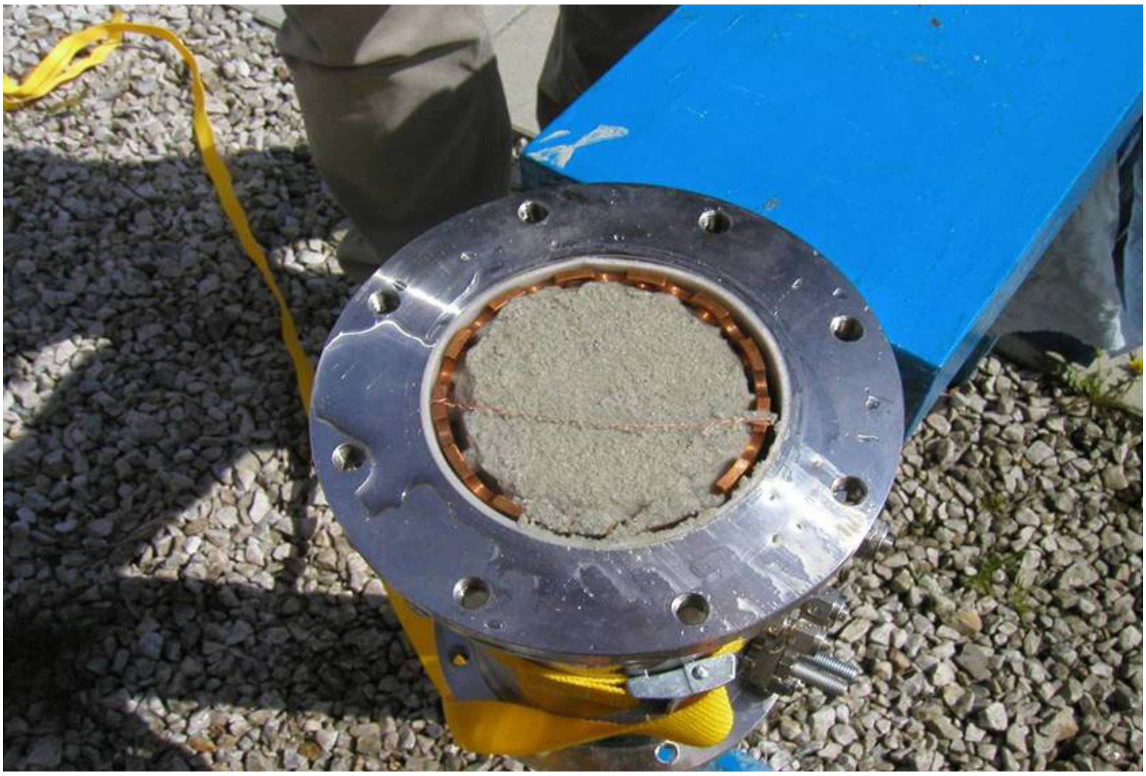

Figure 5-9 *Lab and small-scale field testing of erodability of clay components in perforated tubes*

Sub-project 2

This sub-project will comprise plugging and testing of eight 5 m deep, 76-80 mm diameter boreholes at Äspö. While the basic clay plug concept for sealing longer holes than about 100 m implies use of perforated copper tubes with tightly fitting cylindrical blocks of highly compacted smectite-rich clay, simpler techniques are estimated to be applicable in shorter boreholes, especially in holes drilled from repository rooms within the near-field. Some of these techniques will be tested, taking the following issues into consideration:

- Practicality - This includes assessment of how doable the plugs are, estimation of the need for rigs and tools for placement and possible retrieval, and required forces for bringing the plugs into and out from the holes. Also, the techniques and costs of manufacturing, transporting and storing of the plug components must be estimated.
- Possibility to plug graded horizontal and upward-directed holes.
- Risk of failure in placement and retrieval of plugs by breakage and loss of clay and other components or problems related to too quick maturation of the clay.

Sub-project 3

This sub-project comprises preparation, stabilisation and installation of plugs in the 76 mm wide core hole OL-KR24 at Olkiluoto. The major issues are:

- Demonstration of the feasibility of the basic plugging method, i.e. placement of segments of jointed units of perforated copper tubes filled with highly compacted Na-bentonite columns (the basic concept).
- Demonstration of the feasibility of filling parts of the borehole that intersect fracture zones with chemically stable quartz-based fill.
- Demonstration and evaluation of a technique to bring down a dummy for checking the clearance of a real plug segment before installing it.
- Demonstration of the accuracy of replacing natural water in the hole by tap water.

Sub-project 4

The aim of this sub-project is to test the feasibility of three candidate techniques intended for mechanical securing of the tight seals emplaced lower in deep boreholes as outlined in the main Borehole Plugging Report.

This sub-project comprises plugging and testing of four 1.5 m long, 200 mm diameter boreholes at Äspö. The boreholes are located within the same area as the 5 m long holes at Äspö. The 200 mm holes are planned to be used for simulating sealing of the upper ends of deep boreholes.

Present status

Work on the respective sub-projects has been going on since September 2003, a brief summary being as follows:

Sub-project 1 - A report “Theoretical study of water saturation and homogenisation of borehole plugs” has been completed by Clay Technology. It has been taken as a basis for selecting the geometry of the perforation of the copper tubes used in the various plugging tests. A separate report has been completed by Clay Technology for selecting a suitable density and way of manufacturing clay columns for the various plugging tests.

Sub-project 2 - Preliminary structural modelling of the 5 m holes has been made for selecting suitable holes for plugging and pressuring in the pair-wise arranged holes. Hydraulic characterisation has started (inflow tests) and will continue during coming months.

Sub-project 3 - Most of the performed work concerns the deep hole OL-KR-24 at Olkiluoto. The work has comprised:

- Borehole and core inspection for identifying sections that needs to be stabilized.
- Development of stabilization techniques for deep boreholes.
- Identification of suitable recipe for the grout used in the stabilization work.
- Identification of suitable recipe for plugging stabilized sections with mixtures of low pH cement and quartz filler.
- Development of design of perforated tubes of different materials and different safety factors.
- Preparation of perforated copper tubes for 76 mm holes by reducing the dimensions of standard 80 mm tubes.
- Development and manufacturing of techniques and tools for placing clay plugs in deep holes.
- Placement of plug comprising of cement/quartz (top and bottom) and clay (middle) at the -520 m level in borehole OL-KR24.

Parts of the hole, which goes through fractured rock, were stabilised by the SKB-developed method, so that the plugs could safely pass these parts of the hole. These activities at Olkiluoto were finalised in the end of 2005. After excavation of the ramp down to level -520 m, which is expected to be completed in 2009, a room or niche reaching to the borehole will be excavated. At this level the plug, which comprises of cement/quartz (bottom and top) and clay (middle), may be sampled. The upper part of the borehole was filled with ordinary cement.

Sub-project 4 - Preliminary plans have been worked out for plugging of wide holes, represented by 1.9 m deep holes with 200 mm diameter. Based on the preliminary investigations the following three techniques will be tried:

- The Basic Concept in terms of on-site casting of a plug consisting of cement-stabilized quartz fill mixed with quartzite fragments with up to 30 mm size.
- The Rock Lock Concept implying construction of rock elements that are brought into local reamed parts of the hole to form a rigid block system.
- The Metal Plug Concept implying casting of molten metal in the hole.

Scope of work for 2006

The aim is to proceed with the work according to the general R&D plan implying the following activities:

Sub-project 1 - Design and modelling of the performance of borehole plugs. Laboratory work for determining the evolution of the clay plugs with respect to the density distribution, swelling pressure on the rock, and the rate of maturation as well as the erosion caused by flowing water. In addition, modelling of the maturation process will be made.

Sub-project 2 - Preparation and conduction of testing four different plugging techniques in 5 m holes at Äspö. The preparation includes (a) hydraulic characterisation of the holes and, based on it, theoretical prediction of the maturation process; (b) performance of field tests for evaluating the actual maturation rate expressed as the increase in resistance to piping with time and determination of the adhesion of the clay plug to the rock by extrusion, (c) laboratory analysis of the dissected samples after completion of the field tests and (d) investigation of the possibility to plug steep long holes at Äspö and making preliminary test plans if suitable holes can be identified.

Sub-project 3 - Continued evaluation of all stages in plugging Posiva's borehole OL-KR-24 including predictions of the maturation of the cement/quartz plugs and the clay plug under actual conditions. In addition, an outline of the test programme for testing the plugs after extraction will be prepared.

Sub-project 4 - Initiation of plugging tests in three or four 1.9 m holes with 200 mm diameter at Äspö by working out detailed test programs and making predictions of the evolution of the plugs and their interaction with the rock.

5.11 Alternative Buffer Materials

Background

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS-3 concept the demands on the bentonite buffer are to serve as a mechanical support for the canister, reduce the effects on the canister of a possible rock displacement and minimise water flow over the deposition holes. The MX-80 bentonite from American Colloid Co (Wyoming) has so far been used by SKB as a reference material. A large scale programme to study the use of possible alternative buffer material has been initiated, mainly to correlate the physical and chemical properties to fundamental mineralogical properties.

A number of commercial bentonites, from large producers, have been investigated with respect to mineralogy and swelling properties. So far the investigations have been done on the reference material MX-80, four samples from India (Ashapura) and one sample from Greece (Silver and Baryte). This project aims at studying the long term stability of bentonites and the influence by the accessory minerals in the materials.

Objectives

The project will be carried out using material that according to laboratory studies are conceivable buffer materials. The experiment will be carried out in the same way and scale as the LOT experiment at Äspö HRL. The project objectives are to:

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

Experimental concept

The testing principle is just as in the LOT experiment, see Section 4.3. Parcels containing heater, central tube, pre-compacted clay buffer, instruments and parameter controlling equipment will be emplaced in vertical boreholes with a diameter of 300 mm and a depth of around 4 m.

In addition to the deposited bentonite blocks in the parcels, identical bentonite blocks will be stored to monitor the effects of storage.

The final experiment design is not completed. The layout of the parcels regarding bentonite type as well as the conditions of the experiment regarding temperature, artificial water saturation etc. are also to be decided.

Present status

The project has been initiated and several partners to SKB are invited to participate. Initial planning and preparatory work have been done.

Scope of work for 2006

All field activities related to the emplacement stage of the project will be carried out during 2006 according to the project time schedule. This work includes final experiment design, preparation of the test site, manufacturing of the clay blocks, assembly of the experiment parcels and emplacement of parcels. Finally, the boreholes will be sealed and the heaters started.

5.12 Rock Shear Experiment

Background

Rock displacement is one out of a few processes, which can seriously damage a canister, and constitutes thereby a threat against the integrity of a final repository. The effect of the process is thus of importance to analyse and describe in an accurate way.

Fractures and fracture systems are natural components in granitic rock, and can not be avoided totally in the repository areas. Deposition holes will be bored through such features and the issue for the final decision on accepting or rejecting a bored deposition hole will among other things be based on the properties of the fractures the deposition hole is crossing. One of these properties is the possible displacement along the fracture caused by seismic events. The buffer in KBS-3 is assumed to protect the canister from loosing its integrity for instant displacements up to 100 mm. The forces on the canister at such a major displacement have been modelled as well as analysed based on experiments in laboratory scale (up to 1:10 scale). The results are, however, proposed to be verified in larger scale than 1:10, if a significantly more accurate criterion shall be feasible to apply in the accepting/rejecting process.

Objectives

The project aims at observing the forces that act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole at canister height. Such a displacement is considered to be caused by an earthquake, and the test set-up needs to provide a shearing motion along the fracture that is equal to an expected shearing motion.

Experimental concept

The test set-up is planned to use the site of the Äspö Pillar Stability Experiment since the rock mechanics test there has been completed. Two full scale deposition holes thus exist with a rock pillar of one metre in between. Figure 5-10 illustrates the present, schematic idea for a test set-up. The left deposition hole is used for the buffer and canister, while the right deposition hole is used for the shearing equipment. Half of the rock between the holes is removed (partly fractured after the pillar experiment) and replaced by a steel structure that has a plane for movements. Half of the upper part of the left hand hole is enlarged by sawing away about 200 mm in order to make room for the shear displacement. This upper part, which shall be sheared, is surrounded by a steel pipe, which is attached to the steel structure and is mobile in the direction of the shearing. The hole is plugged by a combined steel and concrete structure, which is anchored to the rock by a steel beam or by cable bolts as in Canister Retrieval Test and Temperature Buffer Test.

The shearing may not be done before the buffer has saturated. This time can, however, be reached after about two years by using highly saturated bentonite blocks, 95–98% saturation, and lining the hole with permeable mats for artificial water supply. Planned shearing speed is 0.1 m/s. For this shearing speed pistons may be used as shown in Figure 5-10.

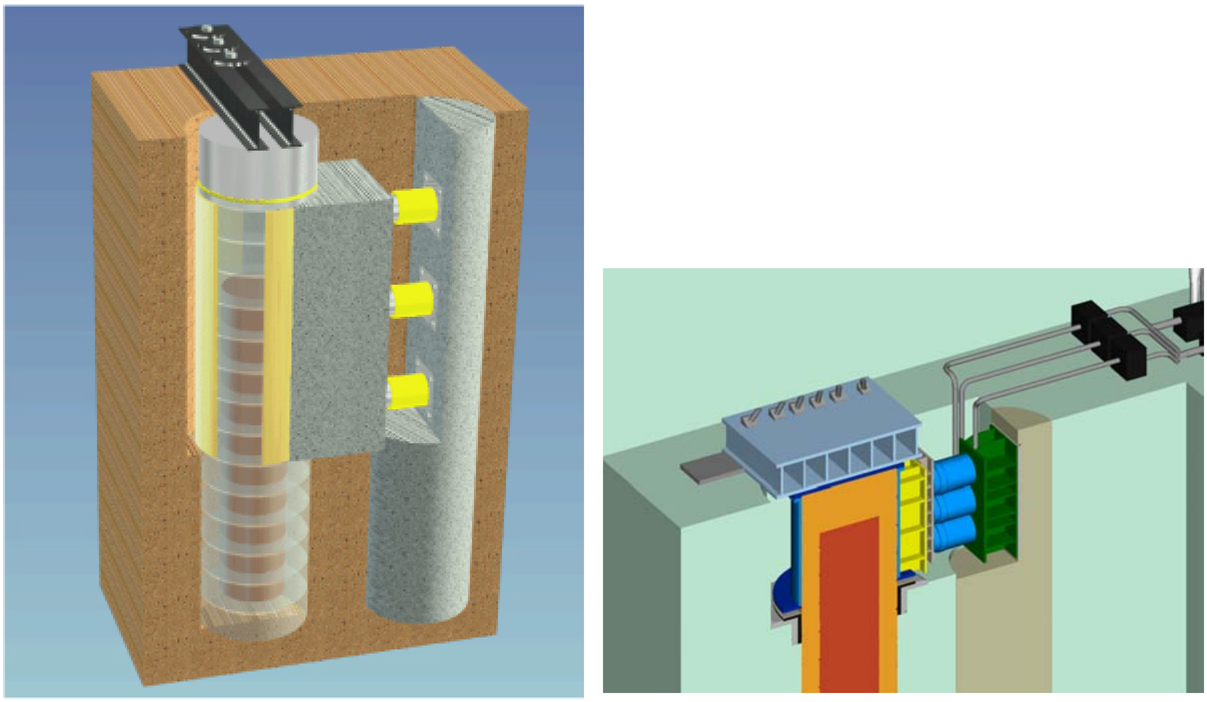

Figure 5-10 *Schematic view of a possible test set-up for verification of the stress and strain a canister may exhibit during an instant shearing of 100-200 mm.*

Present status

A feasibility study has been done and is reported. The main conclusion of the study is that the test is feasible. A preliminary decision to realize the plans has been taken but the time schedule is not yet set.

Scope of work for 2006

The work 2006 will mainly include planning of supplementary laboratory tests. The main test will not be started until later.

5.13 Earth Potentials

Background

A stray current is a current flowing via a path other than the intended circuit. Due to the resistance variations in the path, a potential difference can be measured between different locations. If this current intersects a conducting (metallic) object, the point on the structure at which the current enters will be cathodically protected and the point at which the current leaves the structure and re-enters the ground path will be anodically polarized. Based on the source of the current, stray currents can be classified as either man-made or Geomagnetically Induced Currents (GIC).

Man-made currents result from interference from either direct current (DC) or alternating current (AC) power cables. Direct currents could also occur in AC installations if the system is not grounded purportedly. Corrosion is most severe for DC and stray currents are less of a problem for AC installations. Geomagnetically induced currents arise from two sources, interaction of the earth’s magnetic field with solar particles emitted from the sun and voltage gradients induced at the earth/sea interface by tidal movement. The magnitudes of GIC due to solar particles (often referred to as telluric currents) are greatest in polar and sub-polar regions.

Objectives

The main objectives of the project are to identify the magnitude of potential fluctuations and stray currents for GIC and man-made stray current sources at repository depth and by that estimate the potential problems that could occur. The project will include the following investigations:

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

Present status

Simultaneous measurements of the surface electromagnetic field at a reference site located about 15 km from the main site at Äspö as well as surface and borehole measurements at Äspö have been made. The borehole measurements were made in the three boreholes HAS17, HAS18 and HAS09. In each borehole a $Pb-PbCl_2$ electrode was inserted as deep as possible in order to measure the potential differences between boreholes HAS17-HAS18 and HAS09-HAS18, respectively. All boreholes are about 120 m long, but the electrode in HAS18 reached down only 40 m along the borehole length, whereas the other two electrodes could be lowered to the bottom of the corresponding holes. The distances between electrode pairs in the boreholes are about 250 m.

In ongoing laboratory experiments the impact of copper ions on bentonite properties is studied. The aim of one experiment is to quantify swelling pressure and hydraulic conductivity of montmorillonite, which has been treated to contain only copper ions in exchange positions. The second experiment aims at qualitatively examine fixation of copper in the montmorillonite clay structure.

Another laboratory set up has started to study the interaction between copper and bentonite. The main purpose of that is not to study corrosion, but more the electric field distribution and the transient phenomena between copper and bentonite.

Scope of work for 2006

The laboratory studies will be finished during the year. All the results from the laboratory studies together with information from the field work will be summarised in a technical report in the end of the year.

5.14 Task Force on Engineered Barrier Systems

Background

The Task Force on Engineered Barrier Systems (EBS) was in 2000 decided to focus on the water saturation process in buffer, backfill and rock. Since the water saturation process also was a part of the modelling work in the Prototype Repository project, the work was transferred to the Prototype Repository project, and the Task Force was put on a stand-by position. As the European Commission funding of the Prototype Repository project ceased in February 2004 the Task Force on EBS was reactivated. A kick-off meeting was held in 2004 and two tasks were chosen for the Task Force work, namely:

Task 1: THM processes in buffer materials.

Task 2: Gas migration in buffer material.

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), OPG (Canada) and RAWRA (Czech Republic).

Present status

The Task Force on EBS has started with a first phase that comprises four years. This phase addresses two tasks, THM processes and gas migration in buffer material, and ends with a State-of-the-art report. The work will take into account the interaction between the buffer and backfill barriers and the host rock. Experimental data are in both tasks taken from small scale laboratory experiments as well as large scale field experiments, which will be selected by the Task Force in the course of the work.

Two benchmark tests for Task 1 (THM-processes) were delivered in spring 2005 and the modelling teams requested to simulate these laboratory tests and report the results at the Task Force meeting that was held in October. At this meeting the benchmark tests for Task 2 (gas migration) were presented.

A suggested EC project named Theresa was also presented. It consists of 6 work packages. The present Task Force on Engineered Barrier Systems is proposed to be included in WP4 - Coupled Processes in Buffer and Near-Rock Interfaces. Theresa will be concluded 2009.

Scope of work for 2006

The results of Task 1 benchmark tests will be analysed and the capability as well as the prerequisite for further development of the codes will be evaluated. A report that includes comments on the capability and potential of each participating code is planned to be issued during 2006.

The results of Task 2 benchmark tests are requested to be reported by the modelling teams at the next meeting that will be held in Äspö HRL on April 25-26.

6 Äspö facility

6.1 General

Important parts of the Äspö facility are the administration, operation, and maintenance of instruments as well as development of investigation methods. The Public Relations and Visitor Services group is responsible for presenting information about SKB and its facilities e.g. the Äspö HRL. They arrange visits to the facilities all year around as well as special events.

6.2 Facility operation

Background

The main goal for the operation is to provide a facility which is safe for everybody working in, or visiting it, and for the environment. This includes preventative and remedial maintenance in order to ensure that all systems such as drainage, electrical power, ventilation, alarm and communications are available in the underground laboratory at all times.

Present status

The plant supervision system has considerably increased the possibility of running the facility in a safe and economic way. The facility is well maintained and has a very high degree of operational time, 99% in 2005. The long term rock control and reinforcement programme has been continued to ensure safe and reliable rock conditions.

The facility is equipped with an operational and monitoring system and any alarms are sent to operational personnel who are prepared for emergency action even out of office hours. Operational and maintenance contracts have been set up with a number of contractors. A PC-based maintenance system has been implemented and the aim is that the system will facilitate the planning of maintenance of the facilities, vehicles and machinery.

The facility is equipped with fire and evacuation alarms both above and below ground. Each year fire-fighting and first-aid courses are organised for all the personnel. Investigations have been performed on how back up power could be supplied in order to secure the operation of the facility and its experiments during longer power cuts and to ensure operation of emergency systems for the emergency services during, for example, fires.

Extension of storage space and adaptation for the KBS-3H project has been made. An existing and unheated storage building at the tunnel entrance has been extended. The highest part of the storage building has been insulated and equipped with heating and ventilation. Two roof-windows have been installed to enable construction of Super containers for the KBS-3H project.

Scope of work for 2006

Work planned and goals for 2006 are summarised below:

- One of the main targets for a number of years has been to increase the reliability in the underground-related systems. The goal for 2006 is to provide an availability of 99%.
- Safety of the personnel is of main concern and safety-related education and fire fighting training will be held, and the long term rock control and reinforcement programme will be continued.
- In the RFID project, a method will be developed for the identification and registration of people and property in the facility in order to know their location in emergency situations. The system should also be capable of steering the ventilation in order to ensure a good working environment in an energy-efficient and economic way. The first phase of the project including acquisition and installation of equipment is completed. At present, testing and remediation of faults is in progress and the education of the users of system is planned to be completed the first quarter of 2006.
- The maintenance and service of equipment, installations, and vehicles shall be of high quality. A computerised system for the purchase of machines and vehicles is available in order to improve the documentation, follow-up, and effectivity of maintenance.
- The waste water treatment plant at Äspö is under-dimensioned. A pre-study will investigate and suggest the most suitable water treatment methods for the waste water from the offices and workshops. The work will be reported in 2006.
- A laboratory for testing of bentonite will be built, with start during the summer 2006.

6.3 Public Relations and Visitor Services

Background

SKB operates three facilities in the Oskarshamn municipality: Äspö HRL, Central interim storage facility for spent nuclear fuel (Clab) and Canister Laboratory. In 2002 SKB began site investigations including drilling of deep investigation boreholes at the sites Simpevarp/Laxemar and Forsmark.

The main goal for the Public Relations and Visitor Services group is to create public acceptance for SKB, which is done in co-operation with other departments at SKB. The goal will be achieved by presenting information about SKB, the Äspö HRL, and the SKB siting programme on surface and underground.

During the year 2005, the Äspö HRL and the site investigation activities were visited by about 10,500 visitors. The visitors represented the general public, municipalities where SKB perform site investigations, teachers, students, politicians, journalists and visitors from foreign countries.

The total number of visitors to all SKB facilities, Äspö HRL, Clab, Canister Laboratory and SFR was almost 26,000. The information group has a special booking team at Äspö HRL which books and administrates all visitors.

Planned special events for 2006

During the year 2006 the summer tours for the general public, called U500, will start in June and finish up in August. The goal is to reach 2,500 visitors this year. Several bus tours a day take visitors to the laboratory where they are given information about the ongoing research.

The annual event “The Äspö Day” is 2006 planned to take place on May 14. It is an open house where the visitors can visit the underground laboratory and also participate in tours on the surface. These tours provide information on e.g. geology, history and nature. In 2005 about 200 visitors came and the plan for 2006 is to increase the number of visitors.

In 2006 “The Geology Day” will be celebrated for the sixth time in Sweden. SKB is going to be host for the inauguration of the event. This will take place at Äspö on September 15. The county governor is invited as well as students and other interested people.

In addition, the Äspö running competition in the tunnel will take place on December 9. This has been a yearly event since seven years.

7 Environmental research

7.1 General

Äspö Environmental Research Foundation was founded 1996 on the initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its resources available for national and international environmental research. SKB's economic engagement in the foundation was concluded in 2003 and the activities are now concentrated to the Äspö Research School.

7.2 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.

Present status

The research activities 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 the University of Kalmar, the school receives funding from the city of Oskarshamn. There are currently a variety of research activities at sites outside Äspö HRL. These activities have during 2005 resulted in several scientific publications. In the Äspö HRL, however, the activities are as yet minor. In accordance with the agreement, the Äspö Research School was during autumn evaluated and the internal evaluation report was published in November.

The first Ph.D. dissertation took place in January 2005 after which the Ph. D. in June was appointed research assistant at the Äspö Research School. The research assistant works within several research projects and as assistant supervisor with special competence in urban geochemistry. In May 2005 a Ph.D. student was appointed focusing on hydro-chemistry whereas in September another Ph. D. student requested study intermission. By the end of 2005, the scientific team consisted of a professor of Environmental geology, a research assistant, four assistant supervisors and five Ph.D. students.

Scope of work for 2006

During 2006 the work within the Äspö Research School will continue. The aim for the year is to appoint more Ph.D. students. The final goal of in total ten Ph.D. students can hopefully be reached in the year 2007 if the planned research activities are appropriate and the finances are sufficient. In May 2006 the second Ph. D dissertation is planned to take place.

8 International co-operation

8.1 General

Nine organisations from eight countries will in addition to SKB participate in the co-operation at Äspö HRL during 2006. Six of them; Andra, BMWi, CRIEPI, JAEA, OPG and Posiva together with SKB form the Äspö International Joint Committee (IJC), which is responsible for the co-ordination of the experimental work arising from the international participation. The committee meets once every year. In conjunction with each IJC meeting a Technical Evaluation Forum (TEF) is held. TEF consists of scientific experts appointed by each participating organisation. For each experiment the Äspö HRL management establishes a peer review panel consisting of three to four Swedish or international experts in fields relevant to the experiment. Presentations of the organisations represented in the IJC are given below.

Most of the organisations participating in the Äspö HRL co-operation are interested in groundwater flow, radionuclide transport, rock characterisation and THMC modelling. Several of the organisations are participating in the two Äspö Task Forces on (a) Modelling of Groundwater Flow and Transport of Solutes and (b) THMC modelling of Engineered Barrier Systems. These specific technical groups, so called Task Forces, are another form of organising the international work. The 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, has been working since 1992. The Task Force on Engineered Barrier Systems, a forum for code development on THMC processes taking place in a bentonite buffer and gas migration through a buffer, has been on stand-by but was activated during 2004 and will be increasingly active and a prioritised area of work in coming years.

SKB also takes part in several international EC-projects and participates in work within the IAEA framework. During 2006 an IAEA training course on modelling will take place at Äspö HRL and IAEA-fellows will be hosted at Äspö HRL for a period during the year.

The international organisations are taking part in the projects, experiments and Task Forces described in Chapters 2, 3 and 4 (Geo-science, Natural barriers and Engineered barriers). The co-operation is based on separate agreements between SKB and the organisations in question. The participation by JAEA and CRIEPI is regulated by one agreement. The participation of each organisation is given in Table 8-1.

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

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

8.2 Andra

Since 1992 L'Agence Nationale pour la Gestion des Déchets Radioactifs (Andra), has had a co-operation agreement with SKB for participation in Äspö HRL. In 2004 the co-operation agreement was renewed to cover the co-operation in the Äspö HRL through to 2008. Andra provides experimental and modelling support to the Äspö HRL with emphasis on site characterisation and on engineered barrier systems, EBS, to complement research activities in France. Andra's participation aims at enhancing the understanding of flow and transport in fractured rock and to evaluate experimental and modelling approaches in view of site characterisation. In conjunction with SKB's development of experiments related to the repository system, Andra is carrying out research on EBS for either spent fuel or reprocessed waste. An objective is to extend current THM understanding of bentonite buffer behaviour during saturation to include high temperatures. The knowledge gained in the EBS field is valuable for granite host rock, but also for clay host rock.

8.3 BMWi

The first co-operation agreement between Bundesministerium für Wirtschaft und Technologie (BMWi) and SKB was signed in 1995. The agreement was extended in 2003 for a period of six years. Five research institutes are performing the work on behalf of and funded by BMWi: BGR, DBE Tec, FZK, FZR and GRS. The purpose of the co-operation with the HRL Äspö programme is to improve the knowledge on the engineered barrier system and on potential host rocks for radioactive waste repositories in Germany.

The topics of special interest are:

- Behaviour of the bentonite buffer.
- Characterisation of fracture zones in the rock mass and disturbed zones surrounding underground openings.
- Geochemical investigations of the migration behaviour especially of actinides under near-field and far-field conditions.
- Geochemical modelling of individual processes controlling migration.
- Thermodynamic databases for radionuclides relevant for long-term safety.
- Behaviour of colloids and microbes and their respective interaction with radionuclides.
- Groundwater flow and transport of solutes.

8.4 CRIEPI

Central Research Institute of Electric Power Industry (CRIEPI) signed a contract with SKB for the Äspö HRL Project in 1991 and renewed it 1995, 1999 and 2003. Since 1991, CRIEPI has participated in the exchange of information concerning research and technology for geological disposal of high-level radioactive wastes with other organisations within the Äspö HRL co-operation. In addition, CRIEPI has performed a few voluntary works, groundwater dating, fault dating and measurement of velocity and direction of groundwater flow etc., as well as participated in the Task Force on Modelling of Groundwater Flow and Transport of Solutes. The main objectives of CRIEPI's participation are to demonstrate the usefulness of its numerical codes, develop its site investigation methods and improve the understanding of the mechanisms of radionuclide retention in fractured rock and the interaction between engineered barriers and surrounding rock. In addition, to participating in a number of projects in the Äspö HRL during 2006, CRIEPI will take part in information exchange on research, disposal technologies and methodologies for site investigations.

8.5 JAEA

On October 1, 2005, the Japan Atomic Energy Agency (JAEA) made its first steps as an independent administrative institution. JAEA is the result of the integration of the Japan Atomic Energy Research Institute (JAERI) and the Japan Nuclear Cycle Development Institute (JNC). The JAEA participation in the Äspö HRL is regulated by the trilateral project agreement between JAEA, CRIEPI and SKB signed in 2003 and remaining in force up to the end of 2006. JAEA is currently constructing underground research laboratories in fractured granite at Mizunami and in a sedimentary formation at Horonobe. The aims are to establish comprehensive techniques for investigating the geological environment and to develop a range of engineering techniques for deep underground applications. The results obtained from these laboratories will contribute to ensure the reliability of repository technology and to establish a safety assessment methodology. JAEA also continues to be active in the research at Äspö HRL, which is directly applicable to the Japanese programme. The objectives of JAEA's participation in Äspö HRL during 2006 will be to:

- Develop technologies applicable for site characterisation.
- Improve understanding of flow and transport in fractured rock.
- Improve understanding of behaviour of engineered barriers and surrounding host rock.
- Improve techniques for safety assessment by integration of site characterisation information.
- Improve understanding of underground research laboratory experiments and priorities.

These objectives are designed to support high level waste repository siting, regulations and safety assessment in Japan.

8.6 OPG

In January 2004, Ontario Power Generation Inc. (OPG) signed a five-year agreement with SKB for participation in the Äspö HRL. The prime objective of OPG's participation at Äspö HRL is to enhance the Canadian technology base for a deep geological repository through international co-operation projects. In addition to participation in the two Task Forces OPG will participate in other projects e.g. Long Term Diffusion Experiment and Large Scale Gas Injection Test.

8.7 Posiva

Posiva's co-operation with SKB deepened due to an extensive co-operation agreement signed in 2001 and in 2005 negotiations started to extend the co-operation. Focus of the co-operation is on encapsulation, repository technology and site characterisation, and evaluation and safety related R&D. In addition, Posiva contributes to several of the research projects within Natural barriers. The implementation and construction of the underground rock characterisation facility Onkalo in Olkiluoto in Finland give new possibilities to co-operate within the research and development of underground construction technology. Posiva's co-operation is divided between Äspö HRL and more generic work that can lead to demonstrations in Äspö HRL.

8.8 Enresa

SKB and Empresa Nacional de Residuos Radioactivos, S.A. (Enresa) signed a project agreement in February 1997 covering the co-operation for technical work to be performed in the Äspö HRL. Both parties renewed the agreement in January, 2002. Due to the decision taken in the Spanish parliament in December 2004 to focus on a central interim storage of spent nuclear fuel before 2010, Enresa in 2004 chose not to renew this agreement and have now left the central and active core of participants.

Enresa is however still participating in the Temperature Buffer Test (TBT) in Äspö HRL and is co-ordinating the integrated project Esdred within the 6th EU framework programme. Some of the demonstration work of the integrated project Esdred is carried out in Äspö HRL.

8.9 Nagra

Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Nagra, has the task to provide scientific and technical basis for the safe disposal of radioactive waste in Switzerland. Nagra has had agreements with SKB for participation in Äspö HRL since 1994 to include mutual co-operation and participation in Äspö HRL and Grimsel Test Site projects. The last agreement expired 2003 and Nagra has now left the central and active core of participants. During 2006 Nagra is taking part in the Task Force on Engineered Barriers.

8.10 RAWRA

Radioactive Waste Repository Authority, RAWRA, was established in 1997 and has the mission to the ensure the safe disposal of existing and future radioactive waste in the Czech Republic and to guarantee fulfillment of the requirements for the protection of humans and the environment from the adverse impacts of such waste. RAWRA is new in the Äspö co-operation and participates during 2006 in the Äspö Task Force on Engineered Barriers.

8.11 IAEA framework

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.

During 2006, an IAEA training course on modelling will take place at Äspö HRL. The course will centre on the Prototype Repository project and is given in collaboration with Cardiff University, UK. IAEA-fellows will also be hosted at Äspö HRL for a period during 2006.

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