International Progress Report

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Äspö Hard Rock Laboratory

Planning Report for 2004

Svensk Kärnbränslehantering AB

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Äspö Hard Rock Laboratory

The Äspö Hard Rock Laboratory
Planning Report for 2004

This report presents the planned activities for year 2004 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 2001, 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) constitutes an important part of SKB's work to design and construct a deep geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. Most of the research is focused on 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 and development of technique during the period 2002-2007 are presented in SKB's RD&D-Programme 2001. 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 2004. Äspö HRL and the associated research, development and demonstration tasks, managed by the Repository Technology Department within SKB have so far attracted considerable international interest.

Technology

One of the goals for Äspö HRL is to demonstrate technology for and function of important parts of the repository system. This implies translation of current scientific knowledge and state-of-the-art technology into engineering practice applicable in a real repository. It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. The experiments focus on different aspects of engineering technology and performance testing, and will together form a major experimental programme.

The *Canister Retrieval Test*, located in the main test area at the -420 m level, is aiming at demonstrating the readiness for recovering of emplaced canisters also after the time when the bentonite is fully saturated. Bentonite blocks, bentonite pellets, and canisters with heaters have been installed in one vertically bored in full repository scale. The test has been running for a little more than three years and the bentonite in the cylinder along the canister is now saturated. The artificial water supply will continue during 2004 until the bentonite below and above the canister also reaches saturation. In parallel the registration of sensor readings continues. Reporting of measurements and evaluation of the results will be done as well as further modelling for increased understanding of the processes. The actual retrieval test is scheduled for 2006.

The *Prototype Repository* is 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. It is also 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. The inner section was installed and the plug cast in 2001. During 2003, the two canisters in the outer section were installed, the heaters were turned on, and the tunnel was backfilled and plugged. The instrument readings in the two sections will continue and the surface between the outer plug and the rock of the tunnel will be grouted at the end of 2004. Modelling teams will continue the comparison of measured data with predictions.

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. Wetting of the backfill from the rock and filter mats supplying artificial water has continued during the years 2000 to 2003 and data from transducers has been collected and reported. Flow testing in the backfill started during the autumn 2003 and will continue until 2004 or 2005. Supplementary modelling will complement the flow testing and data collection and reporting will be continued. The excavation of the backfill materials is planned to start late 2005.

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 tests are finalised and reported, and the report on the third extracted parcel is under production. The remaining four parcels are functioning well and water pressure, total pressure, temperature, and moisture content are continuously measured and data stored every hour. The data will be carefully analysed and reported in April and October. Minor maintenance and improvement work are also planned to be made during 2004.

In the project *Cleaning and sealing of investigation boreholes* the best available techniques for this are to be identified and demonstrated. Investigation boreholes are drilled during site investigations and detailed characterisation in order to obtain data on the properties of the rock. These boreholes must be cleaned and sealed, no later than at the closure of the deep repository. Cleaning of the boreholes means that instrumentation is removed. Sealing of the boreholes means that the conductivity in the borehole is no higher than that of the surrounding rock. In the first Phase of the project a state-of-the-art report summarising the developments of the techniques during the last 10–15 years was prepared. In November 2003 the decision was taken to continue with a second Phase. This Phase, planned to be carried out during 2004, comprises the definition of a basic concept for cleaning and sealing of boreholes, laboratory studies on candidate sealing material, as well as characterisation and preparation of boreholes to be used in a field-tests with the aim to demonstrate and test different sealing techniques.

The project *Injection grout for deep repositories* is a continuation of a project with the aim to qualify the use of low-pH products (≤11). A pre-study was carried out in 2001, followed by a feasibility study in 2002 – mid 2003. The current project aims at achieving some well quantified, tested and approved low-pH injection grouts that can be used in the construction of a deep repository. The project is divided into four sub projects: 1) Low-pH cementitious injection grout for larger fractures, 2) Non-cementitious low-pH injection grout for smaller fractures, 3) Field testing in Finland, and 4) Field testing in Sweden. The sub-project connected to Äspö HRL consists of field tests with silica sol, a gel of silica colloids in water. The proposed test site is a pillar that has been used earlier for a similar test. The project is a joint project between Posiva, SKB and NUMO. The sub-project start was December 2003 and the field tests should be carried out before April 2004. A final report for the entire project is planned to December 2004.

Late 2001 SKB published an R&D programme for the *KBS-3 method with horizontal emplacement* (KBS-3H). The programme, which is carried through by SKB and Posiva in co-operation, was divided into four parts: 1) Feasibility study, 2) Basic design, 3) Construction and testing at the Äspö HRL, and 4) Evaluation. The Feasibility study suggested in 2003 that the KBS-3H method is worth further development work, and the Basic design phase started with the technical development of the KBS-3H method, preparations for a future demonstration of the method at Äspö HRL, and studies of the barrier performance. The Basic design phase will be reported early 2004. Preparations for full scale demonstration at Äspö HRL will continue during 2004 with finalisation of a test niche at -220 m level, boring of three deposition drifts, detailed design and manufacturing of deposition equipment, and analyses of buffer and long-term safety issues.

The aim of the *Large Scale Gas Injection Test* is to perform gas injection tests in a full-scale KBS-3 deposition hole. The 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 experiments will be performed in a bored full-size deposition hole with a full-scale canister without heaters and a surrounding bentonite buffer. Water will be artificially supplied and the gas injection tests start when the buffer is fully saturated, which is expected to take two years. Planning of and preparations for the installation of the test were made during 2003. The installation phase including testing of the gas injection system and other equipment is planned to be completed before the summer 2004. The artificial saturation of the buffer starts as soon as the installation is completed.

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, in order to be able to model this behaviour. 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 continuously ongoing and a data link to Andra's head office in France has been established. The operation phase will continue during 2004 and the planning for the evaluation modelling is under way with the aim to issue an evaluation programme in March 2004 where after the modelling group will resume its work.

The project *Shearing of canister in deposition hole* aims at observing the forces that would act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole. Such a displacement is considered to be caused by an earthquake, and the test set-up need to provide a shearing motion along the fracture that is equal to an expected shearing motion in real life. The first phase, which will last all of 2004, is a pre-study of design and feasibility. Scoping calculations are assumed to indicate the forces and shearing speed needed and thereby provide the basis for the design of the test set-up. The test set-up is planned to be installed at the site of the Äspö Pillar Stability Experiment when the rock mechanics test has been completed.

The *Task Force on Engineered Barrier Systems* was put on a stand-by position in 2001. As the European Commission funding of the Prototype Repository project will cease in February 2004 it is judged most convenient to activate the Task Force and continue the modelling work in the Prototype Repository project within this frame, where also modelling work on all other experiments can be conducted. A modelling meeting will be held in March 2004 with the prime aim of establishing the progress in modelling. This event will also bring up the issue of the Task Force with the intention to outline the prime issues and to form a proposed programme for the official decisions on the activation of the Task Force on engineered barrier systems.

Geo-science

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

A new system for *Geological mapping and modelling* to be used in the deep repository construction work will be developed within a new project. The major reasons to develop a new system for underground mapping are aspects on time required, precision in mapping and traceability. The work with the new system was started during autumn 2003 and will continue during 2004 and probably also during the following years. The three dimensional geological RVS model of Äspö will be updated and a model showing the tunnel layout is planned to be available in the beginning of 2004.

Rock stress measurements with different measuring techniques have during the years been performed as well as numerical modelling of the stress. To be able to make correct assessments of the *in situ* stress field from results from different types of measurements it is important to know the limitations and shortcomings of the different techniques. A co-operation with Posiva with the objective to quality-assure overcoring data has been initiated. The first phase has been completed which includes development of a numerical tool for isotropic and elastic conditions.

The objective with the *Rock Creep Project* is to develop better conceptual models for the evaluation of the influences of the rock damaged zone and rock creep on rock stability. A literature study and scooping numerical modelling with a three-dimensional coupled hydromechanical computer code (3DEC) have been performed. The literature study is under review and the results from the modelling are in progress and will be reported in 2004.

Äspö Pillar Stability Experiment was initiated to demonstrate the capability to predict 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 is carried out in a rock mass with a virgin stress field and two vertical holes at a distance of one metre was drilled in the floor of the tunnel. The pillar is designed in such a way that spalling will occur when the pillar is heated. The heating starts early 2004 and will be completed in July. The evaluation of the experiment takes place thereafter.

The project on *Heat transport* aims at decrease the uncertainties in the estimates of the temperature field in the repository. Less uncertain estimates of the temperature field around a repository makes it possible to optimise the distance between canisters in the repository layout. Three reports dealing with heat transport have been completed during 2003. The activities planned for during 2004 comprise on inverse modelling, studies of the scale dependency of thermal properties and anisotropies, as well as analyses of data uncertainties.

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 run and compare the HMS database with other databases compiled elsewhere. The plans for 2004 are to finalise the software development and to analyse the impact of earthquakes and effects of blasts in Äspö HRL as well as in CLAB during the extension of the under ground storage capacity.

Natural barriers

At the Äspö HRL experiments, with the aim to increase the knowledge of the long-term function of the repository barriers, are performed at conditions that are expected to prevail at repository depth. The bedrock with available fractures and fracture zones, its properties and on-going physical and chemical processes, which affect the integrity of the engineered barriers and the transport of radionuclides, are denoted the natural barriers of the deep repository. The experiments are related to the rock, its properties, and *in situ* environmental conditions. The strategy for the on-going experiments is to concentrate the efforts on those experiments that are of 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 with the aim to evaluate the usefulness and reliability of different numerical models and to develop and test methods for determination of parameters 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 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. The work is presently performed in two projects; TRUE Block Scale Continuation and TRUE-1 Continuation. The objectives of the TRUE Block Scale Continuation project is to improve the understanding of transport pathways at the block scale, including assessment of effects of geometry, macro-structure, and micro-structure. The work planned for 2004 focuses on *in situ* experiments with sorbing tracers which commence in January and terminate in May. The *in situ* efforts are paralleled by model predictions employing four different modelling approaches. One of the principal objectives of the TRUE-1 Continuation project is to map the porosity of the earlier investigated Feature A at the TRUE-1 site. A 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 are intended to shed light on the possible three-dimensional aspects of transport at the site. A complication for the scheduling of planned future work lies in the fact that the TRUE-1 and Long Term Diffusion Experiment (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.

The *Long Term Diffusion Experiment* constitutes a complement to performed diffusion and sorption experiments in the laboratory, and is a natural extension of the experiments conducted as part of TRUE. The difference is that the longer duration (approximately four years) of the experiment is expected to enable 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 in the bottom of a large diameter telescoped borehole. The experimental set-up has been installed and during 2003 the installation-test and pre-test programmes were initiated which will be completed in 2004. In addition, the experimental set-up will be documented and failure mode effect analyses are planned to be carried out before the injection of radioactive tracers commence.

Radionuclide Retention Experiments are carried out with the aim to confirm result from laboratory experiments *in situ*, where conditions representative for the properties of groundwater at repository depth prevail. The experiments are carried out in special probes placed in boreholes in the rock. Radiolysis experiments, intended to investigate the influence of radiolysis on the migration of oxidised technetium, have been performed with the CHEMLAB 1 probe. The field experiment is finished, the collected data has been evaluated, and the final report is in progress. Migration of actinides in a natural rock fracture in a drill core is studied in the CHEMLAB 2 probe and the last field experiment will start in March 2004. This experiment will be performed similarly as previous ones and the radionuclides to be studied this time are ^{233}U and ^{99}Tc. Following the actinide migration experiments are Spent Fuel Leaching experiments for which the planning start during spring 2004.

The *Colloid Project* comprises studies of the stability and mobility of colloids, measurements of the colloid concentration in the groundwater at Äspö, bentonite clay as a source for colloid generation, and the potential of colloids to enhance radionuclide transport. Borehole specific measurements, to determine the colloid generation properties of clay in contact with groundwater, were carried out during the first half of the year 2003. The compilation of the final report including laboratory experiments, background measurements and borehole specific measurements is in progress. The planning and initiation of dipole colloid experiments, to study the change in colloid content in the groundwater prior and after its transport through a natural fracture, started in August 2003 and the preparations for the experiment will continue during 2004.

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. There are presently four specific microbial process areas identified that are of importance for proper repository functions and that are studied in the *Microbe Project*. The process areas are: bio-mobilisation of radionuclides, bio-immobilisation of radionuclides, microbial effects on the chemical stability, and microbial corrosion of copper. During 2004 the following activities are planned: evaluation and follow up experiments on immobilisation of radionuclides on bio-films in deep groundwater, investigations on *in situ* mobilisation of radionuclides by microbial complexing agents, quantitative estimates of trace element immobilisation by BIOS, and investigations on migration, production and consumption of microbial.

The first phase of the *Matrix Fluid Chemistry* experiment, which was completed in 2003, increased the knowledge of matrix pore space fluids/groundwaters from crystalline rocks of low hydraulic conductivity, and this complemented the hydrogeochemical studies already conducted at Äspö. A second phase is due to commence in January 2004 which focuses on the small-scale micro-fractures in the rock matrix which facilitate the migration of matrix waters. The understanding of the migration of groundwater, and its changing chemistry, is important for repository performance. The scope of work for 2004 will depend on the impact of tunnel excavation and consequently any potential impact will be determined by evaluating the pressure variations in the matrix borehole and other monitored boreholes. If there is no significant impact resampling of groundwaters and dissolved gases from borehole sections will be made during 2004, with the same experimental set-up as was used in the first phase.

An important goal for the activities at Äspö HRL 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. 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 where 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 reporting of Task 5 was almost finalised in 2003 and the currently active task is performance assessment modelling using site characterisation data (Task 6). The work during 2004 within Task 6 focuses on reporting of the modelling sub-tasks and continuation of the external review.

PADAMOT (Palaeohydrogeological Data Analysis and Model Testing) is an EC-project that includes developments of analytical techniques and modelling tools to interpret data, but also focusing research to investigate specific processes that might link climate and groundwater in low permeability rocks. 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-project was initiated in the beginning of 2002 and is running to the end of 2004. The work on Swedish drill core material has continued during 2003 with sample preparation and analyses of calcite samples. The presently available data set is very small but more stable isotope analyses of morphologically classified calcites will be carried out during 2004. In addition, results of the detailed studies of zoning, morphology and fluid inclusions will be combined with bulk analyses of stable isotopes and chemistry in order to give a palaeohydrogeological model based on fracture mineralogy and water chemistry.

The basic idea behind the project *Fe-oxides in fractures* is to examine Fe-oxide fracture linings, in order to explore for suitable palaeo-indicators for their formation conditions, while at the same time learning about the behaviour of trace component uptake in general, both from the natural material as well as through testing of behaviour in controlled parametric studies in the laboratory**.** The three year project on Fe-oxides started late autumn 2003. The work carried out during the first months concentrated on summing up the results from a pilot tests carried out during 2003. The results of the first pilot study will be brought to completion during 2004. The compilation and evaluation work will continue and new sampling of Äspö material will be carried out during the spring 2004.

Äspö facility

An important part of the activities at the Äspö facility is the administration, operation, and maintenance of instruments as well as development of investigation methods. The main goal for the operation is to provide a safe and environmentally correct facility for everybody working or visiting the Äspö HRL. This includes preventative and remedy maintenance in order to withhold high availability in all systems as drainage, electrical power, ventilation, alarm, and communications in the underground laboratory. Other issues are to keep the stationary hydro monitoring system (HMS) continuously available and to carry out the programme for monitoring of groundwater head and flow and the programme for monitoring of groundwater chemistry.

International co-operation

Seven organisations from six countries will participate in the co-operation at Äspö HRL during 2004. One organisation, Ontario Power Generation of Canada, becomes a new participant from January 1st, 2004, and one, Nagra, will leave the central and active core of participants. 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 Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes.

SKB is through Repository Technology co-ordinating three EC contracts and takes part in several EC projects of which the representation in three projects is channelled through Repository Technology. SKB takes also part in work within the IAEA Network of Centres of Excellence.

Environmental research

The experiments performed in Äspö HRL are not exclusively focused on radionuclide related processes but also on non-radioactive environmental issues. Äspö Environmental Foundation was founded 1996 on initiative of local and regional interested parties, with the aim to make the underground laboratory available for environmental research. SKB's economic engagement in the foundation was concluded in 2003 and the activities are now transferred to the Äspö Research School, which was founded in 2002 with the objective of providing conditions for today's and tomorrow's research concerning environmental issues. It has a special interest in the transport of pollutants and their distribution in rock, ground, water and biosphere. During 2003 detailed plans for the school activities were worked out and during 2004 the PhD students will establish a field test base in the Äspö Research Village and initiate the first field test in the laboratory.

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 to design and construct a deep geological repository for spent nuclear fuel and to develop and test methods for characterisation of a suitable site. One of the fundamental reasons behind SKB's decision to construct an underground laboratory was to create an opportunity for research, development and demonstration in a realistic and undisturbed rock environment down to repository depth. Most of the research is focused on processes of importance for the long-term safety of a future deep repository and the capability to model the processes taking place, while 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 3600 m where the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The first part of the tunnel has been excavated by conventional drill and blast technique. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts.

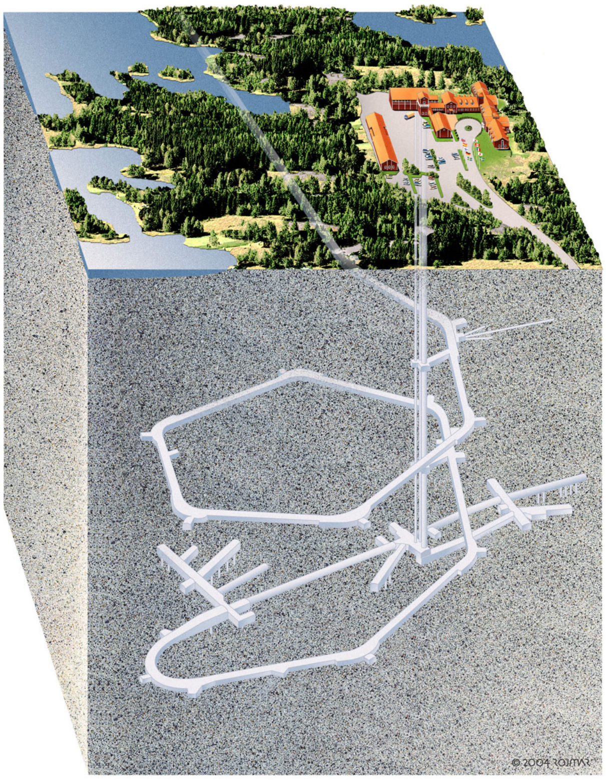


Figure 1-1. *Overview of the Äspö HRL facilities.*

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 2001 /SKB, 2001a/.

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.* Test, investigate and demonstrate on full-scale different components of importance for the long-term safety of a deep repository and to 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 Investigation Department of SKB which performs site investigations at two sites, Simpevarp in the municipality of Oskarshamn and Forsmark in the municipality of Östhammar.

In order to reach present goals the following important tasks are performed at the Äspö HRL:

- Develop, test, evaluate and demonstrate methods for repository design and construction, and deposition of spent nuclear fuel and other long-lived waste.
- Develop and test alternative technology with the potential to reduce costs and simplify the deep repository concept without sacrificing quality and safety.
- Increase the scientific understanding of the deep 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 deep repository.
- Provide information to the general public on technology and methods that are being developed for the deep repository.

1.3 Organisation

SKB's work is organised into four departments; Safety and Technology, Site investigations, Operations, and Business support. The research, technical development, and safety assessment work is organised into the Safety and Technology department, in order to facilitate co-ordination between the different activities.

Repository Technology (TD), one of five departments organised under the Safety and 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 three 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 undertaken at Äspö HRL, 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, QA and Economy* is responsible for providing administrative service and quality systems.

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 Manger 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.

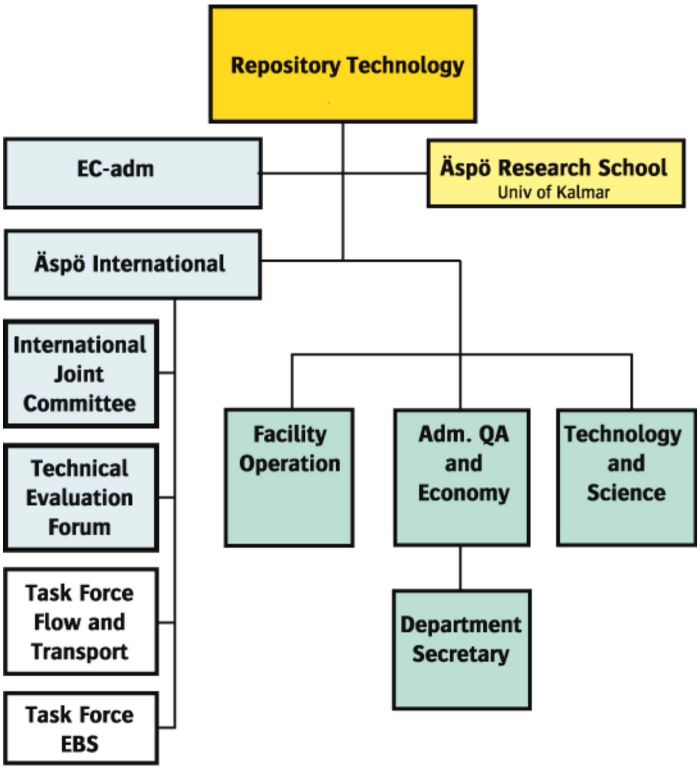


Figure 1-2. *Organisation of Repository Technology and Äspö HRL.*

1.4 International participation in Äspö HRL

The Äspö HRL has so far attracted considerable international interest. Seven organisations from six countries will participate during 2004 in the Äspö HRL in addition to SKB. The participating organisations are:

- Agence Nationale pour la Gestion des Déchets Radioactifs (Andra), France.
- Bundesministerium für Wirtschaft und Arbeit (BMWA), Germany.
- Central Research Institute of Electric Power Industry (CRIEPI), Japan.
- Empresa Nacional de Residuos Radiactivos (Enresa), Spain.
- Japan Nuclear Cycle Development Institute (JNC), Japan.
- Ontario Power Generation Inc. (OPG), Canada.
- Posiva Oy, Finland.

For each partner the co-operation is based on a separate agreement between SKB and the organisation in question. The international partners and SKB reached a joint decision to form the Äspö International Joint Committee (IJC). IJC is responsible for the co-ordination of the 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 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.

Specific technical groups, so called Task Forces, are another form of organising the international work. A Task Force on Groundwater Flow and Transport of Solutes in fractured rock has been working since 1992 and a Task Force on Engineered Barrier Systems has been on stand-by but will be activated during 2004.

Some EC projects are co-ordinated by the Director of Repository Technology and administrated by the Repository Technology staff. Examples are EC projects concerning the Prototype Repository that has a direct coupling to the test set-up at Äspö and the CROP project that is coupled to experiments carried out in the Äspö HRL. Both those projects will be concluded in 2004.

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.

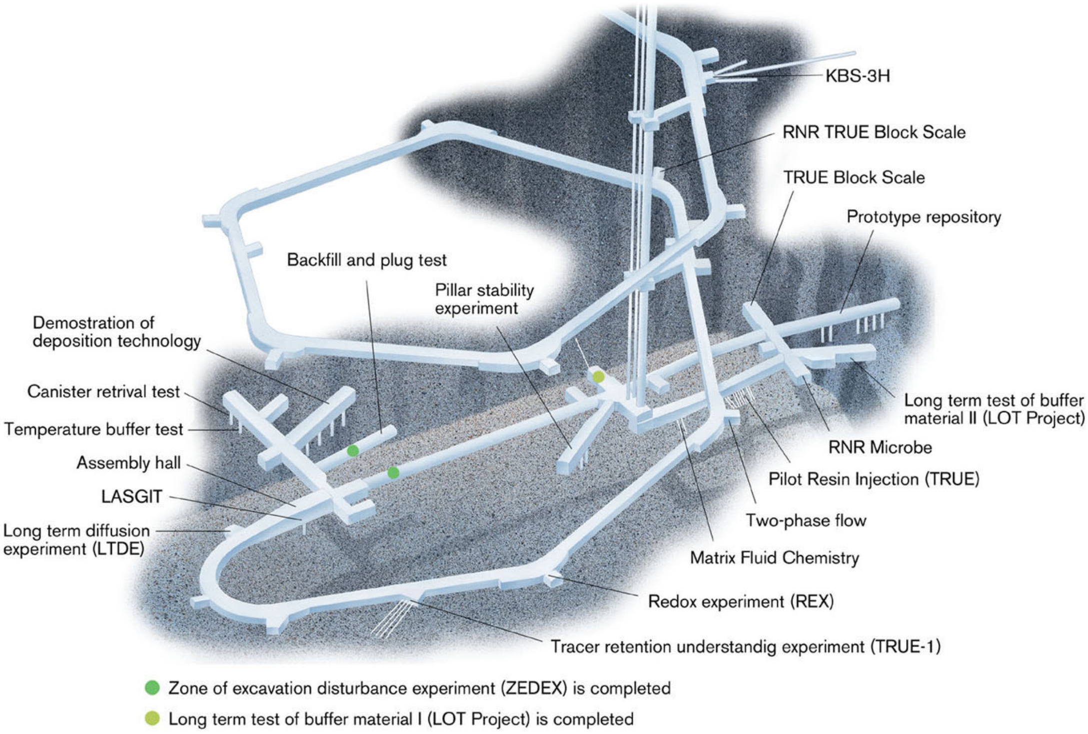


Figure 1-3. *Allocation of experimental sites from -220 m to -450 m level.*

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 2002–2007 are presented in SKB's RD&D-Programme 2001. 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

2004. 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 and also to the Quality Management Standard ISO 9001, and since 2003 also 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 document 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 as well as specific routines for Äspö HRL can be found.

Employees and contractors related to the SKB organisation are responsible for that work will be performed in accordance with SKB's management system.

SKB are constantly developing and enhancing the security, the environmental and quality-control efforts to keep up with the company's development and 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 SKB's operations can be described as follows:

- A high level of security at all SKB's facilities.
- A low level of environmental impact.
- Efficiency.
- Meeting the demands imposed by legislation, statutes and regulations by a comfortable margin.
- Openness.

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 manage 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 each 3rd 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 2004 is described in six chapters in this report:

- Technology – demonstration of technology for and function of important parts of the repository system.
- 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.
- Äspö facility – operation, maintenance, data management, and monitoring etc.
- International co-operation.
- Environmental research.

2 Technology

2.1 General

To meet stage goal 4, to demonstrate technology for and function of important parts of the repository 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 real repository.

It is important that development, testing and demonstration of methods and procedures, as well as testing and demonstration of repository system performance, are conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore conducted at Äspö HRL. The experiments focus on different aspects of engineering technology 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 components of the repository system as well as the function of the integrated repository system.

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

- Canister Retrieval Test.
- Prototype Repository.
- Backfill and Plug Test.
- Long Term Test of Buffer Material.
- KBS-3 method with horizontal emplacement.
- Large Scale Gas Injection Test.
- Temperature Buffer Test.
- Shearing of canister in deposition hole.

2.2 Canister Retrieval Test

Background

The stepwise approach to safe deep 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 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 testing the results of monitoring and manual excavation with laboratory testing of 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 is separated into three stages:

Stage I — Boring of deposition hole and installation of instrumented bentonite blocks and canisters with heaters. 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 2-1.

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.

Present status

Two deposition holes were bored but only one has been installed, the main reason being that only one robust method for freeing the canister is presently being considered to be tested in full-scale in Äspö HRL. 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 3 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 a few exceptions. Data reports are produced twice a year.

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 yet. Some clogging of the filters may explain the inhomogeneous appearance.

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. The water pressure was temporarily reduced to 100 kPa during the period 5/12 2002 – 9/1 2003 and to 400 kPa during the period 9/1 2003 – 23/1 2003. The problems with the heaters caused by low resistance to earth have remained but the heaters have worked properly and a steady power has been maintained during 2003.

Scope of work for 2004

The plan is to continue the artificial water saturation of the bentonite, to maintain the power of the canister at 2100 W, to maintain the water pressure 800 kPa in the mats, and to continue the registration of sensor readings during 2004. Reporting of measurements and evaluation of the results will be done as well as further modelling for increased understanding of the processes. The actual retrieval test is scheduled for 2006.

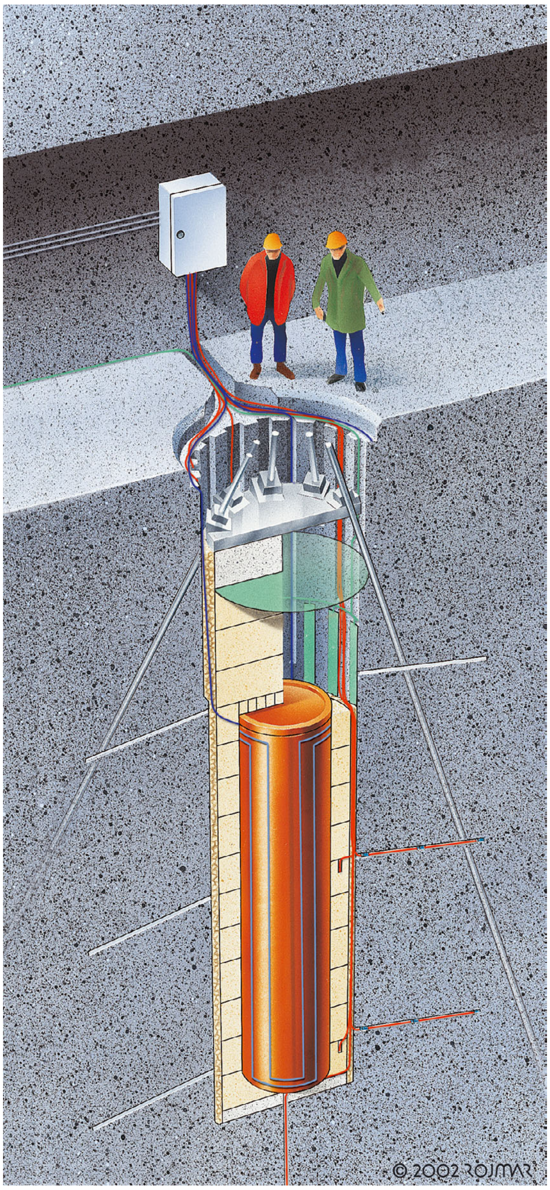


Figure 2-1. *Illustration of the experimental set-up of the Canister Retrieval Test.*

2.3 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. It is envisaged that this technology can be tested, developed and demonstrated in the Prototype Repository.

The execution of the Prototype Repository is a dress rehearsal of the actions needed to construct a deep repository from detailed characterisation to resaturation of deposition holes and backfill of tunnels. The Prototype Repository will provide a demonstration of the integrated function of the repository and provide 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 Prototype Repository has been co-funded by the European Commission with SKB as co-ordinator. The EC-project started in September 2000 and will end in February 2004.

Objectives

The main objectives for the Prototype Repository are:

- To test and demonstrate the integrated function of the deep repository components under realistic conditions in full-scale and to compare results with model predictions and assumptions.
- To develop, test, and demonstrate appropriate engineering standards and quality assurance methods.
- To 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 2-2. The tunnels will be backfilled with a mixture of bentonite and crushed rock (30/70). A massive concrete plug designed to withstand full water and swelling pressures will separate the test area from the open tunnel system and a second plug will separate the two sections. This layout will in practice provide two more or less independent test sections. Canisters with dimension and weight according to the current plans for the deep repository and with heaters to simulate the thermal energy output from the waste will be positioned in the holes and surrounded by bentonite buffer. The deposition holes are with a centre distance of 6 m. This distance is evaluated considering the thermal diffusivity of the rock mass and the fact that maximum acceptable surface temperature of the canister is 90°C.

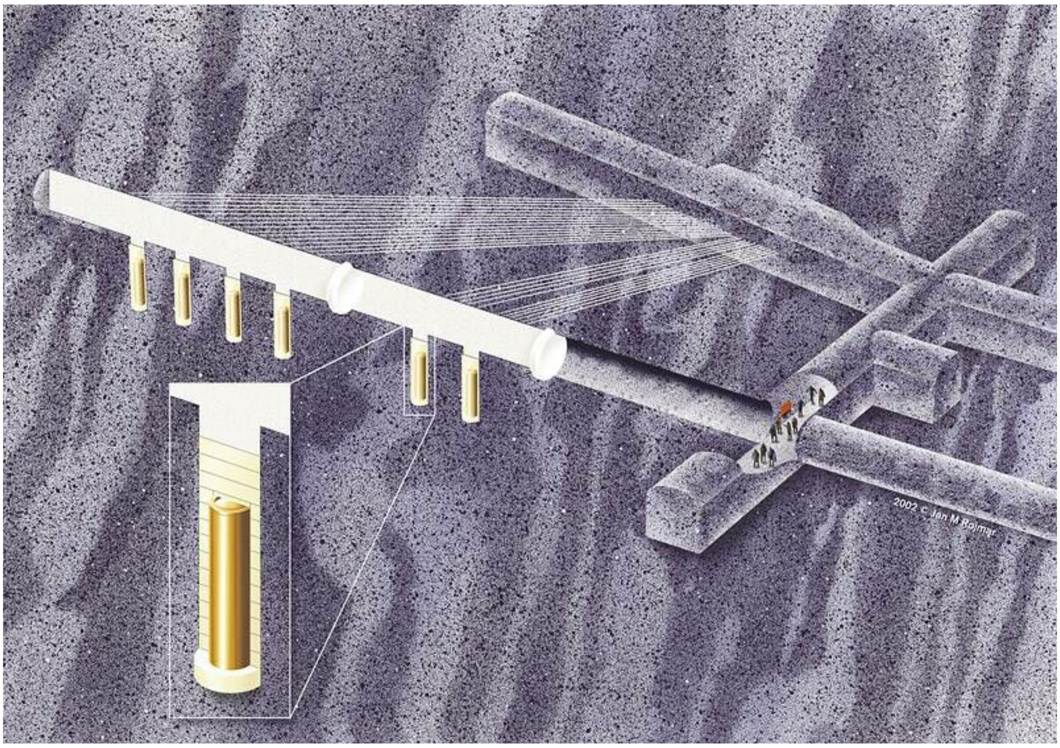


Figure 2-2. *Schematic view of the layout of the Prototype Repository (not to scale).*

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.

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 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 year 2003. Immediately after the installation of the buffer, the tunnel section was backfilled. This work was finished at the end of June 2003. The heaters in the two canisters in the outer section were turned on when the backfilling reached the section of the deposition holes. At these stages the monitoring of processes was started. The construction and casting of the outer plug started in August and were finished in September 2003.

Scope of work for 2004

The instrument readings in the two sections will continue. At the end of 2004 the surface between the outer plug and the rock of the tunnel will be grouted. Reporting of measurements and evaluation of the results will be done. Modelling teams will continue the comparison of measured data with predictions.

2.4 Backfill and Plug Test

Background

The Backfill and Plug Test includes 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 is 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 2-3 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.

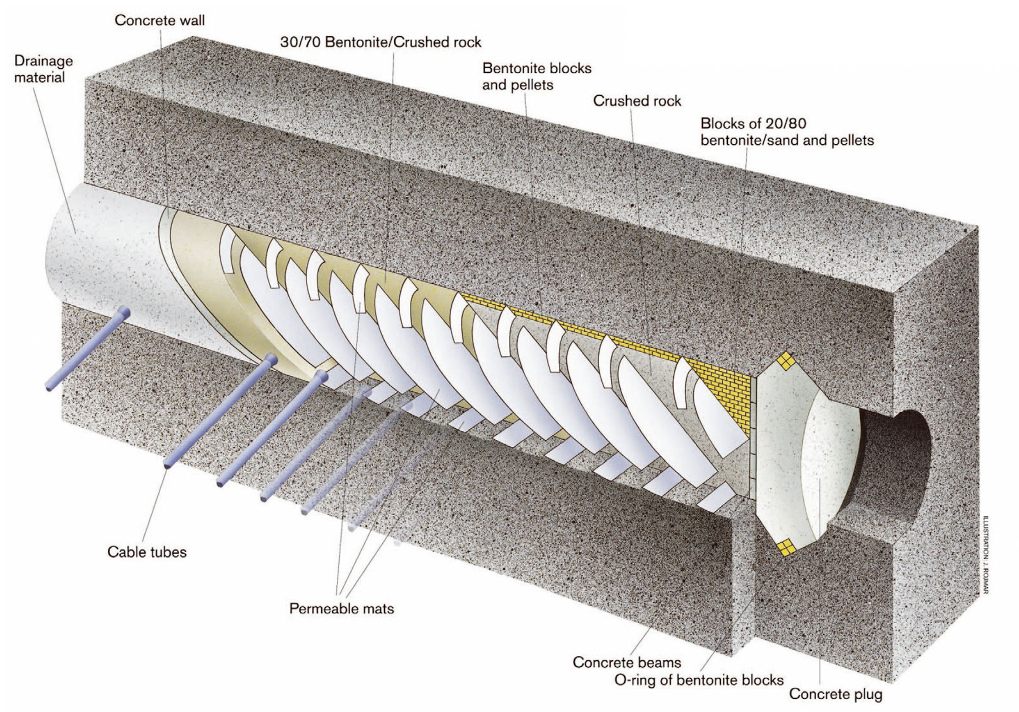


Figure 2-3. *Illustration of the experimental set-up of the Backfill and Plug Test.*

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 dm was left between the backfill and the roof and 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.

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 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 will after water saturation be 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.

The flow testing in the backfill is planned to start after saturation, when steady state flow and pressure have been reached.

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.

During 2003 the water pressure has been kept at 500 kPa in all mats during a major part of the year. Preparations and rebuilding of the wetting system for adapting it to the flow testing have been done. During autumn the flow testing has been started by decreasing the water pressure in the permeable mats sections (one by one) to 400 kPa and measuring the flow between the mat sections.

Data reports are produced twice a year. Almost all transducers seem to work well so far but the measuring system with the psychrometers for measuring relative humidity of unsaturated soil has been closed.

Scope of work for 2004

The flow testing will continue during 2004 as planned. The strategy of the flow testing is in the first phase to successively decrease the water pressure in the mat sections starting with the mat at the plug as already done for the first layers. Then the pressure will be decreased in each section and the flow measured from the neighbouring mat section that still has a pressure of 500 kPa to the mat section where the pressure just has been decreased. The water pressure must be kept equal in all three mats in each mat section in order to prevent water flow between the mats in a section. The pressure will be decreased in steps of 100 kPa and the hydraulic gradient kept for such long time that a steady flow could be observed.

The water flow to and from the two mats sections surrounding the tested backfill section will be measured separately in the three mats in the mat layers. If the measurements indicate that large air pockets are present in the backfill or mats it may be necessary to increase the water pressure in the mats to 1–2 MPa in order to reduce the influence of enclosed air.

After finalised test programme the pressure will successively be increased again starting from the mat at the plug implying that the water will flow in reversed direction.

In addition to the flow testing the following activities will be accomplished:

- 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.

The flow testing is planned to continue until 2004 or 2005 and the excavation of the backfill material is planned to start late 2005 or in the beginning of2006 depending on the results.

2.5 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 method 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 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 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:

- 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.
- Information concerning survival, activity and migration of bacteria in the buffer.
- Check of data concerning copper corrosion, and information regarding type of corrosion.
- Data concerning gas penetration pressure and gas transport capacity.
- 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 planned 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. The experimental set-up and a blow-up of a test parcel are shown in Figure 2-4. 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 regulated and temperature, total pressure, water pressure and water content are continuously being measured.

The test series are performed under realistic repository conditions except for the scale and the controlled adverse conditions in four tests, see Table 2-1. Adverse conditions in this context refer to high temperatures, high temperature gradients over the buffer, and additional accessory minerals leading to i.a. 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.

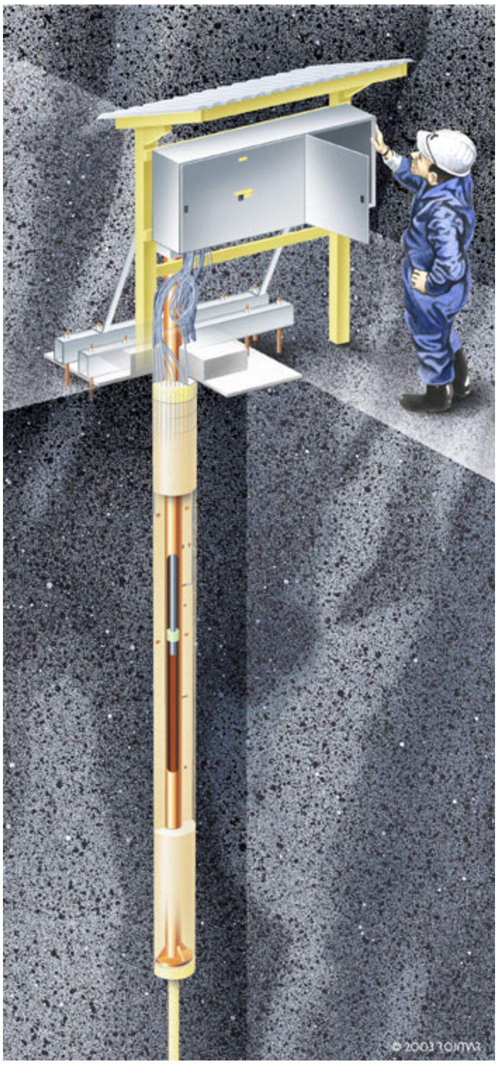
At termination of the tests, the parcels are extracted by overlapping core-drilling outside the original borehole. The water distribution in the clay is determined and subsequent well-defined chemical, mineralogical analyses and physical testing are performed.

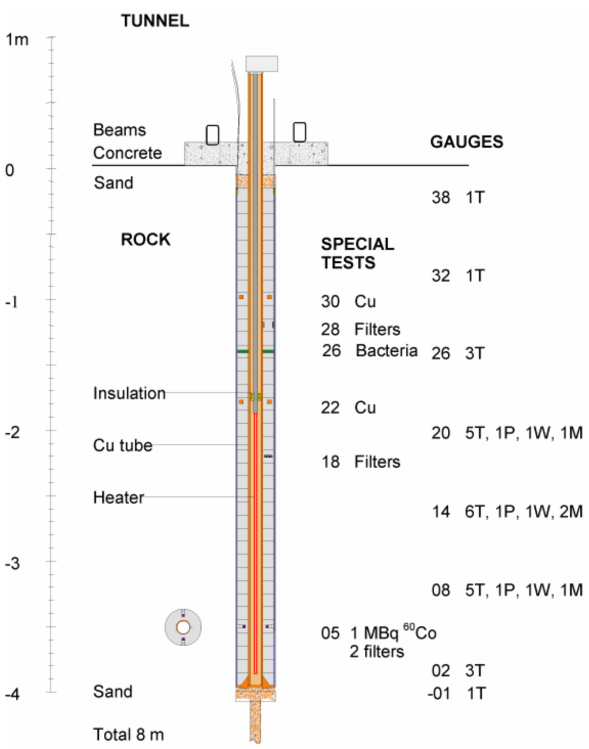
Present status

The A1 and S1 parcels are finalised and reported, the A0 parcel are being analysed and a report is under production. The remaining four parcels are functioning well and only minor service was needed during the past year.

Scope of work for 2004

Water pressure, total pressure, temperature and moisture in the four remaining parcels will be continuously measured and stored every hour. The data are being checked monthly, and the results are planned to be analysed more carefully and reported in April and October. Measurement of real time copper corrosion will be made in the same way as during 2003. Minor maintenance and improvement work will be made. The A2 parcel is planned to be terminated during the spring 2005. Planning for the uplift and analyses activities will start in October 2004.





The first figures in the columns “special tests” and “gauges” denote block number and second figures in the column “gauges” denote the number of sensors. T denotes thermocouple, P total pressure sensor, W water pressure sensor, and M moisture sensor.

***Figure 2-4.** Illustration of the experimental set-up in the Long Term Test of Buffer Material and a cross-section view of one S-type parcel.*

Table 2-1. Buffer material test series.

Type	No.	max T, °C	Controlled parameter	Time, years	Remark
A	1	130	T, [K^+], pH, am	1	finalised
A	0	120–150	T, [K^+], pH, am	1	finalised
A	2	120–150	T, [K^+], pH, am	5	main test, ongoing
A	3	120–150	T	5	main test, ongoing
S	1	90	T	1	finalised
S	2	90	T	5	main test, ongoing
S	3	90	T	>>5	main test, ongoing

A= adverse conditions T= temperature pH= high pH from cement

S= standard conditions [K^+]= potassium concentration am= accessory minerals added

2.6 Cleaning and sealing of investigation boreholes

Background

Investigation boreholes are drilled during site investigations and detailed characterisation in order to obtain data on the properties of the rock. These boreholes must be sealed, no later than at the closure of the deep repository, so that they do not constitute flow-paths from repository depth to the biosphere. Sealing of the boreholes means that the conductivity in the borehole 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 two phases. Phase 1 is mainly an inventory of available techniques, and Phase 2 aims to develop a complete cleaning and sealing concept and to demonstrate it. Phase 1 of the project was finalised in the end of 2003 and the project has now come to Phase 2. In Phase 2 the work is divided in the four main areas described below:

- Laboratory studies on potential materials and combinations of different materials. Laboratory tests on selected candidate materials to evaluate if the criteria set on hydraulic conductivity, shrinkage, and physical and chemical long-term stability can be fulfilled.

- Cleaning of the borehole to be used at a later stage in the project. Identification of the type of equipment left in the borehole and investigations of the distribution of equipment along the borehole. Specification of methods and equipment needed to catch and bring up the left equipment in the borehole. Finally, select methods and equipment to be applied for cleaning the hole.
- Preparations for full-scale testing in the field. Present the requirements to be set on preparations to be made before plugging the borehole. Specify the requirements to be fulfilled by equipment and material to be used for plugging of long and short boreholes from the surface and from underground.
- Compile a complete "Basic concept" for sealing of boreholes. The concept should include measures to be taken before plugging, evaluation of long-term stability of selected materials, and techniques for manufacturing and installation of plugs in boreholes. In addition, recommendation should be made on full-scale tests of the concept.

Present status

The first Phase of this project is completed. A state of the art report summarising the developments of the sealing and cleaning techniques during the last 10–15 years has been published as an internal report (TD) titled "Borehole plugging – State of art". The major conclusions were that smectite clay has been used successfully for borehole plugging and is recommended as main candidate material in the forthcoming work. Cement is concluded to serve less good, primarily because of questionable chemical stability.

In November 2003 the decision was taken to continue with Phase 2 of the project. During 2003 efforts have been spent on detailed planning of the second phase of the project and planning of laboratory test to be performed on candidate materials (e.g. bentonite and cement mixtures). Studies on techniques for manufacturing perforated copper pipes that can host precompacted clay blocks have also been made. Investigations of different techniques to be used for stabilising the upper 50 meters of the boreholes that can withstand the pressure from potential ice loads have also been initiated.

Scope of work for 2004

During this year work within the second phase will be carried out comprising:

- Definition of a complete "Basic concept" for sealing of boreholes to be ready in September.
- Characterisation of potential boreholes that can be used to test and demonstrate different sealing techniques.
- Laboratory studies on candidate materials to be started in February.
- Preparations for full-scale tests to begin in October with an initial field test.
- Compilation of the basis for continuation of the next phase of the project should be available in December.

2.7 Injection grout for deep repositories

Background

Posiva and SKB are planning to deposit spent fuel in deep repositories. Use of common construction materials, as steel and concrete, are foreseen. With respect to the repository long-term safety a suitable chemical environment is vital. The use of low-pH products is necessary in order to get leachates with a sufficiently low pH (≤11). A pre-study was carried out in 2001, followed by a feasibility study in 2002–mid 2003. The Feasibility study is reported both as a SKB working report and a Posiva R&D report /Bodén and Emmelin, 2003/.

The current project aims at achieving some well quantified, tested and approved low-pH injection grouts to be used from the start of the construction of the underground rock characterisation facility ONKALO. The project is divided into four sub projects:

SP1 Low-pH cementitious injection grout for larger fractures.

SP2 Non-cementitious low-pH injection grout for smaller fractures.

SP3 Field testing in Finland.

SP4 Field testing in Sweden.

The work to be carried out at the Äspö HRL is part of SP4 – Field testing in Sweden. The sub-project connected to Äspö HRL consists of field tests with silica sol a - gel of silica colloids. The proposed test site is a pillar that has been used earlier for a similar test. Further, not connected to Äspö HRL, is an evaluation of possibilities to couple behaviour of grout in sand column tests to behaviour when grouted in a rock fracture. This evaluation includes a comparison between results obtained in a sand column test and the Äspö field test. The actual sand column tests are carried out in a project at Chalmers.

The injection grout project is a joint project between Posiva, SKB and NUMO. The sub-project (SP4) started in December 2003 and the field test is planned to be carried out before April 2004.

Objectives

The objective of the field test in Äspö HRL is to investigate if it is possible to estimate/predict the penetration of silica sol (a Newton fluid) based on transmissivity and hydraulic aperture, resulting from hydraulic tests.

The field tests and the evaluation of grouted rock fractures and sand column tests will increase the knowledge concerning the behaviour of silica sol, which will be useful for predictions and selection of grouting strategies.

Present status

Plans and programme for the field tests at Äspö HRL are being written and resources booked.

Scope of work for 2004

The field tests, performed in an earlier cement grouted fracture of the rock at section 0/670 in the access tunnel, will include the following activities:

- Hydraulic tests to investigate the hydraulic aperture of the fracture (available boreholes will be used when possible).
- Modelling to decide appropriate recipe of silica sol, pressure and grouting time.
- Grouting of silica sol and control of grout properties in field.
- Drilling of new core boreholes for observation of the grouted fracture. Visual observations of fracture surfaces to identify where silica sol is found. Possibly preparation of thin sections of silica sol/rock along fracture.
- Analyses of data.
- Reporting.

The coupling between penetration of grout, hydraulic conductivity, and the specific surface area, which is likely to influence the transport of both water and grout, will be investigated. Central issues are:

- Is it possible to predict the penetration of Newtonian fluids based on hydraulic tests and hydraulic conductivity (transmissivity)?
- Do sand column tests and analytical estimates indicate that the penetration length in sand can be coupled to the penetration length in a fracture? The analyses should include results from the field test at Äspö HRL.

If there is an analytical coupling between observed penetration of grout in sand and in a fracture, penetration tests in sand could be used with more confidence in laboratory studies for predictions of fracture grouting. A final report for the entire project is planned to December 2004.

2.8 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 drifts (KBS-3H) instead of vertical emplacement of single canisters in the deposition hole (KBS-3V) has been considered since early nineties, see Figure 2-5. The deposition process requires that each copper canister and its buffer material are assembled into a prefabricated perforated disposal container.

Late 2001 SKB published an R&D programme for the KBS-3 method with horizontal emplacement. The RD&D programme /SKB, 2001b/ 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.

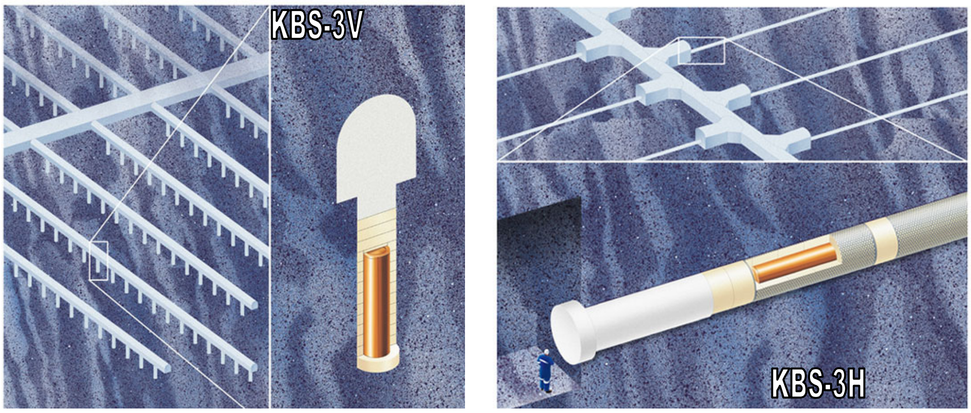


__Figure 2-5.__ Schematic illustrations of variants of the KBS-3 method.

Objectives

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

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 deposition drifts, the deposition technique and the function of the buffer.

Present status

The Basic Design phase will be reported early 2004. Within Basic Design three different sub-projects have been carried through:

- Technical development of the KBS-3H concept. It includes conceptual design of equipment for deposition of a 50 tonnes container using a lifting technique with water cushions. It also includes design, manufacturing and testing of a cluster drilling machine.
- Preparations for a future demonstration of the concept at Äspö HRL. A niche has been excavated at the -220 m level and exploration drilling has been performed for the future deposition drifts.
- Studies of the barrier performance of the KBS-3H concept has partly been performed. An expert review of the concept and safety evaluation has been performed and reported. A literature study of the interaction between Fe(II) and bentonite has been performed. Tests of bentonite barrier performance under expected repository conditions using a steel container and with high water pressure and flow are still ongoing.

Scope of work for 2004

Preparations for the full scale demonstration at Äspö HRL will continue and the following activities are planned for 2004:

- Finalisation of the test niche at -220 m level at Äspö HRL, including hydraulic characterisation of the rock mass and preparation of the invert.
- Boring of three deposition drifts with a diameter of 1.8 m, one 100 m long and two 30 m long drifts.
- Perform detailed design for the deposition equipment and start manufacturing. Container- and bentonite block dummies will also be needed for demonstration purposes.
- Continuation of buffer and long term safety issues and also other analyses, e.g. thermal analysis for estimation of required deposition area.
- Continuation of the work on critical issues for the KBS-3H project, including analyse and documentation of the design prerequisites.
- Discuss and establish a line of action for a presumed full scale test at Äspö HRL.
- Discuss and establish a line of action for retrieval strategies and activities.

2.9 Large Scale Injection Test

Background

The aim of the large scale gas injection test (Lasgit) is to perform a large scale gas injection test in a full-scale KBS-3 deposition hole.

The bentonite buffer is an important barrier in the KBS-3 system. The 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.

The small scale experiments that have been performed over the last ten years indicate that effects described above do not occur. The 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 and all these findings have to be verified in a large scale experiment. The project will be conducted as a SKB and Posiva joint project.

Objectives

The objective of this experimental programme is to undertake a large-scale gas injection test 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

The experiment will be performed in a bored full-size deposition hole at Äspö HRL. A full scale canister, without heaters, and a surrounding bentonite buffer is installed, see Figure 2-6. Water will be artificially supplied to the buffer and the gas injection tests will start when the buffer is fully saturated. The test is divided into a three phases: installation phase, hydration phase, and gas injection phase.

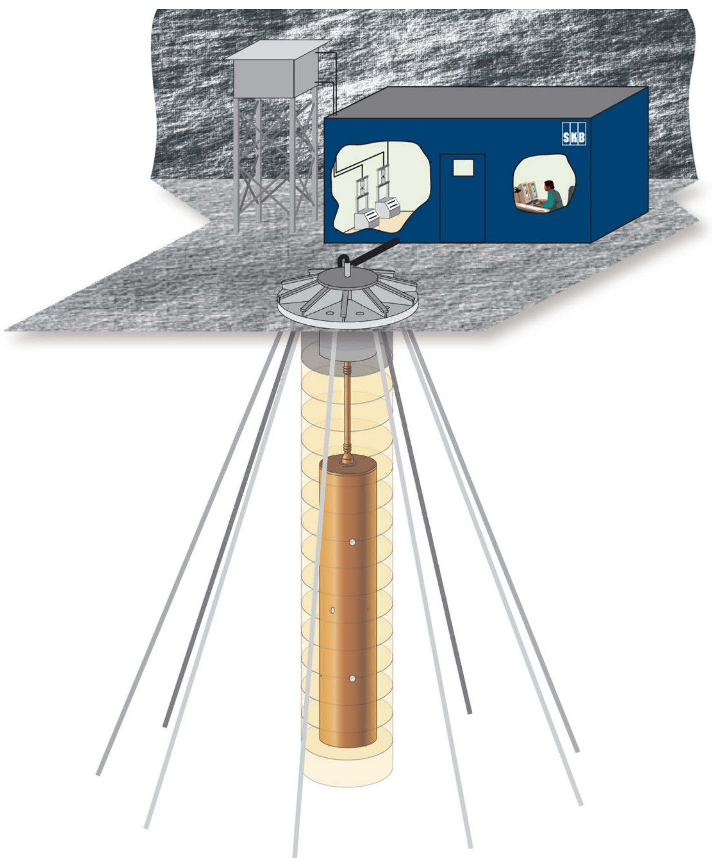


Figure 2-6. *Illustration of experimental set-up of the Large Scale Injection Test.*

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

- Characterisation of the deposition hole and hydraulic measurements of the wall of the deposition hole (major fractures and EDZ properties).
- Development of a technique for the manufacturing of buffer blocks with exceptional high water content. Manufacturing of a set of blocks for one deposition hole. 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.
- Instrumentation of the wall of the deposition hole.
- Design and construction of a gas injection and measurement field laboratory and installation of the laboratory at the site.
- Testing of the equipment before deposition of the canister.
- Preparatory works in and around the deposition hole.
- Installation of canister and buffer in the deposition hole.
- Installation of the lid and sealing of the deposition hole.

The aim with 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 clay 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* starts when the buffer is considered to be fully saturated. Gas injection might be accomplished using a combination of controlled flow rate and constant pressure test stages.

Present status

Planning of and preparations for the installation of the test have been made during 2003. The test will take place in an existing deposition hole (DA3147G01) in the TBM drift. The information available on the hole is sufficient and no new characterisation is planned.

The bentonite blocks to be used in the test have been manufactured in a hydrostatic well press (30 000 tonnes). The goal was to achieve a water saturation degree of 95 % in the rings (surrounding the canister) and 98 % in the cheeses (emplaced above and below the canister). The pressing was successful and resulted in 1 % higher water saturation degree in all blocks. A full-scale canister with gas injection equipment and instrumentation is being manufactured.

The measurement field laboratory hosted in a blue container, designed and constructed by BGS Nottingham, is as well being manufactured.

A lid for the upper part of the deposition hole, very similar to the one used in the Temperature Buffer Test, has been designed and is under construction.

Scope of work for 2004

The installation phase including testing of the gas injection system and other equipment is planned to be completed before the summer. The artificial saturation of the buffer, the hydration phase, will start as soon as the installation is completed. The hydration phase is expected to take about two years. The saturation process will be monitored and the gas injection will start when the buffer is considered fully water saturated.

Predictive modelling performed of the saturation phase will be evaluated against monitoring data.

2.10 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 EBS 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 (TBT) 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 2-7.

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.

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 comparison of results.

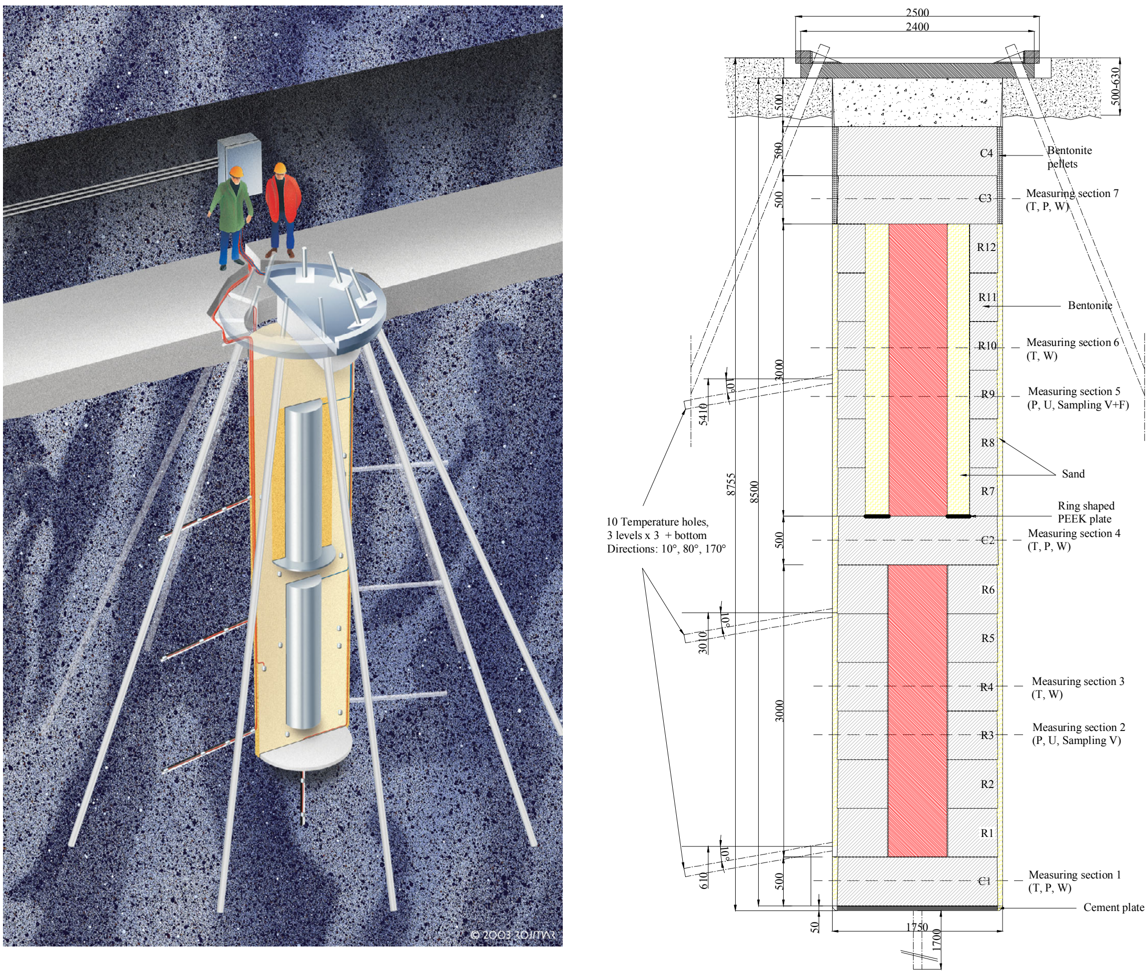


__Figure 2-7.__ Principle design and experimental set-up of the Temperature Buffer Test.

Present status

During 2002, TBT design modelling, procurement of instruments, fabrication of bentonite blocks have been carried out by Clay Technology and heater probes built by AITEMIN.

Early 2003, the experiment has been installed in Äspö HRL. The operation phase started late March 2003. Artificial water pressure and heater power have been set according to plan. Monitoring and sampling of experimental data are continuously ongoing during the operation phase. A data link to Andra´s head office in France has been established.

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.

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

Scope of work for 2004

The operation phase continues. Planning for the evaluation modelling is under way and an evaluation programme should be issued in March 2004. Then the modelling group will resume its work, with the aim of issuing a report early 2005.

Active management of the test is likely to augment the results. The heat output could be increased in the composite buffer to try to produce controlled desaturation. The suitability of such an action is currently being assessed.

In parallel with TBT, research on the phenomenology of bentonite samples subjected to temperatures exceeding 100°C are conducted by the French CEA on a mock-up.

2.11 Shearing of canister in deposition hole

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 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 theses 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 (small up to 1:10 scale). The results need, however, 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 would act on a KBS-3 canister if a displacement of 100 mm would take place in a horizontal fracture that crosses a deposition hole at mid-height (worst case scenario). Such a displacement is considered to be caused by an earthquake, and the test set-up need to provide a shearing motion along the fracture that is equal to an expected shearing motion in real life.

Present status

Different investigations have been made and the latest work was done in the laboratory with shearing of the buffer at different shearing speeds up to 6 m/s. The results form the basis in a material model. The work also comprised finite element calculations of a 200 mm long horizontal shearing across a deposition hole. In the calculations the shear place in the hole, the shear speed and the density of the buffer were varied. The calculations show that the actual values of the varied parameters have a substantial impact on the result. At the combination of a shear speed of 1 m/s, displacements of 200 mm and a buffer density of 2.1 Mg/m^3 will the iron insert yield a plastic deformation with up to 19 %, while the deformation becomes only 1.6 % for a buffer density of 2.0 Mg/m^3 and a displacement of 100 mm.

Today a good theoretical basis exists for analysis as well as prediction that provides for an accurate planning of an *in situ* test.

Experimental concept

The test set-up is planned to use the site of the Äspö Pillar Stability Experiment (APSE, see Section 3.5) when the rock mechanics test there has been completed. Two full scale deposition holes then exist with a rock pillar of 1 m in between. Figure 2-8 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 (is partly fractured after the APSE test) and replaced by concrete 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 concrete 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 (shown in the figure) or by cable bolts as in Canister Retrieval Test and Temperature Buffer Test.

The shearing may not be done before the buffer has saturated, but this time can be reached after two years by using highly saturated bentonite blocks, 95–98 % saturation, and lining the hole with permeable mats for artificial water supply. Needed shearing speed is between 0.1 and 1 m/s. If the lower speed is chosen pistons may be used as shown in Figure 2-8, but if the higher speed is required another technique is probably more favourable.

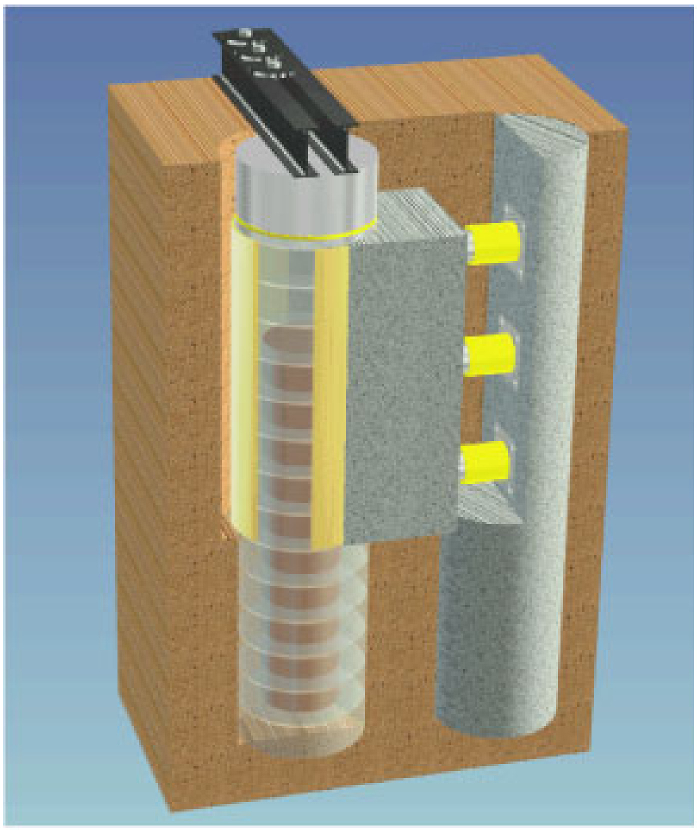


Figure 2-8. *Schematic view of a possible test set-up for verification of the stress and strain a canister may exhibit during an instant shearing of 100-200 mm.*

Scope of work for 2004

The first phase, which will last all of 2004, is a pre-study of design and feasibility. Scoping calculations are assumed to indicate the forces and shearing speed needed and thereby provide the basis for the design of the test set-up. The expected outcome during 2004 is a preliminary design of the test geometry that is based on mechanical calculations and analysis of earthquake parameters.

2.12 Learning from experiences

Background

Several large-scale experiments have during the years been installed in Äspö HRL and methods and machines used have provided experiences for refinement and evaluation of limits of the methods applied. Emplacement of buffer and canisters, and backfilling of tunnels have been experienced in Canister Retrieval Test, Prototype Repository and Backfill and Plug Test.

In this project these experiences are documented and analysed with respect to possible improvements as well as limit on acceptable water inflows.

Objectives

The aim is to identify techniques by:

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

Present status

Each experiment has been reported in installation reports. A draft report that summarises the experiences gained and the conclusions drawn from more than ten years underground activities in Äspö HRL has been prepared.

A major programme is run on development of backfill material and means of backfilling deposition tunnels. Field tests may be needed in the future.

Scope of work for 2004

The summary report will be completed and published during 2004. Field tests are initiated on the issue of how water inflow can affect the installed bentonite blocks and *in situ* compacted backfill, and what measures can be taken to avoid such effects, which are deemed to be unacceptable.

2.13 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 will cease in February 2004 it is judged most convenient to activate the Task Force on EBS and continue the modelling work in the Prototype Repository project within this frame, where also modelling work on all other experiments can be conducted. One possibility is also to incorporate the modelling work on EBS experiments carried out in the Grimsel Test Site (GTS) in Switzerland.

Present status

The issue of establishing a Task Force on EBS was revisited during this year's Äspö International Joint Committee meeting. The issue was also raised during this years ISCO meeting (Grimsel Test Site – annual scientific meeting). The indication in both those fora was that there is a need for a co-ordination of similar activities, like conducting modelling work that uses data from experiments in both Äspö HRL and GTS. The IJC meeting recommended SKB to make a proposal, for consideration by the

Äspö HRL participants in the first place, having the goal of fulfilling integration needs as well as being activated in early 2004.

Such a proposal was compiled based on the year 2000 discussion, which resulted in a priority list:

- THM modelling of processes during water transfer in buffer, backfill and near-field rock.
- Gas transport in saturated buffer.
- Hydraulic regime around canister holes after saturation.
- THC in buffer (redox and salt concentration).

A brief review of this earlier result indicates that the top two priorities still are of prime importance and that a Task Force around those two modelling issues would be of interest to initiate.

Scope of work for 2004

A modelling meeting will be held in March 2004 with the prime aim of establishing the progress in modelling, primarily in the Prototype Repository project, since the last modelling meeting in December 2000. Results of modelling work have been presented regularly at the different project's progress meetings but not with the in-depth penetration of pros and cons, which is the intension at the planned event. At this occasion will "Topics" and not "Projects" be in focus for the presentations, like THM processes during saturation and modelling results from different field experiments. The objective is to form a substantial basis for judgement of the present status.

This event will also bring up the issue of the Task Force with the intention to outline the prime issues and to form a proposed programme for the official decisions on the activation of the Task Force on engineered barrier systems.

3 Geo-science

3.1 General

Geo-scientific research is a part of the activities at Äspö HRL as a complement and an extension of the stage goals 3 and 4. Studies are performed in laboratory and field experiments as well as by modelling work. For rock mechanics is all SKB's work directed from the staff of Repository Technology having Äspö as its base. The major aims are to:

- Establish and maintain geo-scientific 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 measurements that can be used in site investigations.
- Determine the rock mechanics characteristics at potential repository depths at candidate sites.
- Develop methods for numerical modelling of stress and strain evolution, and methods for *in situ* stress measurements.

3.2 Geological mapping and modelling

Background and objectives

This coming project aims at developing a new method to be used in the construction of a deep repository. The major reasons to develop a new system for underground mapping are aspects on time required, precision in mapping and traceability. Required mapping time will be unreasonably high with the present system. An increased precision in geological mapping is required for geological features when constructing a deep repository. Increased traceability means that SKB will have better possibilities to establish the tunnel environment pre-rock support and pre-backfilling, thereby showing foundations for interpretations concerning geology, rock mechanics and tunnel maintenance. At this initial stage, the major objective is to decide whether SKB should use a system based on laser scanning, digital photos or another alternative method. Contact has been taken with Posiva, in order to establish a possible co-operation in finding an efficient system for digital underground mapping.

Present status and scope of work 2004

During summer and autumn 2003 the new, 71 m long Q-tunnel has been mapped. Digitized map and associated data has been fed into the Tunnel Mapping System (TMS) database. The report from geological mapping is in progress.

The work of updating the three dimensional RVS models of Äspö will continue. An update of the RVS tunnel layout is planned to be available in the beginning of 2004. Data from mapping and modelling of the TASQ-tunnel will be added to the present RVS models. Further improvements in the models will be added as deformation zones and other geological features are established.

The work of developing a new system for underground mapping has started during autumn 2003. It will continue during 2004 and probably also during the following years. An updating of the documents and instructions concerning the present system for underground mapping will be presented during 2004.

3.3 Rock stress measurements

Background and objectives

To be able to make correct assessments of the *in situ* stress field from results from different types of rock stress measurement techniques it is important to know the limitations and shortcomings of the different measurement techniques. Rock stress measurements with different techniques (bore probe, doorstopper and hydraulic fracturing) have during the years been performed as well as numerical modelling of the stresses.

Present status and scope of work for 2004

A co-operation with Posiva with the objective to quality-assure overcoring data has been initiated. The first phase has been completed which includes development of a numerical tool for predictions of isotropic and elastic conditions in rock. SKB has contributed with seven articles to the special issue of the International Journal of Rock Mechanics and Mining Sciences /IJRMMS, 2003/ where ISRM’s suggested strategy for rock stress measurements is presented.

3.4 Rock creep

Background and objectives

The understanding of the material properties of rock and rock-mass are being developed. The objective with the work is to be able to develop better conceptual models for the influence of the rock damaged zone and rock creep on rock stability.

Present status and scope of work for 2004

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

3.5 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 is 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 has been excavated in Äspö HRL to ensure that the experiment is carried out in a rock mass with a virgin stress field. In the new drift a vertical pillar is constructed in the floor between two large boreholes, each with a diameter of 1.8 m. The pillar is 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 will be drilled in the floor of the tunnel so that the distance between the holes is 1 m. To simulate confining pressure in the backfill (0.8 MPa), one of the holes will be subjected to an internal water pressure via a liner. Convergence measurements, LVDT's, thermistors and an acoustic emission system will be used to monitor the experiment. The experiment drift has a rounded floor to concentrate the stresses in the centre of the drift. The finished drift is shown in Figure 3-1.

Present status

During 2003 the following work with the experiment has been performed:

- The equipment for the confinement pressure has been manufactured and tested.
- The new drift, TASQ, has been excavated and the precise location for the experiment in the drift has been selected.
- Core drilling of holes for instruments and laboratory tests of rock properties has been done and evaluated.
- Convergence measurements during the excavation of the drift was performed and back calculated to derive the *in situ* stress field and Young's modulus of the rock mass.
- The final numerical modelling of the experiment using updated parameters has been performed with the codes Examine3D, JobFem, Flac3D, PFC2D and FRACOD.
- All instruments for the monitoring of the experiment has been purchased and delivered, the acoustic emission system is already installed in the rock.

Figure 3-1. *The experimental TASQ drift shortly after the excavation.*

Scope of work for 2004

During 2004 the following activities are planned:

- The first of the two large boreholes will be drilled and the confinement equipment will be installed and pressurised. The second hole will be drilled thereafter.
- The instruments in the second hole will be installed as well as the electrical heaters outside the pillar.
- The heating will start early 2004 and is planned to be completed in July.
- The evaluation of the experiment will start.

3.6 Heat transport

Background

The deposit canisters generate heat due to radioactive decay. The temperature field in the repository depends on the thermal properties of the rock and the generated heat. The layout of the repository is dependent on the temperature field. The design criterion is the maximum temperature allowed on the surface of the canisters. A low thermal conductivity in the rock leads primarily to a larger distance between canisters than in the case of a high thermal conductivity.

Objectives

The aim of the heat transport project is to develop a strategy for site descriptive thermal modelling to decrease the uncertainties in the estimates of the temperature field in a repository. Less uncertain estimates of the temperature field make it possible to optimise the distance between canisters in the repository layout. The work includes measurements of thermal properties of the rock, examination of the distribution of the thermal conductivities, and to analyse the thermal properties at different scales.

Present status

Three reports dealing with heat transport have been completed during 2003. A strategy for the thermal model development during site investigations is presented in Sundberg /2003a/. An investigation of the distribution of thermal properties at Äspö HRL, scale factors and correlation between thermal properties and density is presented in Sundberg /2003b/. In Sundberg *et al.* /2003/ a comparison between different methods to determine thermal properties is made.

Scope of work for 2004

During 2004 work is planned in the following areas:

- Verify the prognosis of thermal properties at the Prototype Repository by inverse modelling.
- Study of the scale dependency of thermal properties and anisotropies by analysis of density loggings, measurements and inverse modelling.
- Analysis of uncertainties in data and data value analysis.

3.7 Seismic influence on the groundwater system

Background and objectives

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

The data in the database are assumed to bear witness of different seismic activities in Sweden but also abroad, dependent on the magnitude of the event, as well as the position of the epicentre. By analysing the data on changes in the piezometric head at Äspö connections to specific seismic events are expected to be established.

Present status

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

Scope of work for 2004

The software development for cross comparison of different databases should be finalised. The impact of earthquakes in Sweden and abroad and the effects of blasts in Äspö HRL as well as in CLAB, during the extension of the underground storage capacity, will be analysed and documented.

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.

The experiments are related to the rock, its properties, and *in situ* environmental conditions, and 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 deep 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 deep repository.
- Clearly present the role of the geosphere for the barrier functions: isolation, retardation and dilution.

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

- Tracer Retention Understanding Experiments.
- Long Term Diffusion Experiment.
- Radionuclide Retention Experiments with CHEMLAB.
- Colloid Project.
- Microbe Project.
- Matrix Fluid Chemistry.
- Äspö Task Force on Groundwater Flow and Transport of Solutes.
- PADAMOT (Palaeohydrogeological Data Analysis and Model Testing).
- Fe-oxides in fractures.

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, which will be 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. A subsequent 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 4-1. A test of the integration and modelling of data from different length scales and assessment of effects of longer time perspectives is made as part of Task 6 in the Task Force on Modelling of Groundwater Flow and Transport of Solutes, see Section 4.8.

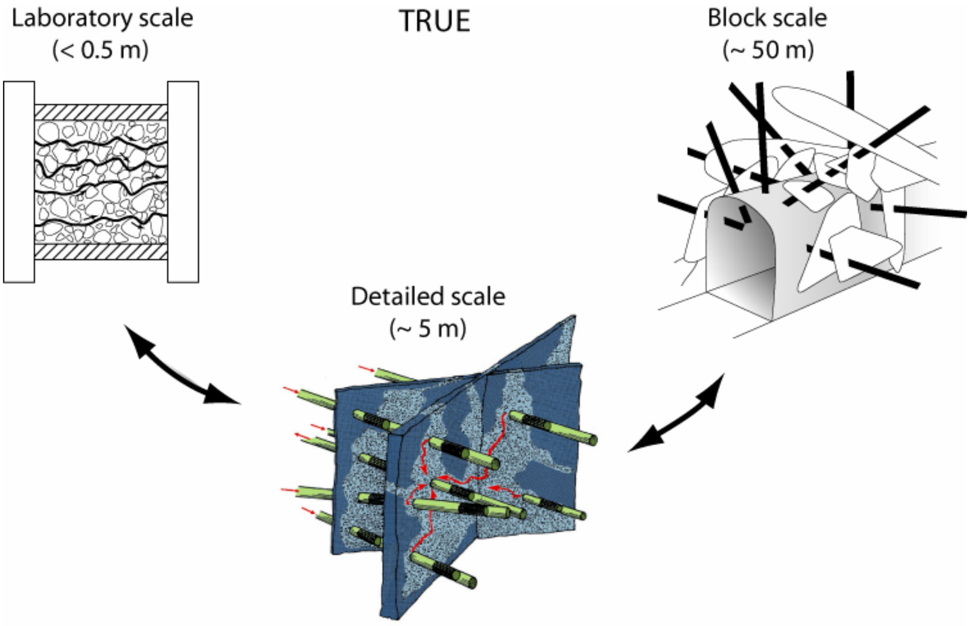


Figure 4-1. *Schematic representation of transport scales addressed in the TRUE programme.*

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

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.

Present status

During 2003 work in TRUE Block Scale Continuation has included preparations for planned new *in situ* tracer tests. This work has included modelling in support of the planned experiments, optimisation of borehole piezometers and initiation of *in situ* pre-tests. The modelling has identified that experimentation over to long distances and in too complex fracture networks will render too long experimental times and too high mass losses. As a consequence focus was placed on Structure #19 (located in the interior of the studied rock volume) , branches thereof and associated background fractures. Additional modelling has addressed specifically the role of background fractures within the framework of a unified framework applied to fractures at multiple scales /Darcel, 2003/, effects on retention by various types of heterogeneity along flow paths /Poteri, 2003/, and effects of correlated properties and finiteness of the altered rim zones on retention along studied flow paths /Cvetkovic, 2003/. Reinstrumentation of boreholes KI0025F02 and KI0025F03 with special emphasis on Structure #19 and its environs has been made. Subsequently, three cross-hole interference tests (CPT-1 through CPT-3) combined with tracer dilution tests were performed aimed at identifying suitable sink and injection sections for the planned tests. These tests singled out a pump section in KI0025F03 including Structure #19 as the best suited one. The tests did, as the installation tests, not show favourable results with regards to prospects of using a injection section in Structure #25 in the neighbouring KI0025F02. As of October a long-term test with non-sorbing tracers (CPT-4) is underway, pumping in KI0025F03 (#19) and injection within Structure #19 (including the branch) in KA2563A and injection in Structure #25 in KI0025F02. Results thus far show good prospects for the planned tests.

In parallel work has started up to produce an updated geological and micro-structural model of Structure #19 and its immediate surrounding. This work builds on models presented by Andersson *et al*., /2002/. In addition, plans are to inform the deterministic structures in the TRUE Block Scale rock volume in parity with what has been presented as part of Äspö task Force Task 6C /Dershowitz *et al*., 2003/. Supporting information to the planned predictive and evaluation modelling is provided by the Fault Rock Zones characterisation and laboratory sorption programme performed as part of the TRUE-1 Continuation project, see Section 4.2.2.

Scope of work for 2004

Work planned for 2004 is dominated by the *in situ* experiments with sorbing tracers. This experimental phase will commence in January and is planned to be terminated in May. These *in situ* efforts are paralleled by model predictions employing four different modelling approaches. Following a basic evaluation of the *in situ* tests an evaluation is made using the four approaches. Reporting is due mid 2005.

4.2.2 TRUE-1 Continuation

The TRUE-1 Continuation project is a continuation of the TRUE-1 experiments, and the experimental focus is here placed on the TRUE-1 site. The discussion and outcome of the 4th International Äspö Seminar (focused on the First TRUE Stage) re-emphasised the need for conducting the planned injection of epoxy resin at the TRUE-1 site. However, before conducting such an impregnation, some complementary cross-hole hydraulic interference tests combined with tracer dilution tests are foreseen. These tests are intended to shed light on the possible three-dimensional aspects of transport at the site. The planned tests would employ both previously used sink sections and some not employed in the already performed tests.

A complication for the scheduling of planned future work 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 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.
- To provide an improved understanding of the constitution, characteristics and properties of fault rock zones (including fault breccia and fault gouge).
- To provide insight into the three-dimensionality of the rock block studied as part of the First TRUE Stage such that the role and effects of the fracture network connected to Feature A on the performed tracer tests can be assessed.
- To test a methodology to estimate fracture aperture from radon concentration in groundwater and radon flux from geological materials.
- 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 identified remaining field and laboratory activities related to the TRUE-1 site includes:

- Complementary cross-hole interference, tracer dilution, and tracer tests with conservative tracers.
- Water sampling and analyses including analyses of radon concentration in groundwater and measurements of radon flux from various geological materials and subsequent evaluation.
- 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.
- Batch sorption experiments on rim zone and fault gouge materials from the TRUE Block Scale site and from other locations along the access tunnel, including zones investigated as part of the Fault Rock Zone characterisation project.
- Injection of epoxy resin into the previously investigated Feature A, with subsequent excavation and analyses.

Present status

The TRUE-1 Continuation has as one of its principal objectives to map the porosity of the investigated Feature A at the TRUE-1 site. A pre-runner for this undertaking is the so-called Fault Rock Zones Characterisation Project. The principal goal is here to learn more about the pore structure of fault rock zones using injection of epoxy resin and subsequent overcoring. Additional understanding is gained through structural-geological work, mineralogy/geochemistry and hydrogeology. During the year, 16 exploration boreholes of 76 mm diameter have been drilled at the four identified geological structures of variable dignity. Subsequent characterisation identified three of the zones as suitable for quantifying analysis, resulting in seven boreholes being useful for epoxy injection. New injection equipment was devised enabling injection of epoxy and the wetting agent (isopropanol) interchangeably. Sections in the boreholes including the target structure were packed off using a mechanical packer. The test section volume was minimised by including a 74 mm polyethylene dummy body. Some 0.1 to 1 litres of epoxy was injected at injections pressures below 10 bars above ambient pressure. The seven impregnated borehole sections will be overcored using a 300 mm drillbit/core barrel that will produce a 277 mm drill core.

The objectives of the Laboratory sorption programme have multiple purposes. These include to provide sorption data for the type of sorbing tracers that so far has been used in the TRUE programme (Mainly tracers sorbing with cation exchange as the major mechanism) using geologic material from Structures #13, #19, #20 and #22 in the TRUE Block Scale experiment. Structures #13, #20 and #22 are presumed to have been involved in the different flow paths in the TRUE Block Scale phase C experiment. Structure #19 is aimed to be the major target for the TRUE Block Scale Continuation experiment. In addition to make sorption studies addressing fault gouge material from the SKB site investigation programme. This activity is a direct link between the TRUE and the laboratory sorption experiment in the site investigation. Furthermore, to provide cation exchange characteristics of geological materials: CEC, fractional occupancies and selectivity coefficients. The latter is performed in order to evaluate the validity of the predictions of sorption properties of fault gouge materials made by Andersson *et al.* /2002/.

Scope of work for 2004

Preliminary results from the laboratory sorption experiments will become available early 2004, which will enable their inclusion in predictive modelling for TRUE Block Scale Continuation sorbing tracer tests. Subsequent analysis and reporting are due in June.

Overcoring to retrieve the epoxy-impregnated portions of the studied fault rock zones is planned to commence in January. Analysis of pore space and complementary geological, mineralogical and geochemical analysis will follow. The analysis of pore space will be performed using image analysis techniques. Subsequently, updates of conceptual models of fault rock zones will be carried out. Preliminary, foremost qualitative, results may be fed into the evaluation of the TRUE Block Scale *in situ* tests with sorbing tracers.

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- and *in situ* 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 in 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-2/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/, which will be subject to a separate report to be presented.

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.
- To improve the understanding of sorption processes and obtain sorption data for some radionuclides on natural fracture surfaces.
- To 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 4-2.

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 away 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 4-3.

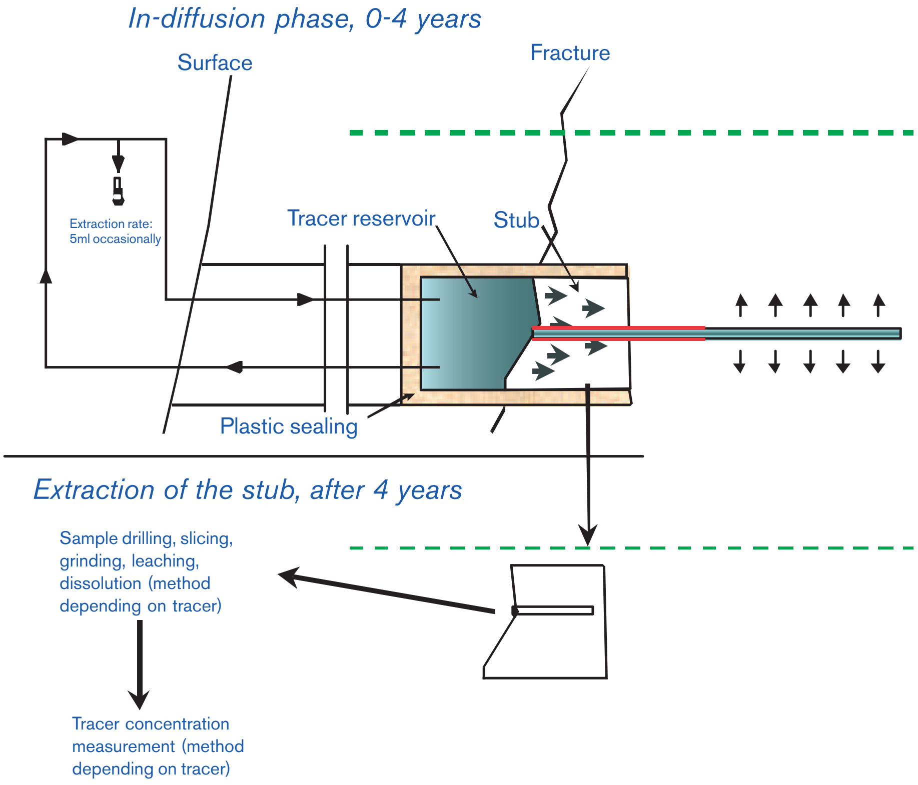


***Figure 4-2.** LTDE experimental concept including injection borehole in contact with a fracture surface.*

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 an 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*. 2004/.

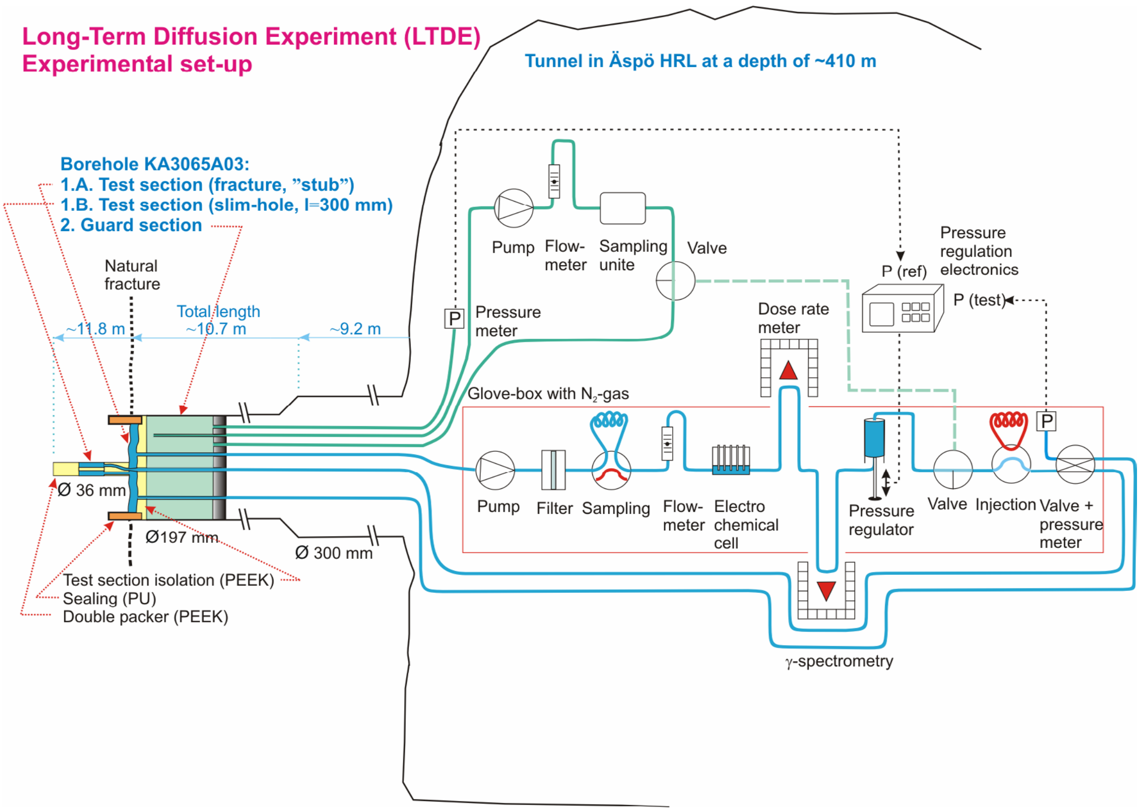


Figure 4-3. *LTDE experimental set-up in the experimental borehole including the water circulation system to the test-section and the hydraulic pressure control system*

Present status

The following topics have been carried out during 2003:

- Instrumentation of the LTDE test-site.
- Start of a installation-test programme focused on system function control and simulation of extreme experimental conditions.
- Start of a pre-test programme in order to evaluate the hydrological conditions in the vicinity of the experimental borehole, KA3065A03, and to study possible hydrological interferences from other activities in Äspö HRL.
- Chemical and microbial analyses of water samples from the LTDE site.

Scope of work for 2004

The following topics are planned for 2004:

- Complete the installation-test programme and the pre-test programme.
- Complete the Failure Mode Effect Analysis (FMEA).
- Documentation of the experimental set-up in Äspö HRL.
- Initialize collaboration with OPG who are providing a technical expert on *in situ* diffusion from AECL, Canada.
- Start of LTDE by injection of radioactive tracers.
- Planning and start of laboratory experiments.

4.4 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, of organic matter, of 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 can be obtained representative for the properties of groundwater at repository depth.

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 tested.

Objectives

The objectives of the radionuclide retention experiments are:

- To validate the radionuclide retention data which have been measured in laboratories by data from *in situ* experiments.
- To demonstrate that the laboratory data are reliable and correct also at the conditions prevailing in the rock.
- To decrease the uncertainty in the retention properties of relevant radionuclides.

Experimental concept

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 4-4. 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 4-5 the principles of the CHEMLAB 1 and CHEMLAB 2 borehole laboratories are given.

In the currently ongoing or already completed experiments the following are studied:

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

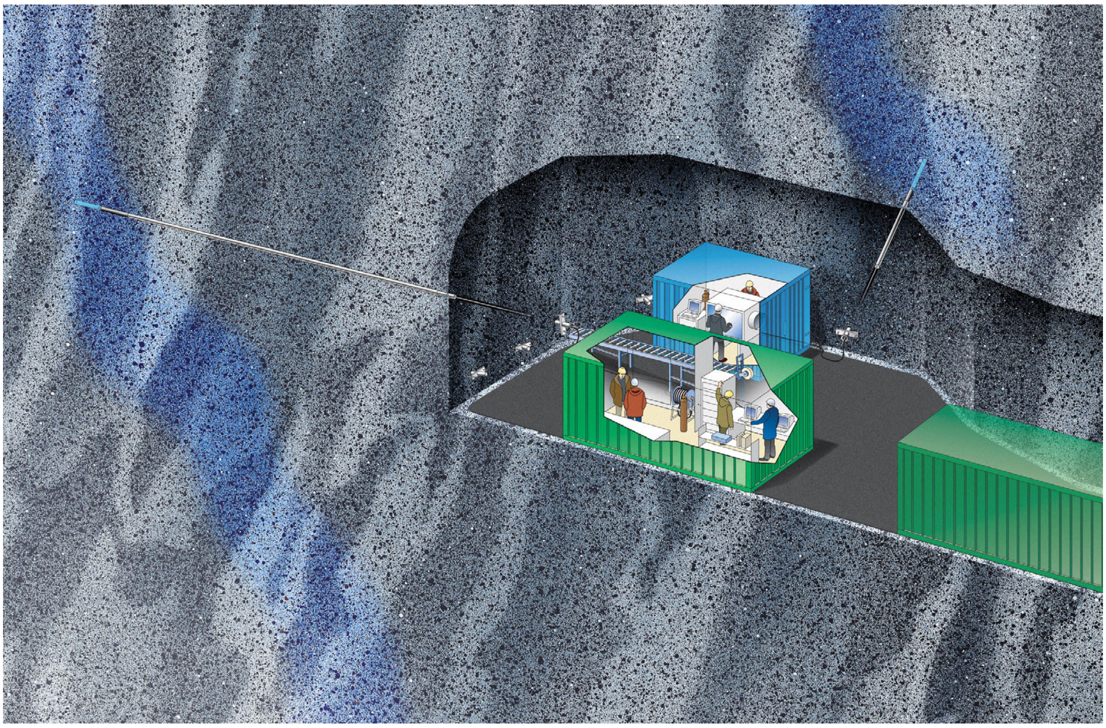


Figure 4-4. *Illustration of the experimental set-up of the Radionuclide Retention Experiments.*

Radiolysis experiments

Reduced technetium will be placed in a diffusion cell containing bentonite. In the experiment with primary formed water radiolysis products the technetium tracer is placed on an irradiation source at the bottom of the cell (direct irradiation). In the experiment with secondary formed products the technetium tracer will be placed inside the cell while an irradiation source will be placed outside the cell (indirect radiation).

Migration of actinides

Experiments on the migration of actinides, americium, neptunium and plutonium, in a natural rock fracture in a drill core are carried out in the CHEMLAB 2. The rock samples are analysed with respect to the flow-path and to the actinides sorbed onto the solid material. Non-destructive and destructive techniques will be applied, such as x-ray computer tomography and cutting the samples after injection of fluorescent epoxy resin. The distribution of actinides along the flow-path will be determined from the abraded material gained by cutting, as well as by coupled laser ablation ICP-MS techniques of the slices.

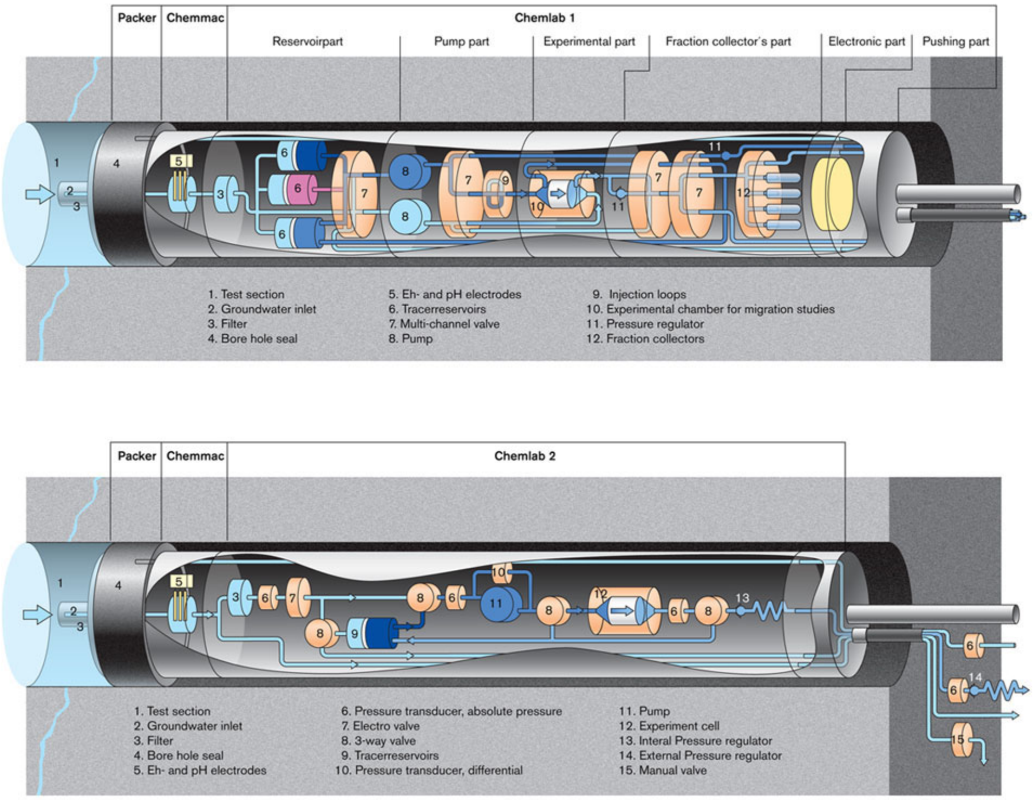


Figure 4-5. *Schematic illustration of CHEMLAB 1 and 2 borehole laboratoriies.*

Present status

Diffusion in bentonite

Experiments on diffusion of cations (Co^{2+}, Sr^{2+}, Cs^{+}) and anions (I^{-} and TcO_4^{-}) in compacted bentonite clay has been carried out with the CHEMLAB 1 unit. During 2001, the results were reported in a final report /Jansson and Eriksen, 2001/.

Radiolysis experiments

The field experiment is finished and the data from the experiments are evaluated. The final report of the radiolysis experiment is under progress and planned to be finished February 2004.

Migration of actinides

The third field actinide experiment has been performed and evaluated. The main finding from the experiment is that breakthrough of the actinides used (Am, Np and Pu) was not detected within the experimental time of about four months. Some conclusions are that Np is retained onto granite and altered minerals by reduction to Np(IV) in presence of Fe(II) minerals and that Pu sorption takes place on a multitude of minerals. The results from the third field experiment are reported in a technical report from Forschungzentrum, Karlsruhe /Kienzler *et al*., 2003/.

Scope of work for 2004

The final report of the radiolysis experiments will be completed in February 2004. The next experiment planned to be performed in CHEMLAB 1 is to investigate whether there is a resistance to transport in the interface between buffer material and rock (water carrying fracture in the rock) and if so, how great that resistance is. The study will include extensive tests in laboratory before the field experiment can be performed. The planning of the laboratory and field experiments will start as soon as the reporting of the radiolysis experiments is completed.

In March 2004 the last field experiment of the actinide migration experiments will be started. The experiment will be performed similarly as the previous ones, but the radionuclides to be studied are ^{233}U and ^{99}Tc. Technetium is not an actinide, but included in the experiment since the oxidised form, Tc(VII), occurs as pertechnetate, which is an anion. The actinide migration experiments will be followed by Spent Fuel Leaching experiments in CHEMLAB 2. The planning of the Spent Fuel Leaching will be started during spring 2004.

4.5 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 associated with the colloidal fraction of 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. The latter include background measurements, borehole specific measurements and dipole colloid experiments.

Laboratory experiments

The role of the bentonite clay as a source for colloid generation at varying groundwater salinity (NaCl/CaCl) was studied in laboratory experiments. Bentonite clay particles were dispersed in water solutions with different salinity and the degree of sedimentation was studied. The experiment investigated in detail the chemical changes, size distribution and the effects from Na versus Ca rich bentonite associated with colloid generation /Wold and Eriksen, 2002a; Karnland, 2002/.

Background measurements

The natural background colloid concentrations were measured in eight different boreholes during 2002, representing groundwater with different ionic strength, along the Äspö HRL-tunnel, see Figure 4-6.

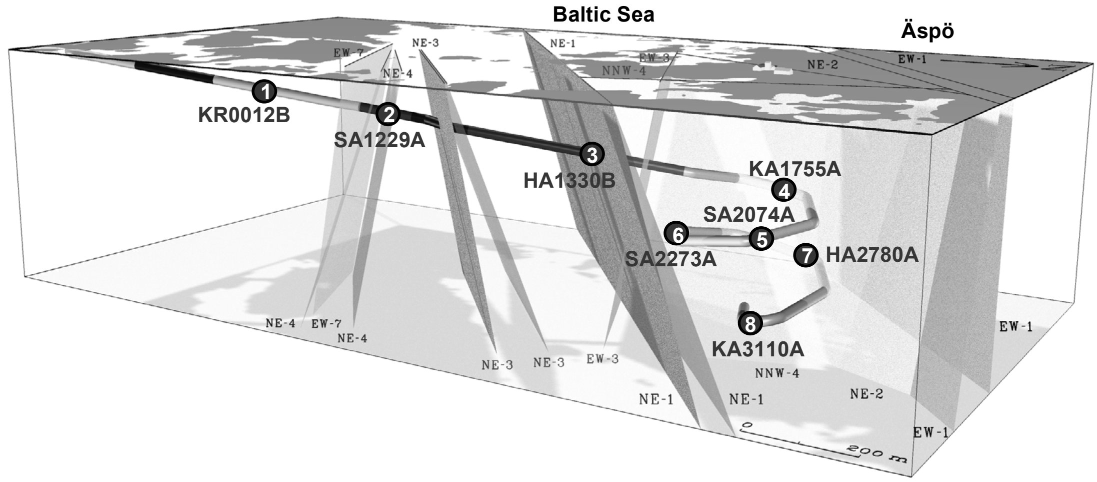


Figure 4-6. *The eight boreholes sampled for colloids along the Äspö tunnel.*

The colloid content is measured on-line from the boreholes by using modified laser based equipment LIBD (Laser-Induced Breakdown-Detection) which has been developed by INE in Germany, see Figure 4-7. The advantage is that the resolution of this equipment is higher compared with standard equipments. It is therefore possible to detect the colloid content at much lower concentrations than previously possible /Hauser *et al*., 2002/. The outcome of these measurements was compared with standard type of measurements such as particle counting by using Laser Light Scattering (LLS) on pressurised groundwater samples /Wold and Eriksen 2002a/. Standard type of filtration and ultra filtration was performed on-line/at-line of the boreholes /Wold and Eriksen 2002b; Vuorinen 2002/. In addition, samples of groundwater /Mattsén 2002; Rantanen and Mäntynen 2002/, microbes /Pedersen, 2002b/ and humic material /Buckau and Wolf, 2002/ were collected from the selected boreholes in order to judge the contribution from these on the measured colloid concentration. The electrical conductivity was measured along the tunnel from water venues in order to reflect the variability of the groundwater composition, which can affect the colloid stability /Gurban, 2002/.

The results from the background measurements indicate that the natural colloid content is decreasing with groundwater salinity and depth. Natural colloidal particles consist of organics, inorganic colloids (clay, calcite, ironhydroxide) and of microbes. The microbe content is increasing with the content of organic carbon. Microbes form few but large particles, organic particles are small but can have a high concentration. The concentration is decreasing with depth and salinity. The colloid content at Äspö is less than 300 ppb and at repository level it is less than 50 ppb /Laaksoharju *et al*., 1995; Degueldre 2002; Hauser *et al*., 2002; Wold and Eriksen 2002a; Vuorinen 2002; Gurban 2002; Wold and Eriksen 2002b; Mattsén 2002; Rantanen and Mäntynen 2002; Pedersen 2002b/.

Borehole specific measurements

The aim of the measurements is to determine the colloid generation properties of bentonite clay in contact with groundwater prevailing at repository depth. For this purpose laboratory tests were carried out in order to optimise the "colloid reactor" (filter textile with bentonite clay) design. For the borehole specific measurements 4 boreholes along the Äspö tunnel and 2 boreholes at Olkiluoto in Finland were investigated. The boreholes were selected so the natural variation in the groundwater composition at Fennoscandia was covered. The groundwater is in contact with the bentonite clay adapted in a container/packer equipment in the borehole and the colloid content is measured prior and after contact with the bentonite clay. The bentonite reactor is 50 cm long and installed in boreholes with a diameter of 36 mm. see Figure 4-8. The colloid content was measured by using conventional filtering and ultra filtration at different flow conditions. The results indicate that the colloid release from the bentonite clay at prevailing groundwater conditions is small and the increased flow did not increase the colloid release from the bentonite reactor.

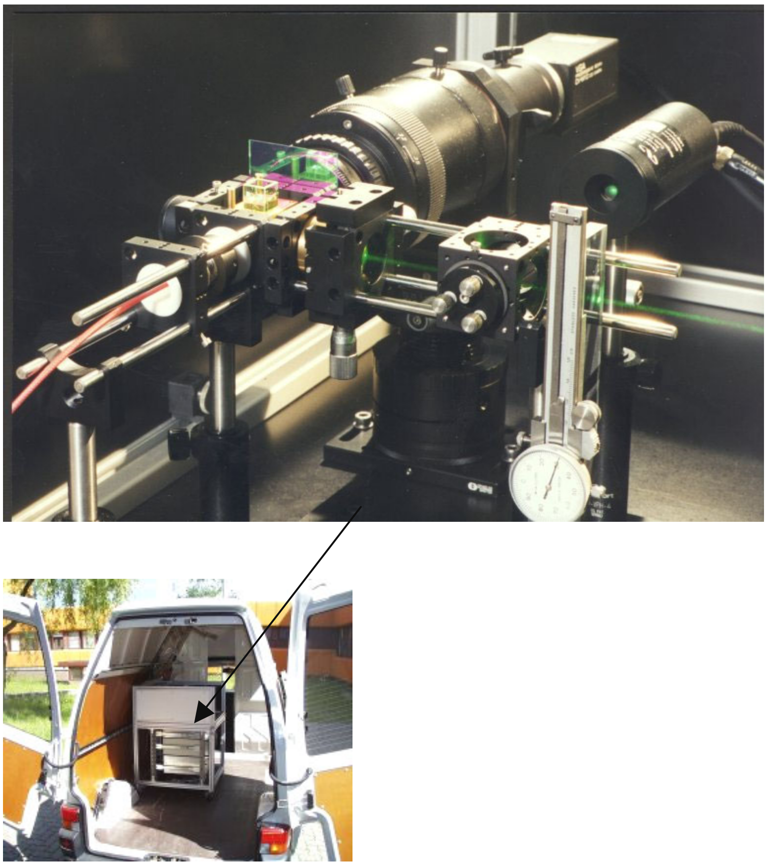


Figure 4-7. *Equipment for Lacer-Induced Breakdown-Detection (LIBD) of colloids (upper picture). The equipment is installed in a van in order to allow mobility and on-line measurements (lower picture).*

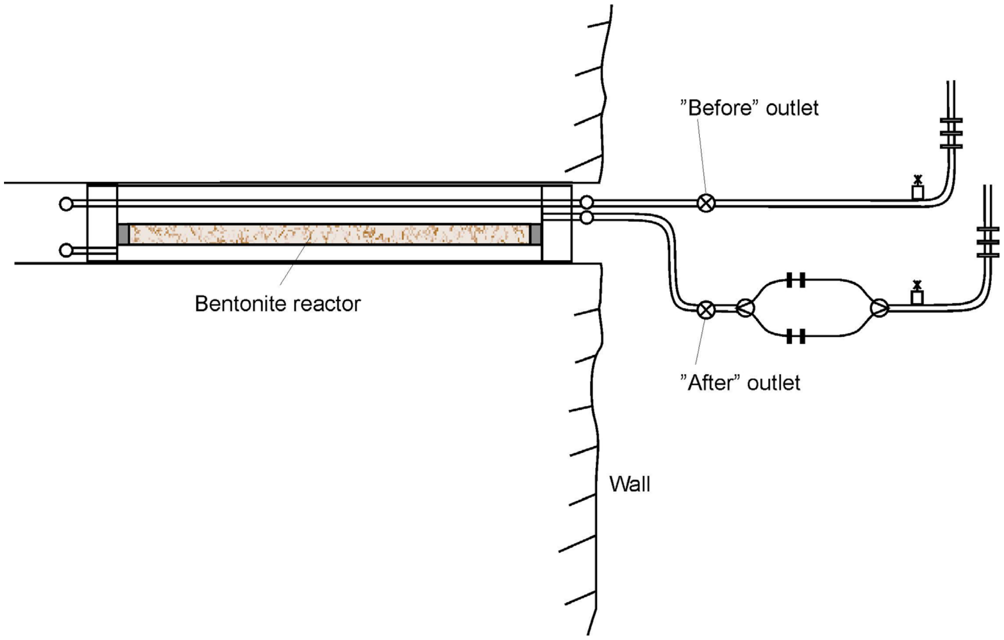


Figure 4-8. *The natural groundwater is in contact with the bentonite clay surrounded by a filter textile. The water flowing by the reactor is sampled and analysed. A bypass allows colloid determination of the natural groundwater. The aim is to determine the colloid generation potential from the bentonite in contact with the water.*

Dipole colloid experiments

The dipole colloid experiment is a fracture specific experiment planned to be performed within the Colloid Project during the time period 2003–2006. According to present plans two nearby boreholes intersecting the same fracture having the same basic geological properties will be 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. After assessing the natural colloid content in the groundwater, bentonite clay will be dissolved in ultra pure water to form colloidal particles. The colloids are labelled with e.g. a lanthanide and the fluid is labelled with a water conservative tracer. The mixture will be injected into the injection borehole, see Figure 4-9. The colloidal content will be measured with laser (LIBD/LLS), the water is filtered and the amount of tracers is measured. The result of major interest is the changes in colloid content prior and after the transport through the fracture. The outcome of the experiment will be used to check performed model calculations and to develop future colloid transport modelling.

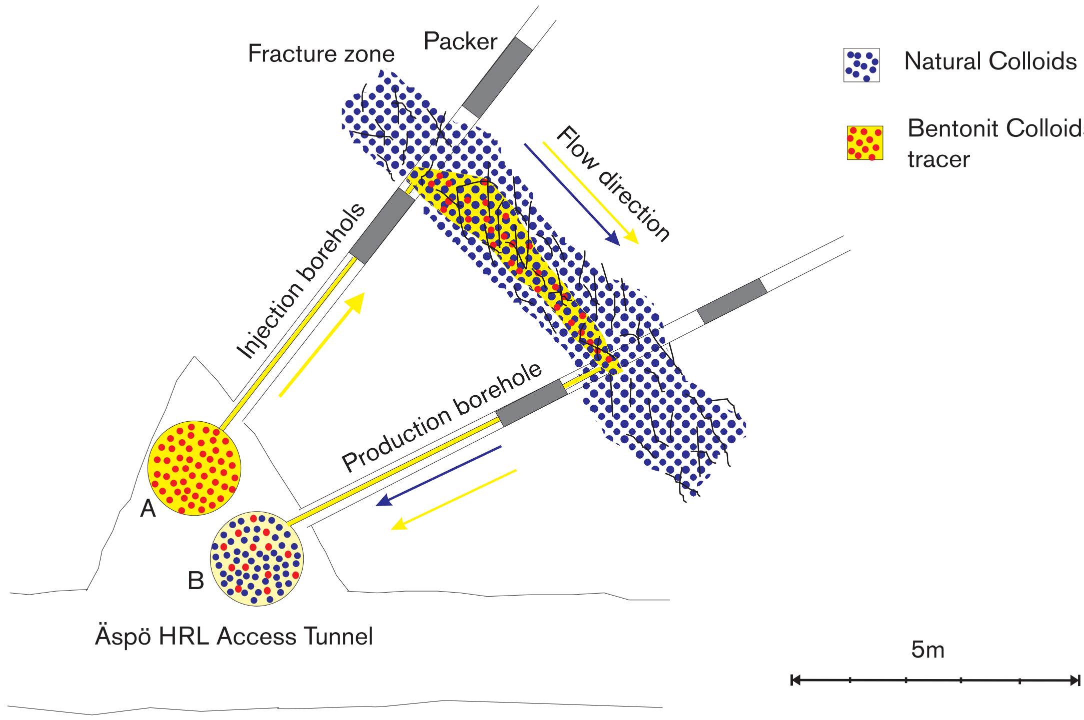


***Figure 4-9.** Dipole colloid experiments – injection of bentonite colloids and monitoring of the injected and natural colloids in the production borehole.*

Present status

A status report including the results from the laboratory experiments and background measurements was printed in March /Laaksoharju, 2003/. The borehole specific measurements were carried out during the first half of the year 2003. The compilation of the final report including laboratory experiments, background measurements and borehole specific measurements is in progress and will be ready in March 2004. The initiation and planning of the dipole colloid experiments started in August 2003.

Scope of work for 2004

The following will be performed:

- Final report for the first phase of the project (March 2004).
- Project steering, initiation and preparation for the dipole colloid experiments.
- Realisation of Task #1 (Detailed planning and manufacturing of test equipment), Task #2 (Laboratory experiments with e.g. labelling of the colloids) and Task #3 (Planning and testing colloid facilitated transport of tracers in the fracture zone) within the dipole colloid experiments.

4.6 Microbe Project

Background

Micro-organisms 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 /Pedersen, 2002a/. 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/. 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 sites for microbiological investigations in the Äspö HRL tunnel. The main site is the MICROBE laboratory at the -450 m level. In addition, three more sites, two along the A-side of the tunnel at 907 and 2200 m tunnel length and one at the B-side of the tunnel at 1127 m, were established during 2002. However, a devastating flood event occurred summer 2003 at the 907-site, and filled it with sand. This site will, therefore, not be used during 2004. At the 1127-m site, the important inflow of groundwater with high concentration of sulphide diminished during 2002 and was almost completely lost during 2003. It is not clear, at present, if the inflow can be restored.

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 sites. 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.

Bio-mobilisation of radionuclides

It is well known that microbes can mobilise trace elements /Pedersen, 2002a/. 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. The MICROBE sites intend to investigate the extent of bacterial dissolution of immobilised radionuclides and production of complexing agents under *in situ* conditions.

Bio-immobilisation of radionuclides

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. The retention effect from BIOS was studied at the site at 2200 m tunnel length. A strong retention of rare earth metals, U and Th was found /Anderson and Pedersen, 2003/.

Microbial effects on the chemical stability

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 contribute 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 and organic carbon. These species buffer towards a low redox potential and will reduce possibly introduced oxygen. The MICROBE 450-m site is designed to investigate the extent of those processes.

Microbial corrosion of copper

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 is now addressed at the MICROBE 450-m site.

Objectives

The major objectives for the MICROBE sites 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 high deep repository for spent fuel.

Experimental concept

Four sites along the tunnel have been in operation. However, at present, only two sites are active. The main site is the MICROBE 450-m site. That is where the research efforts are being focussed. Some tasks require settings that cannot be achieved at the 450-m site. Therefore, an additional site is configured along the tunnel at 2200 m tunnel length.

The MICROBE 450-m site

The main MICROBE site is on the -450 m level in the F-tunnel. A laboratory container has been installed with laboratory benches, an anaerobic gas box and an advanced climate control system, see Figure 4-10. A gas chromatograph and a gas extraction system are installed. This system can analyse the following gases (detection limit): hydrogen (1 ppb), carbon monooxide (1 ppb), carbon dioxide (1 ppm), methane (1 ppm), ethane (1 ppm) and ethylene (1 ppm). Three core drilled boreholes, KJ0050F01, KJ0052F01 and KJ0052F03, intersecting water conducting fractures at 12.7, 43.5 and 9.3 m, respectively, 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 500 cm^2 of test surface in each circulation flow cell (Figure 4-11) set-up for biofilm formation at *in situ* pressure, temperature and chemistry conditions. The systems operate at the pressures 24, 32 and 24 bars in KJ0050F01, KJ0052F01 and KJ0052F03, respectively. The flow through the flow cells is adjusted to about 15 ml per minute, which corresponds to a flow rate over the surfaces of 0.5 mm per second. Temperature is controlled and kept close to the *in situ* temperature at around 15–16 ^{o}C. Remote alarms have been installed for high/low pressure, flow rate and temperature.

Figure 4-10. *An overview of the laboratory environment at the MICROBE 450-m site. The laboratory is equipped with three circulation systems (right), an anerobic box (forward), an in situ gas extractor and a Kappa 5 gas chromatograph (right of the anaerobic box).*

Figure 4-11. *One of the twelve flow cells that are installed at the MICROBE 450-m site. Ten pieces of surfaces can be installed. They can be made of granite, glass metal or combinations, depending on the aim of the experiment. Three flow diffusers before and after the surface pile distributes the flow evenly over the test surfaces.*

The BIOS-site at 2200A m tunnel length

Organic surfaces and iron oxides have been identified as important factors in radionuclide transport modelling. Several micro-organisms oxidise ferrous iron to ferric iron resulting in a mix of organic material (microbes) and iron oxides, here denoted BIOS (Biological Iron Oxide Systems). BIOS can be found everywhere along the Äspö HRL tunnel system. This BIOS is mainly produced by the stalk-forming bacterium Gallionella ferruginea /Hallbeck and Pedersen 1990, 1991, 1995; Hallbeck *et al*., 1993/. One particularly good site for investigations has been identified at tunnel length 2200m, on the A side. A vault is reaching about 10 m into the host rock perpendicular to the tunnel and it has a borehole in the front that delivers groundwater rich in ferrous iron and iron oxidising bacteria. The borehole has been connected to two 200 x 30 x 20 cm artificial channels that mimic ditches in the tunnel, see Figure 4-12. The channels have rock and artificial plastic support that stimulate BIOS formation. Retention of naturally occurring trace elements in the groundwater by the BIOS was investigated during 2003 /Anderson and Pedersen, 2003/. Quantitative experiments will be set up during 2004.

Present status

The *in situ* copper corrosion experiments were decommissioned and analysed early spring 2003. Manuscript preparation is ongoing.

The gas chromatography system is working as planned. It has been calibrated and successfully tested on the deep groundwater from the MICROBE 450-m site circulation. It has also been used to analyse gases in the Matrix Fluid Chemistry experiment described in Section 4.7.

Immobilisation of radionuclides on bio-films from the KJ0052F03 circulation is under investigation. Two consecutive experiments have been run during 2003. The second set of analyses was completed at the end of 2003.

The response of the microbial population in KJ0052F01 upon addition of electron acceptors and carbon sources has been investigated during late summer 2003. Evaluation is ongoing.

A methodology for the quantification of biomass at low concentrations is being adapted. ATP is an energy transport molecule that exists in all living organisms in fairly constant concentrations. Using biochemical protocols and a luminometer, it is possible to extract and analyse this compound. The methodology is presently being tested on deep groundwater microbial populations. If successful, it will be incorporated in the standard protocols for analysis of biomass in the MICROBE experiments.

Investigation of attachment and growth of microbes on minerals is being initiated. Thin sections of granite, prepared from drill cores from KJ0052F03, will be introduced in the flow cells (Figure 4-11). Preparation and preliminary tests are under way in the laboratory at Göteborg University.

Figure 4-12. *The artificial channels at 2200-m MICROBE site are feed by water from a common borehole, but they are inhabited by either iron oxidising microbes (left) or sulphur oxidising microbes (right). The balance between iron and sulphur microbes is very delicate. A small difference in the inlet profile of ground water results in a huge difference in the structure of the respective population.*

Scope of work for 2004

The migration, production and consumption of microbial gases will be investigated. Work during 2003 has revealed some surprising results that will be researched in more detail. The results indicate that the concentration of gases in deep rock groundwater varies significantly over time and distance. This may be a "draw down" effect due to the tunnel or a due to unknown mechanisms. The gas analysis system at the MICROBE 450-m site constitutes an excellent tool to look further into the dynamics of gases in deep hard rock environments.

Immobilisation of radionuclides on bio-films in deep groundwater was investigated 2003. Evaluation and follow up experiments are planned for 2004. Manuscript submission is also planned for 2004.

Trace element immobilisation by BIOS has been thoroughly investigated qualitatively at the MICROBE 2200-m site. Next, we plan to set up flow channels that will enable a quantitative approach. This work is planned to be executed in co-operation with scientists from dept of Geology, University of Toronto, Canada.

In situ mobilisation of radionuclides by microbial complexing agents will be investigated. Plans and scooping experiments will be set up during 2004.

The response of the microbial populations on addition of electron acceptors, energy sources and carbon sources will be further studied.

4.7 Matrix Fluid Chemistry

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 phase will be published in early 2004 /Smellie *et al.*, 2003/.

The continuation phase (2004–2006) will focus 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 or otherwise of laboratory-derived matrix fluid compositions (i.e. crush/leach and diffusion extractions) by conducting a long-term *in situ* out-diffusion pore water experiment in the matrix borehole.
- The confirmation of rock porosity values previously measured in the earlier studies.

This continuation phase, however, requires an initial "Feasibility Study" to assess the potential for further characterising the matrix borehole. This is necessary because of the untimely excavation of a new tunnel close to the matrix borehole for the Äspö Pillar Stability Experiment in April/May, 2003. Repercussions from the excavation may have influenced the hydraulic (and therefore the hydrochemical) character of the matrix borehole and the host rock vicinity. Prior to any further studies, therefore, these repercussions require to be quantified.

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 have been identified:

- To establish the impact of tunnel construction on the matrix borehole by evaluating the monitored pressure profiles (Äspö 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.
- Furthermore, on the same basis, *in situ* out-diffusion experiments will be conducted in the same isolated 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 on-going experiments at Äspö HRL.

Special downhole equipment, see Figure 4-13, 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, will be 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.

Present status

The first phase of the matrix fluid experiments was completed in 2003 and the continuation phase is due to commence in January 2004.

Scope of work for 2004

The scope will depend on the impact of tunnel excavation. Any potential impact will be first determined by the Feasibility Study, mainly by evaluating the pressure variations (i.e. by the Äspö HMS) during excavation in the matrix borehole and other monitored boreholes in the near-vicinity of the matrix borehole. If there is no significant deviation from those measured prior to tunnel excavation, then it will be assumed that no major impact has occurred.

Assuming no significant impact of the tunnel excavation the following tasks will be carried out during 2004:

- Resampling of groundwaters and dissolved gases from the borehole sections containing two identified microfractures.
- Repositioning the borehole equipment to resample groundwaters and dissolved gases from the fracture-free borehole sections earlier characterised hydrochemically.

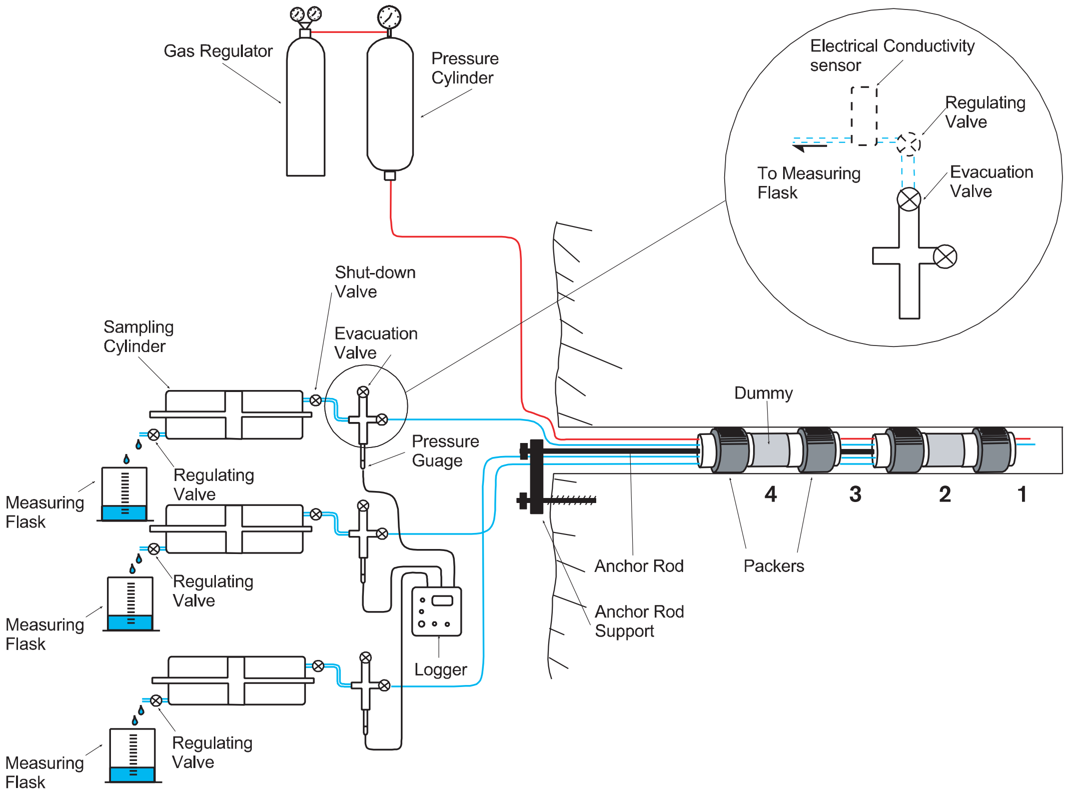


Figure 4-13. *Matrix Fluid Chemistry experimental set-up. Borehole sections 2 and 4 were selected to collect matrix fluid; sections 1-4 are continuously monitored for pressure.*

4.8 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 (LPT-2). 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 (TRUE), 1st stage. Completed.

Task 5: Coupling between hydrochemistry and hydrogeology. Completed.

Task 6: Performance Assessment (PA) Modelling Using Site Characterisation (SC) Data (PASC). On-going.

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 on-going 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 was 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. TRUE Block Scale was a series tracer tests that were performed in 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.

Five sub-tasks have been defined within Task 6:

6A Model and reproduce selected TRUE-1 tests with a PA model and/or a 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.

6C Develop semi-synthetic, fractured granite hydrostructural models. Two scales are supported (200 m block scale and 2000 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.

Present status

The 17th International Task Force meeting, hosted by Nagra was held March11–13, 2003 in Thun, Switzerland. In the meeting 27 attendees from seven countries participated. A summary of the final report for the Overall Evaluation of Task 4 was presented. The modelling groups presented final results of Task 6A, 6B and 6B2 and preliminary results for Task 6D.

The work within the Task Force has been in progress after the meeting. Proceedings of the 17th International Task Force are published on the Task Force web site at SKB. In the planning group, telephone meetings are held on a regular basis. The report of the Overall Evaluation of the modelling conducted in Task 4 is published /Marschall and Elert, 2003/. Task 5 Summary report /Rhén and Smellie, 2003/ and Task 5 Reviewers report /Bath and Jackson, 2003/ have been published. An external review process for Task 6 has been initiated. Drafts of the modelling reports regarding Task 6A, 6B and 6B2 have been sent to the reviewers. The Task 6C report has been printed /Dershowitz *et al*., 2003/. Specifications of sub-task 6E have been sent out to the Task Force members.

A workshop was held regarding Task 6 at Krägga Mansion, September 2003. At the workshop, the obtained results for sub-tasks 6A and B were discussed, as well as how to continue the task by performing sub-tasks 6D and E.

Scope of work for 2004

The main activities targeted to be accomplished during 2004 are summarised below:

- Organise the 18th International Task Force meeting in January, hosted by SKB at Äspö HRL.
- Produce the final modelling reports for Task 6A (modelling selected tracers used within TRUE-1) and 6B (modelling selected tracers used within the TRUE-1 programme with new performance assessment relevant boundary conditions and time scales). Task 6B2 will be included in the same report if performed by modelling group.
- Produce modelling reports of Task 6D.
- Deliver specifications for Task 6E.
- Produce modelling reports of Task 6E.
- Continue the external review process of Task 6.
- Propose a new modelling Task.

4.9 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 nuclear waste programmes of several countries and therefore an EC founded 3 year project with the name EQUIP (Evidences from Quaternary Infills for Palaeohydrogeology) was started in 1997. The EQUIP project was concentrated on the formulation of a methodology for how to conduct a palaeohydrogeological study; what minerals to use, what analyses to perform, and also the preferred sequence in which the different analyses should be carried out. Each participating country also carried out analyses within their selected sites. Within the Swedish study the selected site is Äspö and the drill cores used was from the pre-investigation boreholes KAS02, KAS03 and KAS04. Some samples from the 1700 m deep borehole KLX02 from the nearby mainland Laxemar were also included. The study was concentrated on calcite as this mineral relatively quickly responds to changes in groundwater chemistry. However, information from Fe-oxides and sulphides has also been included when possible.

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 and therefore a new EC-project was initiated in the beginning of 2002 running to the end of 2004. This project is called PADAMOT (Palaeohydrogeological Data Analysis and Model Testing).

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 for 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 also 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 WP 5, which deals with Performance Assessment applications of palaeohydrogeological data and modelling.

Present status

The work on the KLX01 drill core material has continued with sample preparation and analyses of calcite samples. As described above the basic idea behind the sampling/analysis programme is to distinguish and characterise possible recent low temperature calcites. The toolbox for this purpose contains stable isotope analyses (O, C and Sr), trace element analyses of bulk samples, and detailed micro scale analyses using BSEM and cathodolumienescens images, and laser ICP-MS for studies of zoning. Fluid inclusion studies are used to determine salinity, and in case of two phase inclusions, formation temperature. The morphology of calcite crystals grown in open fractures are determined and matched with isotope and trace element composition when possible.

The optimisation in the use of mineralogical/morphological mapping, bulk analyses of isotopes and trace elements, the very detailed analyses of zoning using BSEM, and laser ICP-MS are important tasks. Probably this optimisation varies between different sites.

During the second year of PADAMOT the work started with mapping of open fractures and determination of calcite morphology along drill core KLX01 when Tony Milodowski and Martin Gilespie from BGS visited the core farm. Based on this mapping, and the results from the bulk analyses a number of key samples were selected for BSEM-CL, fluid inclusion and laser ICP-MS studies, performed at BGS and University of Edinburgh. Results are in progress. Attempts have been made to match calcite morphology with bulk $\delta^{18}O/\delta^{13}C$ analyses. Figure 4-14 shows a plot of carbon *versus* oxygen isotope ratios and Figure 4-15 shows a plot of $\delta^{18}O$ *versus* depth, both with the three different morphologies distinguished. The basic concept (used in Sellafield among other sites, /Milodowski *et al*., 2000/) is that short c-axis (nail-head shaped crystals) represent fresh water precipitates, whereas scalenohedral crystals represent saline water calcites, and crystals with equant shape are typical for the transition zone (brackish water).

The results show no evident depth trend in the distribution of the different calcite morphologies, and most remarkably fresh water carbonates are found at both shallow and large depths (down to 950 m). Concerning $\delta^{18}O$, the saline water carbonates (scalenohedral shaped) show a large spread and it is suggested that they represent several generations of which one is formed at somewhat elevated temperatures and is refered to as the "warm brine generation". The equant shaped crystals show a large spread in $\delta^{18}O$ values as well, but are more concentrated towards high $\delta^{18}O$, which is in accordance with influence from brackish sea water, similar to the conditions in the past or present Baltic Sea. The fresh water carbonates in turn show $\delta^{18}O$ values in the range -8 to -11 $^{o}/_{oo}$ similar to precipitates from present meteoric water or cooler climate water. The freshwater carbonates at 840 to 950 meters depth have been incorporated in the detailed study of zoning, in order to get the best possible characterisation of these precipitates. Two of these samples were also analysed for Sr isotope composition and showing values roughly corresponding to the present day groundwater at this site.

Summary of results obtained during 2003 (year two of the PADAMOT project)

The overall picture is that calcite has been precipitated from waters of different salinity and different isotopic composition at depth down to 1000 m. It is probable that the fresh/saline groundwater interface has varied a lot which is in accordance with the findings of the different groundwater end-members and the post glacial scenario that can be reconstructed from shore displacement curves and topography. It is probable that this scenario has been repeated several times during the Quaternary, and it is not at present possible to find out if the calcite precipitates really represents the latest 10 000 years.

Scope of work for 2004

The present data set is very small but more stable isotope analyses of morphologically classified calcites will be carried out during 2004. The ongoing study continues including uranium series analyses carried out on material from fractures hosting fresh water carbonates. This is made in order to see if they represent circulation within the latest 100 000 years and if oxidising conditions are indicated at depth during this time period. During 2004 the results of the detailed studies of zoning, morphology and fluid inclusions will be combined with the bulk analyses of stable isotopes and chemistry in order to give a palaeohydrogeological model based on fracture mineralogy and water chemistry.

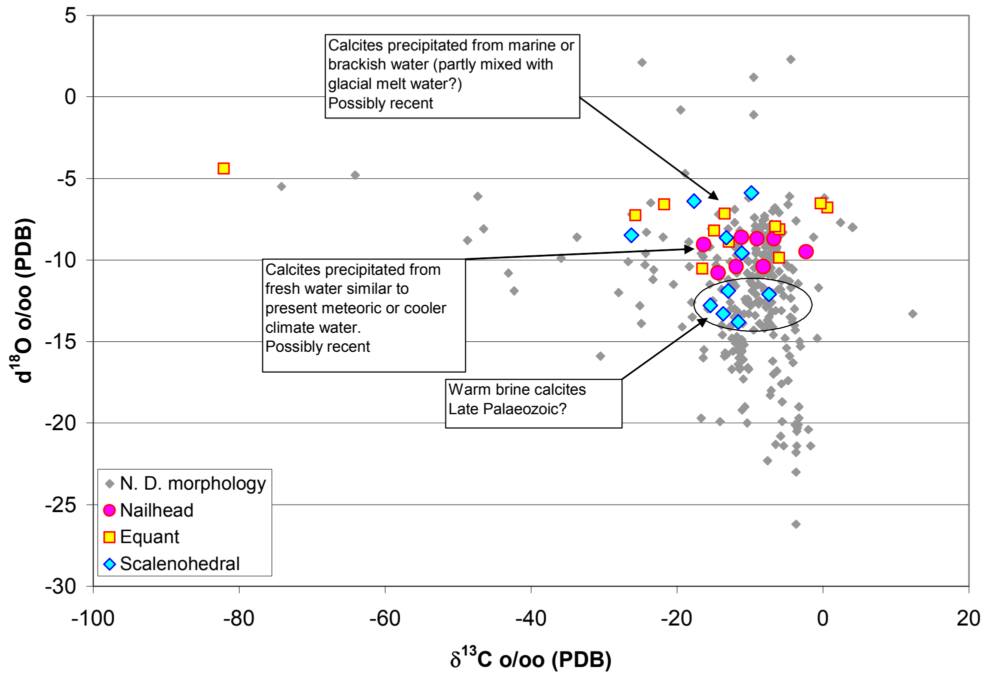


Figure 4-14. *$\delta^{18}O/\delta^{13}C$ analyses of fracture calcites from The Äspö/Laxemar/Simpevarp area. Different morphologies are shown in colour.*

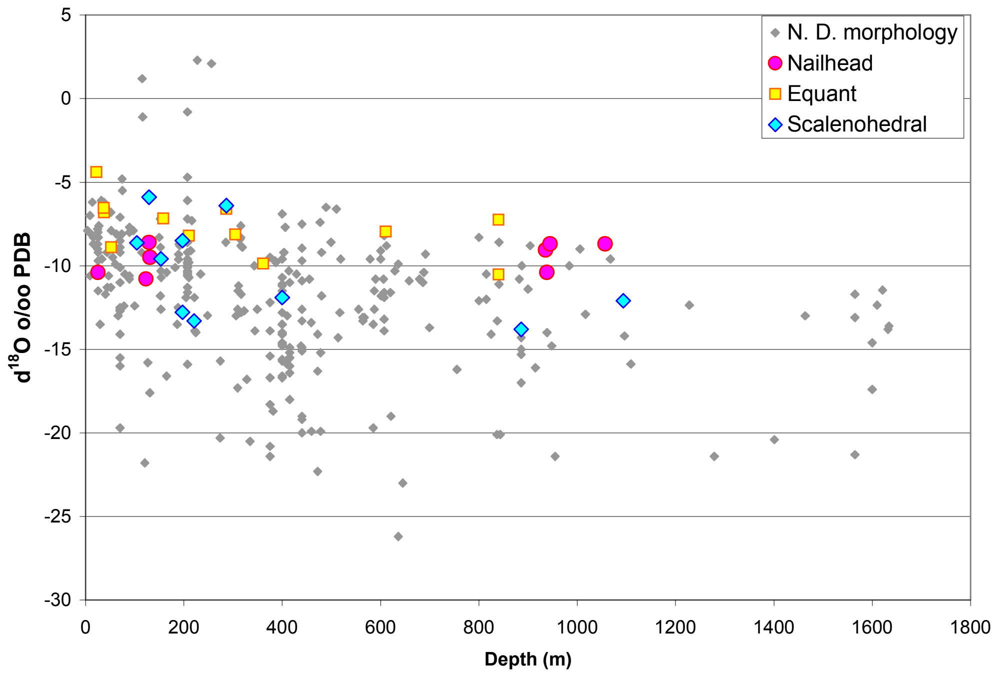


Figure 4-15. *$\delta^{18}O$-values plotted versus depth. Different morphologies are shown in colour.*

4.10 Fe-oxides in fractures

Background

Uptake of radioactive elements in solid phases can lead to immobilisation, thus minimising the escape risk. Uptake extent depends on solution conditions such as concentration, pH, Eh, temperature, pressure and the presence of other components. 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. Fe-oxides line fractures 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 components 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 radionuclides or other toxicants from solution and hold them, even during transformation 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+}, be provide as a model for actinide behaviour, or such as 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 refuse the hypothesis that, at the time of glacier retreat, oxidising water might have penetrated to depths at or below the level of planned canister burial?
- How might secondary Fe-minerals affect the migration of radionuclides accidentally released from a repository?

Objectives and experimental set-up

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

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 and planning of work for 2004

The three year project on Fe-oxides started late autumn 2003 with a group at Copenhagen University as the leading team. The work carried out during these first months has concentrated on summing up the results from the pilot tests carried out during 2003. Work carried out comprises SO_4-green rust formation, and the effect of cations (Li, Na, K and NH4) on the structure and the natural occurrence of green rust.

One presentation will be held at the Goldschmidt Geochemistry conference in Copenhagen in June 2004. Methods for sampling and analyses of Fe-isotopes will also be presented.

The results of the first study, Fe-oxides in Äspö fractures will be brought to completion during 2004. The compilation and evaluation work will continue and new sampling of Äspö material will be carried out during the spring.

5 Äspö facility

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

5.1 Facility operation

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 reliability of the underground-related systems has been more than 98 % during 2003.

An automatic registration and object-monitoring system with the aims of increasing personnel safety underground was taken into operation for testing during December 2003. The control inspection of the lift wire of the underground elevator indicated wear and the wire was exchanged just before the year-end.

The long term rock control and reinforcement programme has been continued to ensure safe and reliable rock conditions. Work on increased fire safety was also of concern during 2003 and safety-related education and fire fighting training was held in co-operation with the local fire brigade. The installation of a pipe from -340 to -440 m level which will supply water to the ramp for fire protection and water to the experiments has been started.

Excavation work has been performed underground for the Äspö pillar stability experiment (APSE) and for the site for demonstration of the KBS-3 method with vertical emplacement (KBS-3H). This work forced a diversion of electricity cables, drainage and water supply on the -450 m level. The diversion has improved the infrastructure, which is now less exposed to mechanical damages.

Energy consumption at the facility has increased by approximately 10 % mainly due to the increase in additional office space and work with rock excavation at the -450 m level (APSE) and the -220 m level (KBS-3H), as well as the start of operations in the outer section of the Prototype Repository and the start of the Thermal Buffer Test (TBT).

To host the staff of the site investigation project, additional office space (450 m^2) was needed. The design and building of an additional extension in the offices to the ventilation building was finalised in April. The temporary barracks earlier used were phased out as offices. An expansion of the storage building, with the addition of workshops for electricity- and experimental equipment, garage space and storage spaces for garden equipment and machines, is currently going on. The parking lot and the area between storage buildings and the main building have received new paving and improved drainage. Road works have also been performed on the road through Ävrö village.

Scope of work for 2004

Work planned and goals for 2004 are summarised below:

- One of the main targets for a number of years has been to increase the reliability of in the underground-related systems. The goal for 2004 is to reach an availability of 99 %. An extension of the electricity supply system reserve to the experiments at the -420 m level will be implemented if found necessary.
- Safety of the personnel is of main concern and safety-related education and fire fighting training will be held. A new fire hazard analysis will be carried out for the underground facility, with the aim of identifying necessary improvements. An extensive inspection of the rock in the underground facility will be performed during the autumn and the long term rock control and reinforcement programme will be continued.
- The maintenance and service of equipment, installations and vehicles shall be of high quality. A computerised system for the purchase of machines and vehicles will be implemented in order to improve the documentation, follow-up, and effectivity of maintenance.
- The water pipe from -220 to -440 m level will be completed. In all the pumps included in the water drainage system, a system for ”smooth start/stop” will be installed.
- A goal for the environmental work is to decrease the energy consumption with 5 %. This is to be done by mechanical trimming of the underground ventilation system and also by informing the staff about energy saving activities. The primary ventilation fans underground will be supplemented with infinitely variable speed control in order to decrease the energy and maintenance costs. Corroded parts of piping for the ventilation system will be replaced.
- The ongoing work with additional workshops and stores will be finalised early in 2004. Next summer the sheds at the tunnel entrance will be partly refurbished and the remaining parts replaced. The road through the Ävrö village will be refurbished.

5.2 Hydro Monitoring System

Background

The monitoring of groundwater changes (hydraulic and chemical) during the construction and operation of the laboratory is an essential part of the documentation work aiming at verifying pre-investigation methods. The great amount of data calls for an efficient data collection system and data management procedures. Hence, the Hydro Monitoring System (HMS) for on-line recording of these data have been developed and installed in the tunnel and at the surface.

The Hydro Monitoring System (HMS) collects data on-line of groundwater head, salinity, electrical conductivity, Eh, and pH. The data are recorded by numerous transducers installed in boreholes. The system was introduced in 1992 and has evolved through time, expanding in purpose and ambition. The number of boreholes included in the network has gradually increased and comprise boreholes in the tunnel and in Äspö HRL as well as surface boreholes on the islands of Äspö, Ävrö, Mjälen, Bockholmen and some boreholes on the mainland at Laxemar. Weekly quality controls of preliminary groundwater head data are performed. Absolute calibration of data is performed three to four times annually. This work involves comparison with groundwater levels checked manually in percussion drilled boreholes and in core drilled boreholes, in connection with the calibration work.

As an effect of the excavated tunnel, the groundwater levels in the core drilled boreholes in the vicinity of the tunnel have been lowered up to 100 meters. Because of this the installations in the boreholes, e.g. the stand pipes (plastic tubes) in the open boreholes have been deformed. This makes it sometimes impossible to lower pressure transducers in the tubes or to lower manual probes for calibration purposes. Development and testing of new types of tubes is in progress. An evaluation of the groundwater monitoring system used at Äspö HRL is needed before a new similar system will be set up at candidate sites for the deep repository.

Measuring system

To date the monitoring network comprises boreholes of which many are equipped with hydraulically inflatable packers, measuring the pressure by means of transducers. The measured data are relayed to a central computer situated at Äspö village through cables and radio-wave transmitters.

Present status

The measuring system is at present working satisfactorily and the availability has up to September been 84 %. In connection with rock works underground a central collection point in the system (HMSB) was damaged. The data loss included 65 measuring points and lasted from 6/7 2003 to 4/8 2003. The missing data concern information on pressure (0−2 000 m tunnel length), inflow of groundwater to the tunnel (0−3 179 m tunnel length), and the amount of drainage water pumped from the tunnel during the above period. In addition, a datascan-unit has been damaged in a collision. Measuring data from this unit, comprising 18 measuring points, is missing for the period 13/7 2003 to 5/8 2003.

Scope of work for 2004

The activities during 2004 comprise operation, maintenance and documentation of the HMS system including implementation of some new boreholes in the measuring system. Equipment that is out of order will be exchanged or renovated.

5.3 Programme for monitoring of groundwater head and flow

Background

The monitoring programme is a support to the experiments undertaken in the HRL and meets the requirements stipulated by the water rights court. The HMS implemented in the Äspö HRL and on the nearby islands is used to supply data to the programme for monitoring of groundwater head and flow. The monitoring of water level in surface boreholes started in 1987 while the computerised HMS was introduced in 1992. The number of boreholes included in the network has gradually increased. 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.

To date the monitoring programme comprises a total of 127 boreholes (52 surface boreholes and 75 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. The measured data is relayed to a central computer situated at Äspö village through cables and radio-wave transmitters. Once a year, the data is transferred to SKB's site characterisation database, SICADA. Manual levelling is also obtained from the surface boreholes on a regular basis (once a month). Water seeping through the tunnel walls is diverted to trenches and further to 22 weirs where the flow is measured.

Objectives

The scope of maintaining such a monitoring network has scientific as well as legal grounds:

- It is a necessary requirement in the scientific work to establish a baseline of the groundwater head and groundwater flow situations as part of the site characterisation exercise. That is, a spatial and temporal distribution of groundwater head prevailing under natural conditions (i.e. prior to excavation).
- It is indispensable to have such a baseline for the various model validation exercises, including the comparison of predicted head (prior to excavation) with actual head (post excavation).
- 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 at the above mentioned areas.

Scope of work for 2004

The measuring points from the previous years will be maintained.

5.4 Programme for 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.

Objectives

At the beginning of the 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. This programme is designed to provide information to determine where, within the rock mass, the hydrogeochemical changes are taking place and at what time stationary conditions are established.

Scope of work for 2004

The annual water sampling campaign is in the same way as earlier years scheduled to take place in the turn of the month September – October.

6 International co-operation

6.1 General

Seven organisations from six countries will participate in the co-operation at Äspö HRL during 2004. One organisation, Ontario Power Generation of Canada, becomes a new participant from January 1st, 2004, and one, Nagra, will leave the central and active core of participants, but continue in the Matrix Fluid Chemistry project as well as in the Task Force on Modelling of Groundwater Flow and Transport of Solutes. Most of the participating organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several organisations are participating in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes, which is a forum for co-operation in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock.

The international organisations are taking part in the projects and experiments described in Chapters 2, 3 and 4 (Technology, Geo-science, and Natural barriers). The co-operation is based on separate agreements between SKB and the organisations in question. The participation by JNC and CRIEPI is regulated by one agreement. The participation of each organisation is given in Table 6-1. A description of the main activities to be performed by the different organisations during 2004 is given in the following sections.

Table 6-1. International participation in the Äspö HRL projects during 2004.

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

SKB is through Repository Technology co-ordinating three EC contracts and takes part in several EC projects of which the representation in three projects is channelled through Repository Technology. SKB takes also part in work within the IAEA Network of Centres of Excellence.

6.2 Andra

L'Agence Nationale pour la Gestion des Déchets Radioactifs (Andra) provides experimental and modelling support to the Äspö HRL with emphasis on site characterisation and on engineered barrier systems to complement research activities in France.

Prime objectives of Andra's participation are to enhance the understanding of flow and transport in fractured rock and to evaluate experimental and modelling approaches in view of site characterisation of a French granite site. In conjunction with SKB's development of major experiments related to the repository system, Andra is carrying out research on the engineered barrier systems behaviour for either spent fuel or reprocessed vitrified high-level waste. The scopes of Andra's contributions in different projects during 2004 are described below.

6.2.1 Prototype Repository

Andra's contribution to the project during 2004 aims at modelling the displacement of the interface between the bentonite buffer in the deposition hole and the backfill in the deposition tunnel, during their free water saturation under thermal constraint.

6.2.2 Temperature Buffer Test

The Temperature Buffer Test (TBT) has been set in operation in March 2003. TBT aims at evaluating the benefits of extending our current understanding of the behaviour of the buffer during the initial stage of deposition to include high temperatures (above 100°C). This means the investigation of how well the bentonite buffer placed in the annular space between the canister and the granite rock wall can endure high temperatures.

The high temperatures occurring in parts of the TBT bentonite buffer (140°C at canister contact) aid to observe, understand, and model THM behaviour of the buffer under thermal constraint. THM modelling is carried out by teams from Sweden (Clay Technology), Spain (UPC and DM Iberia), and France (EDF and Eurogeomat).

6.2.3 TRUE Block Scale Continuation

Diffusion/sorption in immobile pore spaces was identified as a main retention process in the TRUE Block Scale experiments. Some issues are however incompletely resolved, for example the role of rock components and the observed enhanced retention in the field tests as compared to laboratory data. Explanations could be either the effect of underestimated flow wetted surface or the effect of high porosity stagnant zones in fault gouge and rim zone.

TRUE Block Scale Continuation is being designed to address these issues by the mean of *in situ* tracer tests, the feasibility of which has been assessed by modelling approaches carried out in 2003. Andra's modelling contribution during 2004, through ITASCA, will be related to prediction and evaluation of results of the tracer tests carried out as part of the BS2b phase (see Section 4.2.1).

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

Andra is participating in Task 6 with the aim to gain experience on site characterisation and performance assessment modelling. The major objective is to bridge the gap between site characterisation and performance assessment models.

Three modelling teams (CEA, GOLDER Associates and ITASCA) within the Andra group are carrying out modelling based on different approaches and numerical codes.

6.3 BMWA

The first cooperation agreement between Bundesministerium für Wirtschaft und Arbeit (BMWA) 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 BMWA: BGR, DBETec, FZK, FZR, and GRS.

The purpose of the cooperation in the HRL Äspö programme is to complete the knowledge on potential host rocks for radioactive waste repositories in Germany. The items of special interest are: Characterisation of fracture zones in the rock mass and disturbed zones surrounding underground openings; *in situ* measurement of groundwater flow in fractured rock and in the rock matrix; 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; modelling of groundwater flow and transport of solutes. The work to be carried out in 2004 is described below.

6.3.1 Prototype Repository

Electrical resistivity measurements are conducted to investigate time-dependent changes of the water content in the backfill, in the buffer, and in the rock. The measured electrical resistivity is an indication of the fluid content in the materials. In 2001, five electrode arrays were installed in the backfill of Sections I and in the rock around deposition holes #5 and #6 in Section II. Measurements are performed daily and evaluated monthly.

The electrical resistivities are measured by use of multi-electrode arrays. The resistivity distribution in the arrays is determined by means of tomographic dipole-dipole measurements. The recording unit for these arrays is controlled remotely from Braunschweig/Germany through a telephone connection. From the measured apparent resistivity values the "true" resistivity distributions in the different parts are computed applying the latest inversion software. The daily measurements in the five geoelectric arrays will be continued. Data evaluation will be performed in Braunschweig and contributions to SKB's sensor data reports will be provided on a quarterly basis.

To increase the confidence in the results of the inversions of the *in situ* measured apparent resistivities, a laboratory experiment is foreseen in which controlled progressing water uptake in drift backfill will be simulated and monitored by geoelectric measurements. The comparison between the known state of water uptake and the results of the measurements will allow better assessment of the inversion accuracy.

A project that encompasses participation of GRS in the Modelling Working Group of the Prototype Repository project as well as development of simplified resaturation models for bentonite has expired in 2003. A follow-up project is intended.

To determine the influence of two-phase flow processes, the 3D-version of the BGR ROCK-FLOW program will be expanded to include two-phase flow under non-isothermal conditions. The calculation results will be compared with *in situ* measurement results. The sensitivity of the parameters will be highlighted by parameter variations.

6.3.2 Large Scale Injection Test

The work being conducted as part of the Lasgit project (Section 2.9) focuses on the interaction between the bentonite backfill and the EDZ. Surface packers are to be used to determine the hydraulic properties of the tunnel wall EDZ in the mm-range. Threshold pressures are measured by gas tests. The permeability will be determined in hydraulically effective joints. These tests are supported by modelling. The ROCKFLOW finite-element program will be upgraded to include THM coupling of the processes in the backfill and the surrounding EDZ.

This part of the project starts with surface packer tests on bentonite with gas. The model used to calculate the transport of radionuclides in the EBS and the EDZ will be refined during 2004.

6.3.3 Radionuclide Retention Experiments

The objectives of FZK/INE's *in situ* actinide migration experiment in the Äspö HRL are to examine the applicability of laboratory data to natural conditions, to verify the laboratory sorption studies, and to reduce uncertainties connected with the actinide behaviour in a granitic environment. The migration experiments were performed in individual fractures in drill cores in laboratory and in the Äspö HRL. To guarantee most realistic conditions, as close to nature as possible, the experiments are performed in the CHEMLAB 2 probe. Important aspects in these experiments cover the breakthrough of the tracers and the quantification of sorbed actinides along the flow path after termination of the migration experiments. In 2003, a migration experiment was performed providing a residence time of the actinides for about 3 months (core #5, open fracture). Several reports and publications are available describing experiments and results.

Migration experiments are complemented by batch experiments providing detailed information on the relevant retention processes for actinides onto granite and altered fracture material. α-autoradiography and XPS were used to quantify local sorption properties of the rock samples. By application of two independent methods, it could be shown that Np is retained by reduction to Np(IV) in the presence of Fe(II) containing minerals. The sorption coefficient for Pu is significantly higher compared to Np or U. Pu retention takes place on a multitude of minerals. Sorption of U is also strongly correlated with the occurrence of Fe oxide phases.

During the co-operation, SKB asked for a migration experiment with the redox sensitive elements uranium and technetium. After laboratory tests, a migration experiment using these elements was planned for autumn 2003 in the CHEMLAB 2. However, the experiments were postponed due to licensing problems.

Actinide migration experiments

In early 2004, a migration experiment is planned in CHEMLAB 2 with the redox sensitive elements uranium and technetium. The selection of an appropriate uranium isotope is discussed with the licensing authorities. In contrast to Pu, U shows significant less sorption onto altered material and onto granite. From geometrical considerations and from the laboratory sorption data, U-retardation is expected to be a factor of about 6 lower than that of Np. The sampling procedure and the analysis of the solid materials will be performed as reported previously. The duration of the experiment is planned to be three months.

Extension of the actinide migration experiments in CHEMLAB 2

An additional core (core #6) was prepared and is available for CHEMLAB 2. This core contains an open fracture. On the basis of experimental data on colloid stability in the Äspö groundwater and actinide-colloid interaction, it will be decided if a cocktail with actinide bearing colloids can be prepared. In this case, the same set-up as used in the actinide migration studies can be applied. Such an experiment cannot replace the planned dipole colloid experiments, but it will provide information on the migration behaviour under geochemical conditions closer to nature than in laboratory and at low groundwater flow velocity. The sampling procedure and the analysis of the solid materials will be performed like in the previous experiments.

6.3.4 Colloid Project

Colloids may be formed of oxides/hydroxides of the actinides or be generated during waste form dissolution and interactions of backfill materials (bentonite) with groundwater. Aquatic colloids can play a role as potential carriers of radionuclides, mainly polyvalent actinide ions. Natural aquatic colloids present in groundwater are of particular importance. Experiments performed in the scope of the CRR project in the Grimsel test site corroborate the enhancement of actinide migration by colloids. The results obtained at Grimsel cannot be applied directly to other sites because ionic strength and pH of the groundwaters can differ significantly. Moreover, the residence time of the colloids in the fracture at Grimsel may not be relevant for other sites. The groundwater velocities were quite high in the experiments and may be partly responsible for the observations.

In co-operation with SKB a study was performed to determine concentration and size distribution of natural colloids in groundwater from granite fractures in the Äspö HRL under *in situ* conditions. The aim was to identify the relevant parameters controlling the colloid presence in different types of natural groundwater.

To obtain insight in the behaviour of colloids under conditions relevant to the situation in the vicinity of a repository in deep underground, an experiment is planned addressing the transport of colloids and colloid facilitated transport of radionuclides.

Scope of work for 2004

A colloid migration experiment is planned at Äspö in a dipole experiment carried out in a hydrologically well-defined fracture. In 2004 it is planned to conduct a number of preparatory laboratory experiments:

- Experimental determination of colloid stability in groundwater from the site: The stability of groundwater colloids (if present) and colloidal material from bentonite will be studied by light-scattering methods.
- Investigation of metal ion interaction with colloids and fracture infill material: It is planned to study the behaviour of Eu(III), Hf(IV), Th(IV) and U(VI) as chemical representatives for the actinides occurring in nuclear waste.
- Study of colloid interaction (attachment) to fracture infill material.

As an outcome of these laboratory investigations, the design of the colloid migration study will be defined and go/no go criteria developed.

An additional field study will be dedicated to the closer study of the influence of the EDZ on colloids at the Äspö HRL. Mobile LIBD measurements will be conducted at the HA2780A borehole. In an earlier *in situ* study colloids have been detected even though the groundwater exhibited the highest salinity of all water samples. It is assumed that oxygen may diffuse through the EDZ and generate iron-oxide/hydroxide colloids due to oxidation. The following activities are planned:

- *In situ* laser-induced breakdown detection of colloids in a highly saline groundwater (15 g/l chloride) taken from borehole HA2780. The sampling section in the granitic rock will be selected in a great distance from the EDZ of the Äspö HRL tunnel.
- *In situ* determination of pH, Eh, and electrical conductivity in eight representative types of groundwater from a number of boreholes (KR0012B, SA1229A, HA1330B, KA1755A, SA2074A, SA2273A, HA2780A, KA3110A). The determination will be performed under pressure, in-line with the boreholes and without access of oxygen to the groundwater. The data are taken as an input for geochemical model calculations.
- Implementation of a pressure vessel borehole sampling system for inert groundwater sampling, subsequent transportation, and an in-line determination of colloid content, pH, Eh, and electrical conductivity, without contact to oxygen. Comparison of *in situ* and "sampling system" data. Extension of the mobile LIBD with a PC based fast image processing system for direct on-line colloid size detection.

6.3.5 Microbe Project

A project is performed addressing (i) the interaction of actinides (U, Cm, Np and Pu) with relevant bacteria found in Äspö groundwater, (ii) quantification of actinide bonding on micro-organisms in dependence of the chemical conditions in the groundwater, and (iii) spectroscopic characterisation of the actinide complexes/compounds formed by interaction with microbes. The project includes the continuous cultivation and quality control of the used Desul-fovibrio-äspöensis biomass.

To clarify the binding mechanisms of Cm(III) onto the surface of the bacteria, spectroscopic investigations of the interaction of Cm(III) with relevant model compounds simulating the functionality of the bacterial surface of Desul-fovibrio-äspöensis will be conducted during 2004. The spectroscopic characterisation of the formed actinide/compounds/complexes will be continued and the experiments to describe the interaction of neptunium and plutonium with Desul-fovibrio-äspöensis will be concluded.

6.4 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 and related supporting work within the FEBEX project. Both parties renewed the Agreement on January 1, 2002.

One objective of the Agreement is to provide a framework for collaboration on specific tasks within the Äspö HRL Programme. Enresa participates in:

- Backfill and Plug Test.
- Prototype Repository.
- Temperature Buffer Test.

A number of critical issues related to the waste disposal, which are treated in these projects, are of interest to Enresa:

- Disposal technology demonstration in vertical holes and THMCB performance of the engineered barrier system (Prototype Repository).
- Demonstration of technology for and function of important parts of the repository system (Backfill and Plug Test).
- TM performance of the buffer under high heat load (TBT).

The activities planned in the different projects during 2004 are given below.

6.4.1 Prototype Repository

Enresa has contributed to the project with a new device to measure canister displacements in deposition hole number 3. In addition, THM modelling of the behaviour of the barrier using the CODE_BRIGHT program was performed.

THM modelling of the barrier will be performed during 2004. The results will be compared with field measurements that will continue to be recorded during that period.

CODE_BRIHT will be used for the analyses, as it has proven to be a good tool to perform this type of modelling work. Some laboratory information obtained recently by CIEMAT will be incorporated in future simulations, i.e. oedometer tests, and water retention properties as function of temperature and density. In addition, an effort to include the chemical couplings in the THM analyses will be considered in 2004, although the extension of this work will depend on the chemical data available for the barrier.

6.4.2 Backfill and Plug Test

Enresa has contributed to this project by implementing a system to measure local hydraulic conductivity in the backfill based on the pulse tests concept. Several pulse tests have already been performed and a picture of the local permeability at some points of the backfill has been obtained. In addition, Enresa has performed some HM and HC analyses simulating pulse tests and also the global flow tests.

During 2004 the global flow tests will be performed, and the actual hydraulic behaviour of the backfill will be recorded. Enresa will participate in the analyses of the field data recorded during those tests. A comparison with some previous simulations will be performed. If required, further simulations will be carried out at the earliest in the end of 2004 or early 2005 dependent on the evolution of the flow tests.

6.4.3 Temperature Buffer Test

Enresa participates in the modelling of the experiments. Some predictive modelling has already been performed during 2003, and this type of work will continue in the future according to the time schedule of the experiment.

Measurements will be available during 2004, and Enresa will participate in the THM modelling that is expected to be performed during 2004. A comparison between simulations and field measurements will be carried out that will contribute to the improvement of the models and made assumptions. In particular, the effect of high temperatures on the bentonite HM behaviour is considered to be a fundamental issue in this test. Some laboratory experiments will be performed as well in order to clarify that effect. In addition, some changes in the code CODE_BRIHT are expected to be required in order to cope with the effect of those high temperatures on the HM performance of the barrier.

6.5 CRIEPI

Central Research Institute of Electric Power Industry (CRIEPI) made a contract with SKB for the Äspö HRL Project in 1991 and renewed it in 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 2004, CRIEPI will participate in the following projects:

- Prototype Repository.
- Task Force on Modelling of Groundwater Flow and Transport of Solutes.
- Voluntary project on impact of microbes on radionuclide retention.

In addition, CRIEPI will take part in information exchange on research, disposal technologies and methodologies for site investigations. CRIEPI's activities for the individual projects in 2004 are summarised as follows.

6.5.1 Prototype Repository

It is important to evaluate the phenomena around engineering barrier system, since the conditions of the engineering barriers will influence the radionuclide transport. CRIEPI has developed a coupled numerical code for predictions of the thermo and hydro processes expected in the engineered barriers and the surrounding rock. CRIEPI has also collected the basic properties of buffer and backfill material.

CRIEPI has applied the numerical code to the *in situ* experiment performed by JNC in Kamaishi mine. The estimated temperature changes approximately agreed with the measured results, but the changes of the water content disagreed. It is expected that this disagreement is caused by vapour transport. Therefore in 2004, CRIEPI will improve the numerical code to take into account for the vapour transport and apply it to the *in situ* and laboratory tests.

6.5.2 Task Force on Modelling Groundwater Flow and Transport of Solutes

CRIEPI has developed numerical codes, for the analyses of groundwater flow and solute transport in rock formations, to assess the safety of disposal facilities of radioactive wastes. CRIEPI does not have its own underground rock laboratory and will therefore continue to participate in the Äspö Task Force on Modelling of Groundwater Flow and Transport of Solutes to apply its numerical codes to the *in situ* experiments and demonstrate their usefulness.

During 2004 CRIEPI will finish the international progress report on the numerical results for the Tasks 6A, 6B and 6B2. CRIEPI has applied its numerical code for groundwater flow and solute transport in rock mass, FEGM, to Task 6D and will during 2004 perform additional calculations for Task 6D and compose a report on the results. In addition, CRIEPI will start the computational work for Task 6E.

6.5.3 Voluntary project on impact of microbes on radionuclide retention

Micro-organism can have an influence on the geochemistry of the repository environment, such as redox conditions and pH. In particular, redox conditions can affect the chemical form of some radionuclide, resulting in a change of the adsorption behaviour on host rock. The objective for this project is to understand microbial effects on geochemistry radionuclide retention.

During 2004, CRIEPI will make an experimental device and start to perform some indoor experiments for microbial effects on geochemistry using groundwater samples and rock specimens from Äspö. The device will have two reactors packed with rock samples through which the groundwater is circulating. Differences between groundwater with and without an inhibitor of microbial activity will be observed by monitoring physicochemical parameters such as pH, redox potential, dissolved oxygen, temperature, pressure, etc.

6.6 JNC

Japan Nuclear Cycle Development Institute (JNC) is actively conducting research to support both the Japanese implementing body (NUMO) and the regulatory body. As a part of research programmes, JNC is currently constructing two underground research laboratories, one in granite in Mizunami, Gifu Prefecture, and one in sedimentary rock in Horonobe, Hokkaido. In these contexts, JNC continues to be active in repository research at Äspö HRL, which is directly applicable to the Japanese research programmes for high-level radioactive waste disposal.

The objectives of JNC's participation in research at Äspö during 2004 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.

6.6.1 Prototype Repository

JNC will continue to participate in the Prototype Repository project. JNC will carry out simulation analysis for the THM and THMC coupling process using the codes developed by JNC.

During 2004, JNC will carry out coupled THM analysis, perform comparisons with prediction analysis and measurements and perform back analysis of the three-dimensional prediction analysis using the monitored data. JNC will also continue to develop the full-way coupled THMC code.

6.6.2 TRUE Block Scale Continuation

JNC has participated in the TRUE-Block Scale Project since 1997. During 2004, JNC's participation in the TRUE Block Scale Continuation Project will focus on analysis and modelling of tracer experiments on the scale of 50 to 100 m involving fracture networks related to the structure #19.

During 2004, JNC will be involved in all aspects of the TRUE Block Scale Continuation project, including experimental design, analysis, and simulation. JNC plans to analyse and simulate all flow and transport experiments, in order to improve the understanding of flow and transport in fractured rock. Particular attention will be paid to the relative role of deterministic and "background" fractures, immobile zones within and near fractures, and fracture intersection zones.

6.6.3 Task Force on Modelling Groundwater Flow and Transport of Solutes

JNC will continue to participate in the Äspö Task Force on Groundwater Flow and Transport of Solutes during 2004.

Activities during 2004 will focus on the Task 6 − Performance Assessment Modelling Using Site Characterization Data (PASC). The objective of JNC's participation in this task is to provide theoretical and experimental support for integration of site characterisation and performance assessment activities and techniques.

During 2004, JNC will study the implications of site characterisation for safety assessment modelling within the context of the Task 6D and Task 6E projects. JNC will simulate radionuclide and tracer transport at both site characterisation and safety assessment time scales within a 200 m scale block of "semi-synthetic" Äspö granite.

JNC's modelling during 2004 is expected to include both detailed FracMan discrete fracture network simulations and safety assessment GoldSim pipe transport simulations. All simulations will be carried out with the complex hydrostructural model defined as Task 6C. Simulations will be designed to identify the role of site characterisation in reducing safety assessment uncertainty, particularly during the early stages of site characterisation.

6.7 OPG

Ontario Power Generation Inc. (OPG) is leading a programme of research and development into the safe disposal of high-level radioactive waste in Canada. These activities are contributing to the work of the Canadian Nuclear Waste Management Organisation whose current mandate includes the submission to the Canadian government of a report analysing the approaches available for long-term used fuel management. The Canadian government will then select an approach for the Nuclear Waste Management Organisation to implement.

Effective January 1, 2004, OPG signed a five-year agreement with SKB for participation in the Äspö HRL. The prime objectives of OPG's participation at Äspö HRL are to enhance the Canadian technology base for a deep geologic repository through international co-operation projects, improve our understanding of key processes in a repository and to directly share lessons learned in disposal technology development and site characterisation. The work in two Äspö HRL projects to be carried out in 2004 is described below. In addition, OPG will provide SKB with assistance in preparing the 2004 experimental plan for the Long Term Diffusion Experiment at Äspö HRL drawing from the recent experience gained in Canada, and provide suggestions for potential supporting laboratory diffusion experiments and near-field tracer transport modelling of diffusion.

6.7.1 KBS-3 method with horizontal emplacement

OPG is evaluating various emplacement methods for the deposition of spent fuel containers in a deep geologic repository. The Canadian repository programme has developed conceptual designs for both in-floor borehole (vertical) and in-room (horizontal) emplacement of containers, and has completed safety assessments of these designs. OPG is currently studying the technical feasibility and safety of alternative horizontal emplacement methods for crystalline rock, including the KBS-3H concept being developed by SKB and Posiva.

Posiva and SKB have prepared an R&D programme for the development of the horizontal disposal concept and will demonstrate the feasibility of the concept at Äspö HRL. OPG's contribution to the KBS-3H project in 2004 will be to prepare a preliminary safety assessment of the repository design with horizontal emplacement of spent fuel canisters in crystalline rock and compare the findings to previous safety analyses.

6.7.2 Äspö Pillar Stability Experiment

The Äspö Pillar Stability Experiment is a large-scale thermal-mechanical *in situ* test being conducted in a pillar between two deposition holes. The main objectives are to increase the understanding of rock damage in crystalline rock due to high stresses, to demonstrate the capability to predict rock damage and to test the effect of backfill (confining pressure) on the propagation of micro-cracks in the rock mass closest to the deposition hole. OPG is also interested in updating the current experience regarding the performance and longevity of *in situ* instrumentation applied to monitoring conditions in a repository, which are often harsh and challenging.

In 2004, OPG's contribution to the Äspö Pillar Stability Experiment will be the calibration and loan of AECL's linear variable differential transformer (LVDT) instrumentation and technical support.

6.8 Posiva

Posiva's co-operation with SKB has deepened due to the new co-operation agreement during the year 2002. The main focus of the co-operation has been on encapsulation and repository technology. Posiva also contributes to several of the research projects within Natural barriers. The implementation and construction of the underground rock characterisation facility ONKALO at Olkiluoto in Finland give new possibilities to co-operate within the research and development of underground construction technology.

The organisation is participating in the following projects:

- Technology: Prototype Repository, KBS-3 method with horizontal deposition, Large Scale Gas Injection Test, Injection grout for deep repositories, Long Term Test of Buffer Material, Cleaning and sealing of boreholes.
- Geo-science: Äspö Pillar Stability Experiment.
- Natural barriers: TRUE-block scale continuation, Colloid Project, Task Force on Modelling of Groundwater Flow and Transport of Solutes.

The aim of Posiva's co-operation is divided between Äspö HRL and more generic work for development of disposal concept that can lead to demonstrations in Äspö HRL. The work to be performed by the organisation within the different projects during 2004 is described below.

6.8.1 Prototype Repository

The Posiva-VTT team performs geochemical modelling calculations of the engineered barrier system (EBS) in the Prototype repository. The EC-contract of the project ends by February 2004. The final reporting to EC is the first main target for 2004. Further scopes of work proposed here are based on the SKB-Posiva agreement for co-operation.

The modelling approach focuses on the composition of major elements in the pore waters, and changes in solid phases. The modelling considers issues that occur during the wetting of EBS and deals with time-dependent changes at the EBS boundaries. However, all calculations follow the equilibrium thermodynamic assumption, and are not tied to any strict time-span. The prediction concept presented within the EC-project assumes instant full saturation of EBS cell volumes as soon as infiltrating water first time enters in a studied cell. After this initial step, all subsequent reaction cycles occur in the saturated anoxic system. Moreover, no frequencies were assumed for batch reaction cycles. Therefore, the presented prediction concept contains no estimates on how fast saturation (or partial saturation) front advances within the tunnel backfill. The gradual wetting of tunnel backfill is a hydrological TH problem.

More realistic geochemical predictions for the tunnel backfill require co-operation with hydrological modellers. At certain locations, the Prototype tunnel backfill contains instrumentation for on-line pore water sampling. The more elaborate geochemical calculations, at these locations, need hydrological predictions of the degree of saturation as a function of time. Moreover, geochemical calculations need estimates on the flow path lengths (and wetting velocity gradients) from the EBS boundary to the sampling locations. Successful co-operation with hydrologists and possible comparisons with sampled pore water compositions likely guides the modelling work to further geochemical refinements.

6.8.2 Long Term Test of Buffer Material

Posiva´s task in the LOT project is to study pore water chemistry in bentonite. The task will be carried out at VTT Processes. During 2004, Posiva will participate in the planning of the excavation of the next parcel as well as studies and evaluations of it.

6.8.3 Cleaning and sealing of boreholes

The objective of the work is to study appropriate procedures to prepare a deep borehole for sealing. The work can be divided into sub-tasks addressing following issues: requirements, borehole stabilising techniques and tools (applicable for fractured zones, fractures with high in-flow, breakouts etc.), cleaning of boreholes (debris, instruments, casing tubes etc. stuck in the hole) and cleaning of borehole walls.

The requirements to be set on a borehole before sealing, including stabilising borehole sections, are discussed with respect to operational time and long-term aspects. Potential characterisation methods to depict the borehole conditions are included.

Different techniques, tools and materials to stabilise a borehole are presented and discussed as well as validation of the result. A pre-study will focus on dynamic injection techniques with a double-packer for stabilising deep boreholes.

The work proceeds stepwise and the aim is to identify further development of techniques and materials for preparation of a borehole for sealing. The work involves laboratory tests and full scale field tests, which are required for further development. The work will be conducted in close co-operation between SKB and POSIVA and a report on preparing a borehole for sealing will be compiled.

6.8.4 Injection grout for deep repositories

The project consists of four sub-projects (SP1−SP4), see Section 2.7. Posiva is responsible for implementation of SP1 − Low-pH cementitious injection grout for larger fractures; and SP3 − Field-testing in Finland. The aims are to develop low pH grout for sealing wider fractures (> 100 μm) in the bedrock of surroundings of the deep repository and to perform a demonstration.

Scope of work for 2004

The SP1 concentrates on developing a low-pH cementitious injection grout(s) for wider fractures. The technical and chemical requirements that the grouts have to or are desired to fulfil will be listed in the order of importance. The pH and the leaching behaviour of the most promising grouts will be tested. The proposed grout systems or mixes are to be processed and tested in the laboratory and, if needed, refined and tested again, in a step-wise manner. This work is mainly done by VTT building technology and VTT processes.

In SP3, the grouts that fulfil the requirements will be tested in the field during this spring. Field tests in Finland are planned to include a pilot test and small-scale test. The main goals of the field tests are:

- To ensure the workability of selected cementitious grouts (pilot test).
- To ensure that the material properties determined in the laboratory can be met in the field (pilot test).
- To observe and evaluate the penetrability of the grout(s) (small scale test).
- To observe the sealing efficiency (small scale and pilot test).

6.8.5 KBS-3 method with horizontal emplacement

The demonstration phase of the KBS-3H-project includes test boring at Äspö, planning the emplacement equipment and safety evaluations. This project will be jointly executed by SKB and Posiva and have a common steering group. Posiva's main involvement in the project will be the evaluation of the long-term safety aspects.

6.8.6 Large Scale Gas Injection Test

This project will be jointly executed by SKB and Posiva and have a common steering group. The installation phase of the experiment is planned to be completed before the summer and the artificial water saturation of the buffer will start thereafter. The gas injection tests will start when the buffer is fully water saturated.

6.8.7 Äspö Pillar Stability Experiment

The Äspö Pillar Stability Experiment is a large scale thermo-mechanical *in situ* test and is planned to be conducted in a pillar between two deposition holes. The objective of Posiva's work is to contribute to the planning and steering of the project, to carry out rock mechanical modelling of the test, to carry out characterisation of the rock failure and to take part in the analysis of the results.

A novel, linked particle mechanical (PFC) and continuum modelling approach will be used to simulate the damage to the rock and the fracture propagation. The work will include further development of the PFC modelling approach in order to enable a more accurate simulation of the failure of larger geometries, by increasing the model size and the geometrical resolution.

The input and outcome of the experiment are evaluated and support is given to the project steering group. The failure and micro fracturing in the rock are analysed by taking samples from selected positions and using the 14C-PMMA method and *in situ* impregnation if feasible. The micro fracturing in the rock is compared to the results of modelling. If there are significant differences between the real micro fracturing in the rock and the modelling results, these differences will be analysed. The test will be modelled in more detail by using a three dimensional particle mechanical modelling approach and new input data.

6.8.8 TRUE Block Scale Continuation

The overall objective The TRUE Block Scale Continuation project is to improve understanding of transport pathways at the block scale, including assessment of effects of geology and geometry, macrostructure and microstructure. From Posiva's point of view this project is useful for learning more about groundwater flow and tracer transport in a network of fractures. This can be used as a basis for flow and transport conceptualisation in performance assessment.

The experiment is designed to study transport of tracers through a network of fractures. The target volume is a cube with size about 50 m. During years 2003 and 2004 a set of different tracer tests will be carried out. These include pre-testing phase for the characterisation of the flow paths (CPT-tests) and both non-sorbing and sorbing tracer tests that are predicted and evaluated by the modelling groups (BS2b tests). Monitoring of the tracer recoveries will be terminated in May 2004. Prediction and evaluation of the TRUE Block Scale Continuation tracer tests (BS2b tests) will be performed during 2004. This includes also reporting of the prediction and evaluation work.

6.8.9 Colloid Project

During 2004 the second stage of the colloid project will be finalised. The second stage of the project includes *in situ* studies of the role of the bentonite clay as a source for colloid generation. The field tests were carried out at Äspö HRL and at Olkiluoto VLJ repository. At Olkiluoto also the amount of natural colloids were investigated.

The evaluation of the investigation results will be finalised at the beginning of the year 2004. SKB will continue colloid investigation by transport tests at Äspö in 2004 and Posiva is considering participation.

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

Task 6, part of the Äspö Task Force on Groundwater Flow and Transport of Solutes, was started at the end of the year 2000. Task 6 seeks to provide a bridge between site characterisation and performance assessment approaches to solute transport in fractured rock. It will focus on the 50 to 100 m scales, which is critical to performance assessments according to many repository programmes. From Posiva's point of view this project is useful because it can clarify the connection between site characterisation and performance assessment models.

Confidence building in applied performance assessment concepts and transport models is of special interest. In practice this means investigation of structures and processes in bedrock that are relevant in the scale of performance assessment.

During 2004 preliminary results for Tasks 6D and 6E will be presented. Task 6D includes modelling of radionuclide transport in a fracture network at tracer test flow conditions. Task 6E will include modelling of the radionuclide transport in a fracture network at PA flow conditions.

6.9 EC-projects

SKB is through Repository Technology co-ordinating three EC contracts: Prototype Repository, Cluster Repository Project (CROP) and the project NET.EXCEL. SKB takes part in several EC projects of which the representation is channelled through Repository Technology in three cases: FEBEX II, SAFETI and PADAMOT.

6.9.1 Prototype Repository

SKB's reference concept for deep disposal of spent nuclear fuel, the KBS-3 method, has several features in common with other European concepts and full-scale testing is therefore of great value. Components of this system have been thoroughly investigated but the Prototype Repository is the first full-scale application. The Prototype Repository is conducted at Äspö HRL as an integrated test focusing on Engineered Barrier System (EBS) performance but comprising also canister deposition, backfilling and plug construction. It offers a number of possibilities to compare test results with models and assumptions and also to develop engineering standards and quality assurance methods. The co-operative work aims at accomplishing confidence building as to the capability of constructing safe repositories and predicting EBS performance also for somewhat different conditions than those in the Äspö HRL.

Prototype Repository – Full scale testing of the KBS-3 concept for high-level radioactive waste	
Start Date: 2000-09-01	**End Date:** 2004-02-29
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries**: Finland, Germany, Japan, Spain, Sweden and United Kingdom

6.9.2 CROP

The project has the objective of assessing the experience from the various large-scale underground laboratories for testing techniques and aims specifically at comparing methods and data obtained from the laboratories for evaluating present concepts and developing improved ones. Several of these underground projects, which deal with disposal in crystalline rock, salt, and clay formations have been supported by the EC. The Cluster Repository Project (CROP) implies constitution of a forum − a cluster − for the intended evaluation and assessment, focusing on construction, instrumentation and correlation of theoretical models with field data, especially concerning engineered barrier systems.

CROP – Cluster repository project, a basis for evaluating and developing concepts of final repositories for high-level radioactive waste	
Start Date: 2001-02-01	**End Date:** 2004-01-31
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries:** Belgium, Canada, Finland, France, Germany, Spain, Sweden, Switzerland and USA

6.9.3 FEBEX II

The FEBEX project has the dual objective of demonstrating the feasibility of actually manufacturing and assembling an engineered barrier system and of developing methodologies and models for assessment of the thermo-hydro-mechanical (THM) and thermo-hydro-geochemical (THG) behaviour within the engineered barrier system (near-field). FEBEX II consists in the extension of the operational phase of the FEBEX I *in situ* test. The *in situ* test is performed in a TBM-drift at the Test Site at Grimsel in Switzerland, where two full-scale canisters with electrical heaters have been installed horizontally. The canisters are surrounded by bentonite, pre-compacted into blocks possible to handle by man. The FEBEX II includes dismantling of the plug, retrieval of the outer canister and casting of a new plug. The FEBEX project also includes a mock-up test in scale 1:2, and some complementary laboratory tests, as well as modelling works.

The project has been extended 10 months due to the decision to investigate the saturation process longer than originally planned before dismantling the outer section.

FEBEX II – Full-scale engineered barriers experiment in crystalline host rock phase II	
Start Date: 1999-07-01	**End Date:** 2004-10-31
Co-ordinator: Empresa Nacional de Residuos Radiactivos, Spain	**Participating countries:** Belgium, Czech Repblic, Finland, France, Germany, Spain, Sweden, and Switzerland

6.9.4 SAFETI

The aim of this project is to develop an innovative numerical modelling methodology that is suitable for excavation scale simulation of geological repositories. The method, termed "Adaptive Continuum/Discontinuum Code (AC/DC)" will be developed from existing algorithms. Full validation of the codes will be carried out using laboratory and *in situ* acoustic emission and microseismic data collected in previous experiments. Further laboratory tests will be carried out during the proposed project for validation of the performance of both short- and long-term rock mass behaviour. The AC/DC represents a significant advance over current numerical modelling approaches and will have a wide range of application in waste repository engineering, including feasibility studies.

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

6.9.5 PADAMOT

During the Quaternary global climate has alternated between glacial conditions and climate states warmer than the today. In northerly latitudes the potential for cold region processes to affect groundwater pathways, fluxes, residence times and hydrochemistry is significant, whilst for southern European localities the alternation between pluvial and arid conditions is equally important. PADAMOT will investigate the evolution of minerals and groundwater through these climate changes. The project will use advanced analytical techniques and numerical modelling tools. This palaeohydrogeological approach investigates processes that are significant for repository safety studies on length and time scales that cannot be simulated by experiment. Interpretations will be used to constrain the range of scenarios for conceptual model development and time-variant modelling in performance assessments.

PADAMOT – Palaeohydrogeological data analysis and model testing	
Start Date: 2001-11-01	**End Date:** 2004-11-01
Co-ordinator: Nirex Ltd, United Kingdom	**Participating countries:** Czech Republic, Spain, Sweden and United Kingdom

6.9.6 NET.EXCEL

The objectives are a future efficient use of European resources in research and development of safe methods for final disposal of high-level radioactive waste. This calls for close interaction between European end users in planning of national programmes as well as in development of international projects. The proposal concerns the forming of a network of end users for the intended analysis of present status and future requirements in RTD for the three different rock media: salt, clay sediments and crystalline rock. The expected results are common and systematic basis for priorities and co-ordination of future European RTD work for radioactive waste management, and suggested areas and priorities for joint RTD projects. The objective is to develop a common and systematic basis for priorities and co-ordination of future European RTD work for Radioactive Waste Management and suggest areas and priorities for joint RTD projects. This will be accomplished by forming a Network of Excellence with the main European organisations given the national responsibilities to develop systems for safe handling and disposal of long-lived radioactive waste and by jointly working out a document that can serve as an aid for the planning and execution of future co-ordinated RTD activities between European implementers.

NET.EXCEL – Network of excellence in nuclear waste management and disposal	
Start Date: 2002-11-01	**End Date:** 2004-03-31
Co-ordinator: Swedish Nuclear Fuel and Waste Management Co, Sweden	**Participating countries**: Belgium, Finland, France, Germany, Spain, Sweden, Switzerland, and United Kingdom

7 Environmental research

7.1 General

Äspö Environmental Research Foundation was founded 1996 on initiative of local and regional interested parties. The aim was to make the underground laboratory at Äspö and its recourses available for national and international environmental research. SKB's economic engagement in the foundation was concluded in 2003and the activities are now concentrated on the Äspö Research School, which was founded in 2002.

7.2 Äspö Research School

On the initiative of the Äspö Environmental Research Foundation the University of Kalmar has set up the Äspö Research School. The research school is a concrete commitment to provide conditions for today's and tomorrow's research concerning environmental issues. The research school has a special interest in the transport of pollutants and their distribution in rock, ground, water, and biosphere. The research school is co-financed by the municipality of Oskarshamn, SKB, and the University of Kalmar.

During 2003 detailed plans for the activities were worked out. One professor has been hired and three PhD students begun their studies during the fall. The goal is to increase the number of students to about ten during the coming years. During 2004 the students will establish a field test base in the Äspö Research Village and initiate the first field test in the laboratory.

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