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Äspö Hard Rock Laboratory

Planning Report for 2000

February 2000

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Laboratory

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The Äspö Hard Rock Laboratory,
Planning Report for 2000

This report provides a detailed description of the planned work for 2000 and an overview of activities scheduled in the near future.

The report is a detailing of the program for the Äspö Hard Rock Laboratory descried in SKB's Research, Development and Demonstration Programme, RD&D Programme 98, and serves as the basis for the management of the projects undertaken at the Äspö Hard Rock Laboratory. The planning report is revised annually.

SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
Safety and Technology
Repository Technology

Olle Olsson
Director

Executive summary

General

The Äspö Hard Rock Laboratory constitutes an important part of SKB's work to design and construct a deep geological repository for spent fuel and to develop and test methods for characterisation of a suitable site. The Äspö Hard Rock Laboratory has been designed to meet the needs of the research, development, and demonstration projects that are planned for the Operating Phase. 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 450 m. Construction of the facility began in 1990 and was completed in 1995 when the Operating Phase began.

The Äspö Hard Rock Laboratory and the associated research, development, and demonstration tasks are managed by the Repository Technology Unit within SKB.

The Äspö Hard Rock Laboratory has so far attracted considerable international interest. As of February 2000 nine foreign organisations are participating in the Äspö HRL.

To meet the overall time schedule for SKB's RD&D work the work has been structured according to four stage goals as defined in SKB's RD&D Programme 1998.

The Planning Report provides an overview of the planned activities for 2000. Some main activities for 2000 are summarised below:

Investigations and experiments

Stage goal 2 - Finalise detailed investigation methodology

This Stage Goal includes projects with the aim to develop technology and tools to facilitate refinement of site models through investigations from underground excavations and boreholes. The refined models will provide the basis for updating the layout of the repository and adapting it to local conditions.

Different methods for characterisation from underground excavations and boreholes will be tested as part of a number of projects undertaken at the Äspö HRL. When sufficient data has been collected an evaluation will be made. A study will be undertaken to study the limitations of the overcoring method for rock stress measurements and under what conditions anisotropic theory may be applied to such measurements.

Stage goal 3 - Test of models for description of the barrier function of the host rock

This Stage Goal 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 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 experimental outcome and evaluated by the Task Force delegates. The group consists of nine organisations from eight countries. Currently active tasks are evaluation of predictive modelling undertaken of the TRUE-1 experiment (Task 4) and coupling between hydrochemistry and hydrogeology (Task 5). A Task 6 will be initiated.

Further development of codes for groundwater flow and transport will be undertaken and applied to Äspö data. The statistics for the occurrence of high permeability features will be updated and included in the models of Äspö.

Tracer tests are carried out within experiments in the TRUE-projects. These are conducted at different scales with the aim of identifying detailed scale (5m) and block scale (50m) flow paths, retention of weakly and moderately sorbing tracers and the effect of matrix diffusion. During 2000 the final report of the first detailed scale experiment (TRUE-1) will be published. Characterisation for the block scale experiment (TRUE-Block Scale) is completed and the tracer test stage of the project has started. These tests should be completed by the end of 2000. A matrix diffusion experiment (LTDE) will be started. Modelling of the experiments is done by several groups associated to the Äspö Task Force for modelling of groundwater flow and transport of solutes.

CHEMLAB experiments are conducted with the moderately and highly sorbing nuclides. Experiments are carried out in simulated near field conditions (bentonite) and in tiny rock fractures. A new site for the CHEMLAB experiments was selected and prepared during 1999. All future experiment will be conducted in the J niche at 430 m depth. The experiment with radiolysis was prepared in 1999 and will be conducted and completed within 2000. A second CHEMLAB unit, which will be used for experiments with redox sensitive nuclides and transuranics was delivered during 1999. The first experiment in this probe will be the migration of actinides, Americium, Neptunium and Plutonium, in a rock fracture.

The detailed scale redox experiment (REX) focuses on what will happen to the oxygen that is trapped in the tunnels when the repository is closed. This experiment was completed in 1999 and will be reported during 2000. A seminar will be held in Japan, hosted by JNC.

The main objective of the Matrix Fluid Experiment is to understand the origin and age of matrix fluids and their possible effect on fluid chemistry in the bedrock. Matrix fluids will be sampled from a borehole drilled into matrix (fracture free) rock. Fluid inclusions will be studied on core samples.

During 2000 the SMC project will be initiated to study the concentration, stability, and mobility of colloids in the Äspö environment.

A site will be set up at the 450 m level for studies of microbial activity in groundwater at in situ conditions. Microbial effects on redox conditions, radionuclide migration, and gas composition and consumption will be in focus. Studies will also be performed on hydrogen generation and flow in the Äspö granitic rock environment.

Stage goal 4 - Demonstration of technology for and function of important parts of the repository system

The Äspö Hard Rock Laboratory makes it possible to demonstrate and perform full scale tests of the function of different components of the repository system which are important for the long-term safety of a repository. It is also important to show that high quality can be achieved in design, construction, and operation of the repository. The main projects within this Stage Goal are the Backfill and Plug Test and the Prototype Repository which focus on testing the integrated function of the engineered barriers.

The Prototype Repository experiment is located in the last part of the TBM tunnel at the 450 m level and will include 6 deposition holes in full scale. The aims of the Prototype Repository are to demonstrate the integrated function of the repository components and to provide a full-scale reference for comparison with models and assumptions. The Prototype Repository should, to the extent possible, simulate the real deep repository system, regarding geometry, materials, and rock environment. Instrumentation will be used to monitor processes and properties in the canister, buffer material, backfill and the near-field rock. Characterisation of the experimental site is completed. Most of the efforts during 2000 will be directed towards preparations in order to begin installation of canisters, bentonite blocks and backfill in the beginning of 2001.

The Backfill and Plug Test is a test of different backfill materials and emplacement methods and a test of a full-scale plug. It is a test of the hydraulic and mechanical function of the backfill materials and their interaction with the near field rock. During 1999 the experimental setup was finished, the tunnel backfilled, and the plug to seal the drift put in place. Then water saturation was started and will continue for more than a year before testing of backfill properties will commence.

The project Demonstration of Repository Technology will include tests of equipment for drilling of full size deposition holes, deposition of bentonite buffer and full-scale canisters in these holes, and finally retrieval of the canisters. Four full-scale deposition holes have been drilled for the demonstration project at the 420 m level. The deposition machine was delivered during 1999 and will be put into operation during this year. Testing and demonstration of the deposition of full size canisters will then begin.

Two full-scale deposition holes have been drilled for the purpose of testing technology for retrieval of canisters after the buffer has become saturated. These holes have also been used for comprehensive studies of the drilling process and the rock mechanical consequences of drilling the holes. A canister and bentonite blocks will be emplaced in one of the holes and the hole will be sealed with a plug. Heating and water saturation will then begin and is expected to last for 3-4 years.

The Long Term Tests of Buffer Material aim to validate models and hypotheses concerning long term processes in buffer material. Five 300 mm diameter test holes have been drilled and instrumented. Four of the tests are planned to run for at least five years. The temperature for two of the test holes will be 90ºC and the remaining three holes will have a temperature in the range 120-150ºC.

A Task Force on Engineered Barriers will be initiated to increase the understanding and to build confidence in the capability of modelling various thermo-hydro-mechanical-chemical-biological (THMCB) processes of importance for the long term safety of a deep repository, their interaction and consequent need of coupling.

Contents

1 General

In 1986 SKB decided to construct an underground rock laboratory in order to provide an opportunity for research, development, and demonstration in a realistic and undisturbed underground rock environment down to the depth planned for a future deep repository. In the autumn of 1986, SKB initiated field work for the siting of an underground laboratory in the Simpevarp area in the municipality of Oskarshamn. At the end of 1988, SKB decided in principle to site the laboratory on southern Äspö about 2 km north of the Oskarshamn power station. Construction of the Äspö Hard Rock Laboratory started on October 1st, 1990 after approval had been obtained from the authorities concerned. Excavation work was completed in February 1995.

The Äspö Hard Rock Laboratory has been designed to meet the needs of the research, development, and demonstration projects that are planned for the Operating Phase. 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 450 m (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 techniques. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts. Äspö Research Village is located at the surface on the Äspö Island and it comprises office facilities, storage facilities, and machinery for hoist and ventilation (Figure 1-2).

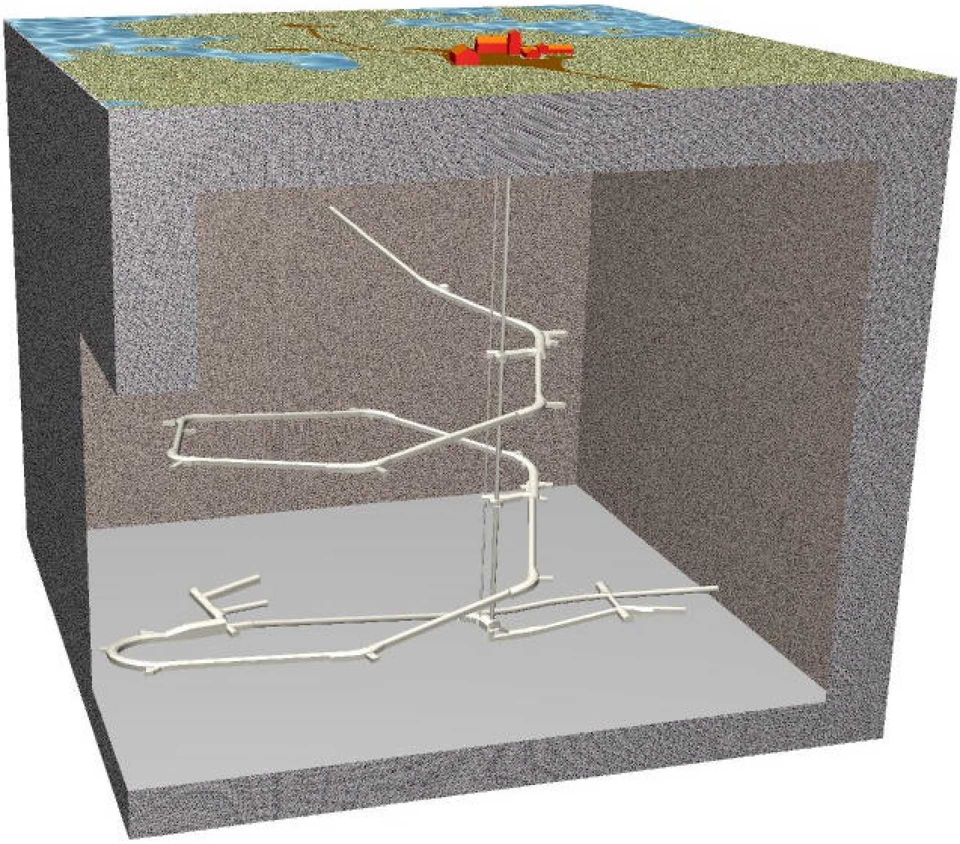

Figure 1-1 *Overview of the Äspö Hard Rock Laboratory Facilities.*

Figure 1-2 *Overview of the Äspö Research Village.*

The work with the Äspö Hard Rock Laboratory, Äspö HRL, has been divided into three phases: the pre-investigation phase, the construction phase, and the operating 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 etc. conditions to be observed during excavation of the laboratory. This phase also included planning for the construction and operating 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 **Operating phase began in 1995**. A preliminary outline of the program for the Operating phase was given in SKB's Research, Development and Demonstration (RD&D) Programme 1992. Since then the program has been revised and the basis for the current program is described in SKB's RD&D Programme 1995.

Annual Reports have been published for the Äspö Hard Rock Laboratory in SKB’s Technical Report series and the reader is referred to these publications for a more detailed account of achievements to date.

The Planning Report gives an overview of the planned activities for the calendar year 2000. The activities have been structured according to the stage goals defined below.

1.1 Goals

SKB decided to construct the Äspö Hard Rock Laboratory for the main purpose of providing an opportunity for research, development and demonstration in a realistic and undisturbed underground rock environment down to the depth planned for the future deep repository. Important tasks for the Äspö Hard Rock Laboratory are:

- to increase scientific understanding of the safety margins of the deep repository,
- to test and verify technology that provide cost reductions and simplifies the repository concept without compromising safety,
- to demonstrate technology that will be used in the deep repository,
- to provide experience and training of staff, and
- to inform about technology and methods to be used in the deep repository.

To meet the overall time schedule for SKB's RD&D work, the following stage goals have been defined for the work at the Äspö Hard Rock Laboratory.

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, and

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 function of the host rock

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 a full scale different components of importance for the long-term safety of a deep repository system and to show that high quality can be achieved in design, construction, and operation of system components.

During year 2000 work will only be undertaken within Stage Goals 2, 3, and 4.

1.2 Schedule

Figure 1-3 presents the schedule for the main activities to be carried out at Äspö Hard Rock Laboratory in the Operating Phase.

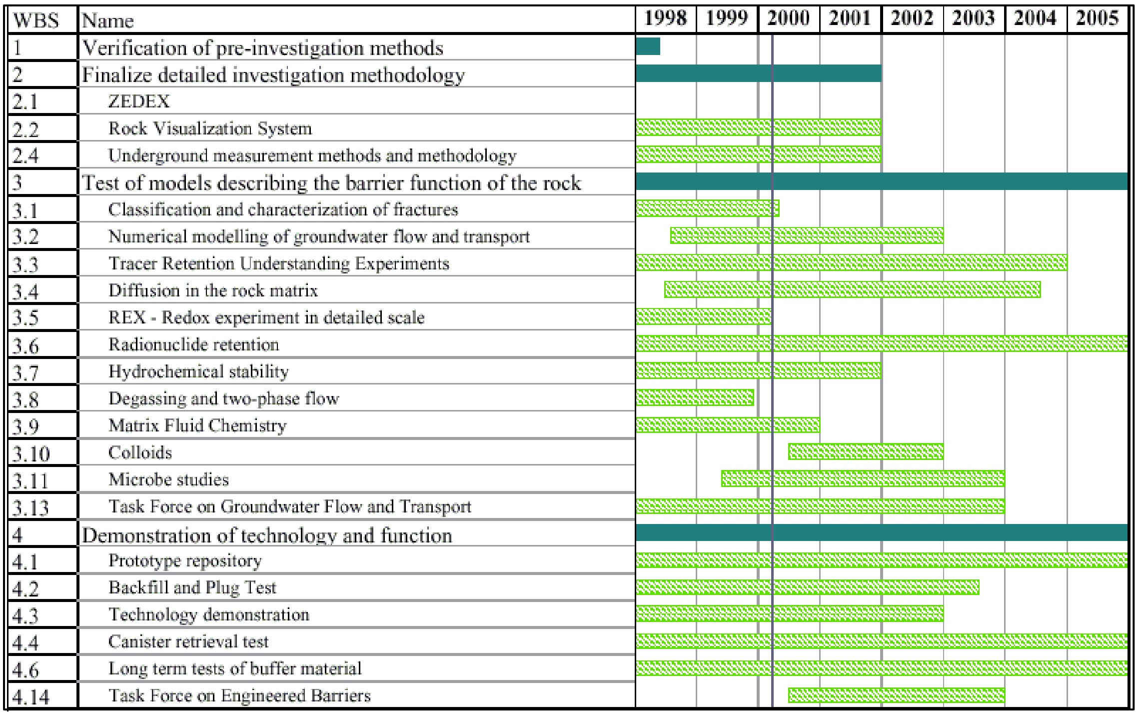

Figure 1-3 Overview schedule for the Operating Phase of the Äspö Hard Rock Laboratory.

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1.3 Organisation

1.3.1 SKB's organisation

The current organisation of SKB that became effective on July 1st 1998 is shown in Figure 1-4. The organisation is set up to provide a focus of activities and use of resources to meet SKB's main near term goal, which is to get acceptance for performing site investigations at two sites in 2001. Investigations, including drilling, should commence in 2002. The strategy to reach this goal is described in the latest Research, Development and Demonstration Program 98, which SKB delivered to the Swedish government at the end of September 1998.

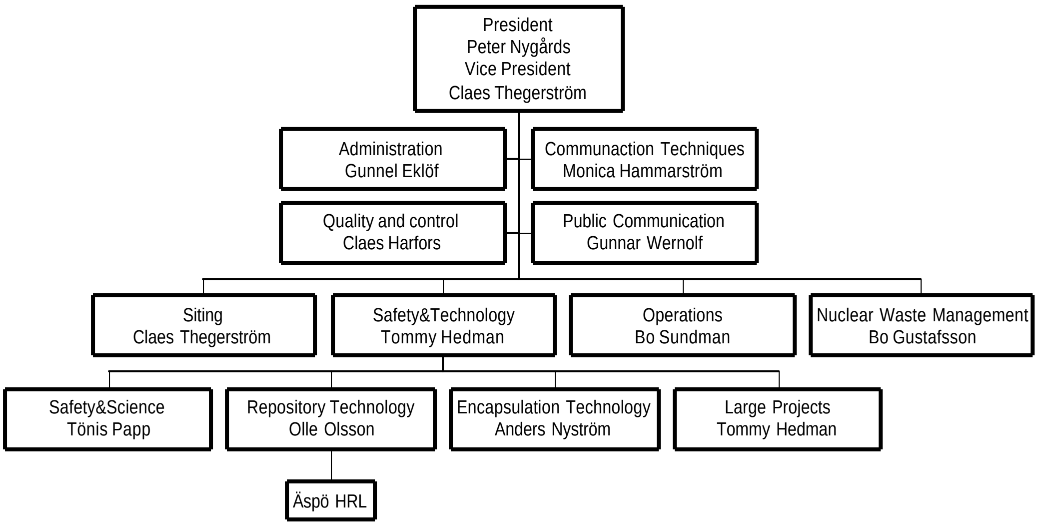


Figure 1-4 *Organisation of SKB valid from July 1st 1998.*

All research, technical development, and safety assessment work is organised into one department, Safety and Technology, in order to facilitate co-ordination between the different activities. The Safety and Technology department is organised into four units;

- Safety and Science with responsibility for research, safety assessments, and systems analysis.

- Repository Technology with responsibility for development of site investigation programs and methods, development and testing of deep repository technology, and in situ research on the natural barrier. The unit is also responsible for the operation of the Äspö Hard Rock Laboratory and the co-ordination of the research performed in international cooperation there.

- Encapsulation technology is responsible for development and testing of the copper canister and the design of the Encapsulation Plant. This unit is also responsible for the operation of the Encapsulation Laboratory located in Oskarshamn.

- Large construction projects have been organised in a separate unit. The main future task of this unit is the construction of CLAB 2, the expansion of CLAB to a total storage capacity of 8000 tons of spent nuclear fuel.

1.3.2 Repository Technology and the Äspö Hard Rock Laboratory

The Repository Technology unit is organised as a matrix organisation with three Senior Project Managers with responsibility to define the programme and manage the projects within their respective areas of responsibility (Figure 1-5). The three main tasks are:

- Site investigations with responsibility to provide an appropriate site investigation program, methods, equipment, and a competent organisation for site and detailed investigations to be applied when needed.
- Repository technology with responsibility for development, testing, planning, design, and demonstration of the technology and the methods needed to construct a deep repository.
- Natural barriers with responsibility for management and performance of research projects at the Äspö Hard Rock Laboratory aimed at resolving issues concerning the function of the natural barrier.

The Senior Project Managers report directly to the Director of Repository Technology.

The staff is organised into the following groups:

- The Technology and Science group is responsible for the co-ordination of projects undertaken at the Äspö HRL and to maintain knowledge about the methods that have been used and the results that have been obtained from work at Äspö.
- The Experiment Service group is responsible for providing service (design, installations, measurements etc.) to the experiments undertaken at Äspö HRL. They are also responsible for operation and maintenance of monitoring systems and experimental equipment at Äspö.
- The Computer Systems group is responsible for operation and maintenance of computer hardware at SKB's offices in Oskarshamn and Hultsfred. They are also responsible for the further development and administration of SKB's geoscientific database, SICADA, GIS systems, and the RVS system.
- The Facility Operations group is responsible for operation and maintenance of the Äspö HRL offices, workshops and underground facilities.
- The Information group is responsible for arranging visits to SKB's facilities and providing information to visitors to Äspö HRL and SKB's other facilities in Oskarshamn.
- The Administration group is responsible for providing administrative service and quality systems.

The Äspö Hard Rock Laboratory and the associated research, development, and demonstration tasks are managed by the Director of Repository Technology (Olle Olsson). The International Cooperation at the Äspö Hard Rock Laboratory is the responsibility of the Director of Repository Technology, Olle Olsson, and SKB's International Coordinator, Monica Hammarström.

Each major research and development task is organised as a project that is led by a Project Manger who reports to one of the Senior Project Managers. Each Project Manager will be assisted by an On-Site Co-ordinator from the Site Office 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.

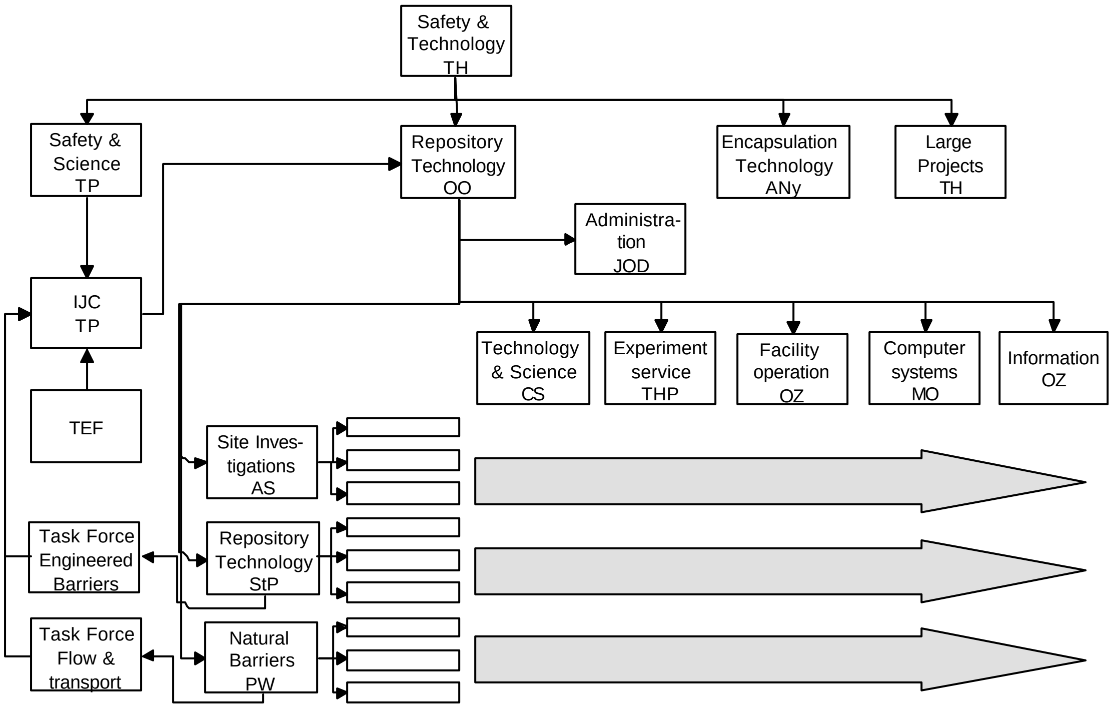


Figure 1-5 Organisation of Repository Technology.

1.3.3 International participation in Äspö HRL

The Äspö Hard Rock Laboratory has so far attracted considerable international interest. As of February 2000 nine foreign organisations are participating in the Äspö HRL in addition to SKB. These organisations are: Japan Nuclear Cycle Development Institute (JNC), Japan; Central Research Institute of Electric Power Industry (CRIEPI), Japan; Agence National Pur la Gestion des Dechets Radioactifs (ANDRA), France; POSIVA Oy, Finland; UK Nirex, United Kingdom; Nationale Genossenschaft für die lagerung von radioaktiver Abfälle (NAGRA), Switzerland; Bundesministerium für Wirtschaft und Technologie (BMWi), Germany; Empresa Nacional de Residuos Radiactivos (ENRESA), Spain, and United States Department of Energy, Carlsbad Area Office (USDOE/CAO).

1.3.4 Advisory Groups

The international partners and SKB reached a joint decision to form the Äspö International Joint Committee (IJC) to be convened in connection with Technical Evaluation Forum (TEF) meetings. The role of the IJC is to co-ordinate the contributions of organisations participating in the Äspö HRL. The TEF meetings are organised to facilitate a broad scientific discussion and review of results obtained and planned work. Technical experts from each participating organisation and the IJC delegates participate in the TEF meetings. Chairman of IJC/TEF is Tönis Papp and secretary is Monica Hammarström (November 1999).

For each experiment the Äspö HRL management will establish a Peer Review Panel consisting of three to four Swedish or International experts in fields relevant to the experiment.

1.3.5 Task Forces

The Technical Co-ordinating Board (TCB) which preceded the IJC established the Task Force on modelling of groundwater flow and transport of solutes. The Task Force reviews and or proposes detailed experimental and analytical approaches for investigations and experiments at Äspö HRL. The group convenes twice a year. Approximately ten different modelling groups are now actively involved in the work. Chairman (November 1998) is Gunnar Gustafson, CTH and secretary is Mansueto Morosini, SKB.

During 2000 a proposal for the initiation of a Task Force on Engineered Barriers will be submitted to the IJC.

1.4 Formulation of experimental programme

The experiments to be performed in the Operating Phase will be described in a series of Test Plans, one for each major experiment. The Test Plans should give a detailed description of the experimental concept, scope, and organisation of each project. The Test Plans are structured according to a common outline. In cases where experiments are planned to extend over long time periods (up to 10 years) it is not appropriate or even possible to plan the experiment in detail in advance. In such cases, Test Programmes will be prepared outlining the objectives and overall scope of the programmes, which will be divided into stages with a duration of 2-3 years. Detailed Test Plans will then be prepared for each stage, following an evaluation of results obtained to date. These evaluations may result in programme revisions.

Initially, draft Test Plans will be prepared which will be submitted for review by the Task Force and other bodies. After review, as well as scoping or design calculations, the Test Plans will be updated, detailed where appropriate, and published as Progress Reports or International Cooperation Reports. The general strategy is to begin preparation of the Draft Test Plans approximately one year before field work or some other significant preparation work is planned to start. The intention is also to actively engage the Task Force on modelling of groundwater flow and transport of solutes in the planning, design, and evaluation of the flow and transport experiments.

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 experimental sites are allocated so that interference between different experiments is minimised. The current allocation of experimental sites within the Äspö HRL is shown in Figure 1-6.

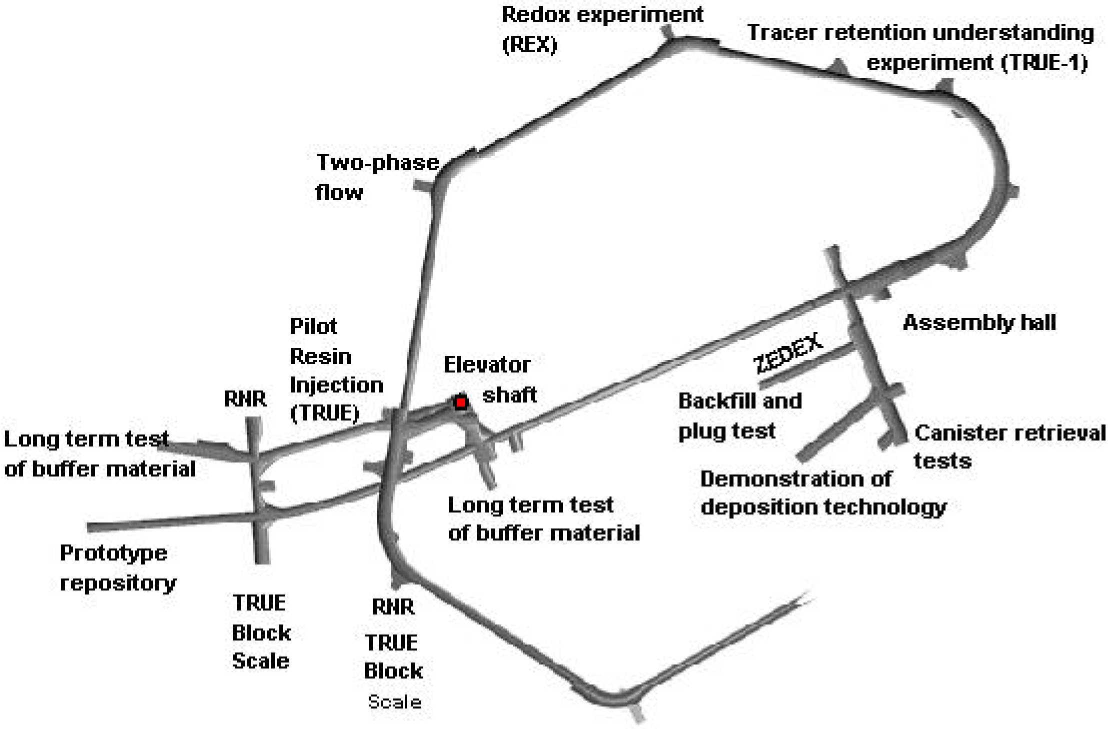


Figure 1-6 *Underground excavations at the 300-450 m levels and current allocation of experimental sites.*

1.6 Documentation

Data produced are mainly stored in SKB's database SICADA. Data and evaluations for specific tasks are published in International Progress Reports (IPR). The information from Progress Reports is summarised in Technical Reports (TR) at times considered appropriate for each project. SKB also endorses publications of results in international scientific journals. In order to facilitate quick distribution of results Technical Documents (ITD) are sometimes prepared.

Joint international work is reported in Äspö International Cooperation Reports (ICR).

Status Reports are published 4 times a year. The Äspö HRL Annual Report is published as an SKB Technical Report.

Planning is often documented in Technical Documents (ITD). Technical Documents constitute working material and are not distributed to third parties.

Table 1-1 provides an overview of the policy for review and approval of Äspö HRL documents during the Construction Phase.

Table 1-1 Review and approval of Äspö HRL Reports

Report	Reviewed by	Approved by
Äspö HRL-related parts of SKB RD&D Programme	Swedish Authorities	SKB
Planning Report (one per year)	SKB Management	SKB
Annual Reports (Summary of work covering each calendar year)	Director Repository Technology	SKB
Technical Reports	Case-by-case	Director Äspö HRL
Äspö International Cooperation Report	Contributing organisation	Director Äspö HRL
Status Reports (Short summary of work covering each 3 month period)		Director Äspö HRL
International Progress Reports	Project Manager	Director Äspö HRL
Technical Documents	Author	Project Manager

1.7 Quality Assurance

Background

Quality assurance means to ensure that activities are undertaken with due quality and high efficiency. In order to achieve this goal it is required that a smoothly running systems are in place to manage projects, personnel, purchasing, economy, quality, safety and environment.

The structure of a quality assurance system is based on procedures, handbooks, instructions, identification and traceability, quality audits etc.
The overall guiding document for issues relating to management, quality and environment is SKB-HLK (SKB:s Handbook for Management and Quality Assurance).

Employees and contractors related to the SKB organisation are responsible that works will be performed in order to achieve SKB quality goals and guidelines.

Objectives/Scope 2000

A project is in progress to implement a common management system for SKB to break down all requirements from legislator, authorities and from other interested parties and also internal requirements of our own organisation. The aim of the project is to certify SKB according to the Environmental Management System ISO 14001 and also to the Quality Management Standard ISO 9001 during year 2001.

The present SKB Management System compares with the requirements from the ISO-standards. Realised GAP-analysis results in suggestions to actions.

Great efforts are required to produce documents and document routines, instructions with the purpose to reach the goal in being ISO-certified.

A new updated Purchasing Handbook will be completed during year 2000.

A revision of the Äspö Handbook (The Handbook cover issues of decision-making, procedural instructions, manuals etc to guide the works pertaining to quality assurance and environmental issues at the Äspö HRL) is undertaken and will be finished in May 2000. Co-ordination is done with the department of Safety and Technology.

Goals have been identified and important environmental aspects which influence the environment have been identified in order to implement an Environmental Management System.

Projects in Repository Technology shall follow the guidelines given by SKB:s Project Handbook. Requirements (from legislator, authorities and internal demands) on quality, safety and environment shall be implemented in the research projects. The plant design for a deep repository in the future and site investigations should also follow these quality procedures.

SKB shall make an inventory of prerequisites for a common identification- and archival system. Important documents from activities shall be recorded and archived in a integrated and traceable manner.

To develop a better structure for managing time and resources is developed. It is a software application called Äspö Plan Right which is running under MS Project.

1.8 Information and public relations

Background

In Oskarshamn municipality SKB has got three facilities (the Äspö Hard Rock Laboratory, CLAB and the Canister Laboratory) and a feasibility study is in progress.

The Äspö information group´s main goal is to create public acceptance for SKB in cooperation with other departements in SKB. This is achieved by giving information about SKB, the Äspö HRL and the SKB siting programme. The visitors are also given a tour of the Äspö HRL. Today there is one visitors administrator and four public relations officers stationed at the Äspö HRL.

Scope for 2000

Due to a larger interest to visit SKB:s facilities in Oskarshamn, the pressure on SKB:s visitors administrator has increased. A cooperation with OKG will start, the plans are to have a shared booking central up and running by the summer of 2000.

The guided summer tours of the Äspö Hard Rock Laboratory will start beginning of June and continue throughout the summer. These tours will be carried out in cooperation with Oskarshamn tourist office, the main target group is the general public. Two guides will be employed for the summer period.

There will also be tours for the general public at the weekends during the spring of 2000.

A safety/instruction video for consultants concerning work and safety under ground will be produced.

2 Methodology for detailed characterisation of rock underground

2.1 General

A programme for detailed characterisation will be devised before detailed characterisation is initiated on a selected site and construction of the surface and underground portions of the deep repository is commenced. In conjunction with the driving of the Äspö tunnel, several different investigation methods have been tried and the usefulness of these methods for detailed characterisation for a deep repository is being evaluated. Preliminary experience from Äspö shows that there is a need for refinement of these methods to enhance the quality of collected data, boost efficiency and improve reliability in a demanding underground environment. Furthermore, the detailed characterisation programme needs to be designed so that good co-ordination is obtained between rock investigations and construction activities.

The objectives are:

- to try out existing and new methods to clarify their usefulness for detailed characterisation. The methods to be tested are chosen on the basis of their potential use within the detailed characterisation programme,
- to refine important methods in a detailed characterisation programme to enhance data quality, efficiency and reliability.

Detailed characterisation will facilitate refinement of site models originally based on data from the ground surface and surface boreholes. The refined models will provide the basis for updating the layout of the repository and adapting it to local conditions. Due to the heterogeneity of the rock, the layout of the repository needs to be adapted to the gradually refined model of rock conditions. This approach has a long tradition in underground construction and it should be used also for a deep repository.

2.2 Underground measurement methods and methodology

Background

Detailed investigation for SKB deep repository will include a characterisation step involving one candidate site, subsequent following the site investigation which will be carried out on at least two sites. Detailed investigations will mostly include investigations from the underground.

During the Construction phase of the Äspö HRL documentation, measurements and testing activities from underground were performed. Other underground investigation methods have been used, and will further on be used, during the Operational phase. Preliminary experiences shows that methods and instruments in some cases have to be improved, with regard to correctness in data, efficiency and robustness.

Objectives

The aim is to evaluate the feasibility and usefulness of the methods used, define areas, methods and instruments where improvements have to be made. The work also includes testing of other methods (mainly commercially available) which have not been used before. Tests of methods for detailed characterisation are mainly intended to be carried out within the framework of ongoing projects.

Scope for 2000

A report on underground investigation methods used during the construction phase of the Äspö HRL will be published during mid 2000. The report will describe the different methods used with regard to instrument or other working tools and measurement methodology. Resolution and accuracy of the measured values as well as general aspects of errors will be discussed. The evaluation part will address the usefulness and feasibility of the methods. Recommendations on possible modifications etc. will also be given.

Based on the report, but also on the basis of other project evaluation and validation reports, further testing of existing methods, testing of new methods, etc. will be planned.

Radar and seismic

Areas of potential interest for further studies are the geophysical methods seismic and radar. Those methods are regarded as remote characterisation methods for location of discontinuities in prospective repository rock volumes, in particular during detailed investigation and repository construction stage. While the seismic method covers relatively large volumes the radar is foreseen to give more detailed information in the near field. These methods have been used at Äspö, and several data sets from different measurement configurations exists. The further studies of these methods preliminary involves examination of the existing data sets aiming at further evaluating the methods capacity (detectability, accuracy, etc. in discontinuity location and orientation). Both borehole and tunnel measurements will be studied. These methods will mainly be applied as part of the characterisation work performed for various projects, e.g. TRUE Block Scale and the Prototype Repository. When sufficient data has been collected an evaluation will be made and reported.

Tunnel and large hole documentation

An other area of interest is methodology for tunnel and large hole surface documentation. The baseline geological documentation of the tunnel during the construction phase was carried out by manually drawing in the tunnel, on a computer produced map sheet. It is foreseen that the documentation in some way could be simplified by means of introducing hand computer or similar.

A method test of overview documentation with the BIPS image video recording system was made in the TBM tunnel when the BIPS borehole system was delivered. This method has a potential to be used not only for TBM mapping but also for large hole documentation like the deposition holes. Laser scanning has been tested as a method for documentation of tunnels, both with respect to their geometric dimensions and as a basis for geological mapping (Nilsson, 1997).

Groundwater monitoring

The groundwater monitoring system developed for Äspö HRL was designed for surface based borehole investigations (during the pre-investigation) and was expanded for the construction phase. The data management system part of the Hydro Monitoring System (HMS) was in general found to fulfil the requirements set-up, while the packer system installations in the boreholes was not functioning properly during the construction phase. The main problem occurred in boreholes where the groundwater draw-down exceeded 50-70 m.

An extensive evaluation of the groundwater monitoring system will be made before a similar programme will be defined for the site investigation for the Deep repository.

Other studies

Method studies will be initiated by ideas from various projects. Therefore all studies or development needed are not yet identified. However, before starting each development the idea must be evaluated with regard to potential use of the proposed technique or possible improvement. Some methods have been tried out within the framework of other projects in the Äspö HRL. For example, the reliability of rock stress measurements performed with the overcoring method has been checked (Myrvang, 1997). When the necessary data are available, evaluation reports will be compiled which summarise experience gained to date and make recommendations for possible refinement of suitable methods. Methods where some tests have already been made and where evaluation is expected to take place during 2000 are measurement of machine parameters during drilling to obtain geological information, water sampling during drilling to obtain undisturbed samples, high-resolution seismic and radar surveys, and methods for accurate position measurements in boreholes.

2.2.1 Rock stress measurements by the overcoring method

Background

In-situ stress measurements is a method for collecting a very important rock mechanical parameter – the load on an underground opening.

Two dominant methods are available: Hydraulic Fracturing and Overcoring. The Overcoring method has been used for measuring of the mechanical boundary conditions for some of the experiments at the Äspö Hard Rock Laboratory. There are however indications that the method may have been used beyond its capacity, i.e. the theoretical assumptions of elastic and homogeneous response may not be fulfilled in all tests. Alternative methods for calculation of the in-situ stresses based on the recovered strains and anisotropic rock properties may be considered.

Objectives

A programme is initiated with the objectives to identify the possible limitations for the Overcoring method and to control under what conditions anisotropic theory may apply.

Experimental concept

The work is planned to be based on existing data, but further laboratory testing of the mechanical properties of the cores.

Scope for 2000

The programme is planned to be completed during 2000.

3 Test of models for description of the barrier function of the host rock

3.1 General

The Natural Barriers in the deep geological repository for radioactive wastes are the bedrock, its properties and the on-going processes in the rock. The function of the natural barriers as part of the integrated disposal system can be presented as *isolation, retention* and *dilution*. The common goal of the experiments within Natural Barriers is to increase the scientific knowledge of the safety margins of the deep repository and to provide data for performance and safety assessment calculations. The strategy for the on-going experiments on the natural barriers is to concentrate the efforts on those experiments which results are needed for the planning of the future candidate site investigations, planned to start in 2002. For this focus there is also a need to involve experts of the different geoscientific disciplines into the on-going experiments in order to make them familiar with the work and quality procedures adopted.

Isolation is the prime function of the repository. It is obtained through the co-function of the engineered and the natural barriers. For deep geological disposal, the flow of water to the canister/waste containment is largely determining the magnitude at which the corrosion and the dissolution of the waste form can take place. For a good isolation it is thus necessary to minimise the groundwater flow to the waste containment. Additional conditions that affect the isolation are the chemistry of the groundwater and the mechanical stability of the rock.

Conceptual and numerical groundwater flow models have been developed through the entire Äspö project up to now. During 2000 focus is on further development of the numerical tools used for groundwater flow and transport calculations.

Hydrochemical stability and potential variability is assessed within several ongoing projects. These aim at explaining possible chemical conditions in a repository host rock based on assumption of different climate conditions in the future. The project will be reported during year 2000. Input to this reporting is provided from EQUIP, TASK#5, REX, Matrix Fluid Chemistry and other experiments. Some of these have not been completed yet. For instance the characterisation of the chemistry of water in the pores and micro fractures.

The *retention* of radionuclides dissolved in groundwater is the second most important barrier function of the repository. Retention will be provided by any system and process that interacts with the nuclides dissolved in the groundwater when eventually the water has come in contact with the waste form and dissolved radionuclides. Retention is provided by the physical and chemical processes, which occur in the near-field and far-field. Some elements are strongly retarded while others are escaping with the flowing groundwater. The major emphasis in the safety assessment calculations has therefore been on the weakly retarded nuclides even if they are not dominating the hazard of the waste.

The large amount of activity in a repository is caused by the fission products, Cs, Sr, I, Tc, and the transuranic elements Am, Np, and Pu. The transuranics, Cs, and Tc are, if dissolved, effectively sorbed in the near field. However, in case neptunium and technetium are oxidised to neptonyl and pertechnetate by radiolysis from the waste they might be transported into the bentonite buffer before they are reduced to the insoluble tetravalent state.

Strontium and all negatively charged elements will be transported through the bentonite buffer by diffusion. They will then be retarded by the interaction with the fracture minerals in the flow paths of the rock and through the diffusion into the rock matrix. The effective retention of these nuclides is a combination of radioactive decay, sorption and diffusion. The more long-lived and the weaker the sorption of the nuclide, the more important is the actual groundwater flow for the migration. The chemical composition of the groundwater is important for the magnitude of sorption for some of the nuclides. Negatively charged nuclides are retarded from the groundwater flow only through the diffusion into the stagnant pores of the rock matrix.

Tracer tests are carried out within experiments in the TRUE-projects. These are conducted at different scales with the aim of identifying detailed scale (5m) and block scale (50m) flow paths, retention of weakly and moderately sorbing tracers and the effect of matrix diffusion. During 2000 the goals are to complete the experimental part of TRUE Block Scale and to start the Long Term Diffusion Experiment (LTDE). Modelling of the experiments is done by several groups associated to the Äspö Task Force for modelling of groundwater flow and transport of solutes.

CHEMLAB experiments are conducted with the moderately and highly sorbing nuclides. Experiments are carried out in simulated near field conditions (bentonite) and in tiny rock fractures. During 2000 experiments including effects of radiolysis will be carried out in the CHEMLAB 1 unit. In the CHEMLAB 2 unit experiments using actinides will be started.

Colloids could affect the transport of radionuclides in the case these exist in a high enough concentration. The investigations made at Äspö and elsewhere give a concentration that it is not possible to detect. That concentration has no impact on the transport of radionuclides. New findings of colloidal transport and the existence of more sensitive instruments are the reasons for a new programme on different aspects of colloid transport.

A particular transport phenomenon could be caused by gas, which may carry nuclides from depth to surface. This two phase flow phenomenon is investigated in an on-going experiment conducted by GRS and BGR. During 2000 the cooperation with the GRS/BGR team continues.

Microbes are of particular interest since they can directly influence the chemistry of the groundwater, and indirectly transport nuclides attached to them. For continuing the basic studies of the microbes in the Äspö laboratory, a site has been allocated in the J-niche at 430 m dept.

Dilution is the third barrier function. It will take place in the rock volume surrounding the repository. The magnitude of dilution is very much depending on the site-specific conditions, and for performance assessment calculations on the conceptualisation of the flow. In the geosphere the dilution is caused by the dispersion in the groundwater flow.

No specific experiment is focussing on dilution. However, this process is included in a proposal for the next-coming modelling task within the Äspö Task Force for groundwater flow and transport of solutes.

3.2 Numerical modelling of groundwater flow and transport (NUMMOD)

Background

Mathematical models for groundwater flow and transport are important tools in the characterisation and assessment of underground waste disposal sites. SKB has during the years developed and tested a number of modelling tools and at Äspö HRL several modelling concepts as Stochastic Continuum (SC) and Discrete Fracture Network (DFN) concepts has been used. SC approach has been used for the regional and site scale models (Svensson 1997a,b) and in the laboratory scale model the starting point has been a fracture network for assigning hydraulic properties to a SC model (Svensson, 1999b). The methodology of how to transform the fracture network to the SC was shown in Svensson (1999a) (Called the GEHYCO concept below). Based on the new data available since the Äspö model 1996, reported in Rhén et al (1997b), and the new concept of generating the conductivity field (Svensson, 1999a), it is planned to update the site, laboratory and (possibly) the regional models of Äspö area.

Tests of embedded grids have been made with the PHOENICS code. The purpose was to see if it was feasible to generate local dense grids to get high resolution and better possibilities to define small features in the model. The technique is expected to be useful for regional, site and laboratory scale models. Both the non-uniform and BFC (Body Fitted Co-ordinates) grids generates cells with high aspect ratio, i.e. $?_x/?_y >>1$, which is a disadvantage when spatial assignment method for hydraulic conductivity is chosen. The advantage with embedded grid is that the cells are cubic which is considered better base for choosing spatial assignment method.

Objectives

The general objective is to improve the numerical model in terms of flow and transport and to update the site-scale and laboratory scale models for the Äspö HRL. The models should cover scales from 1 to 10 000 metres and be developed for the Äspö site, but be generally applicable.

The specific objectives with the updated models are:

- Test and improve new methodology of generating a conductivity field based on a fracture network in a continuum modelling approach.
- Develop models for transport and dispersion.
- Improve the methodology for calibration and conditioning the model to observed conductive features of the groundwater flow models.
- Improve the handling of the inner boundary conditions in terms of generating the tunnel system and applying boundary conditions.
- Improve the data handling in terms of importing geometrical data from RVS to the numerical code for groundwater flow and to export modelling results to RVS.
- Increase the details in the models based on new knowledge of the Äspö site collected during the last years.

Modelling concept

The modelling of groundwater flow and transport in sparsely fractured rock is made with three different concepts: Stochastic Continuum (SC), Discrete Fracture Network (DFN) and Channel Network (CN). The last modelling approach has similarities with the SC approach. Experiences gained from international modelling tasks within the Äspö Task Force on modelling of groundwater flow and transport of solutes have shown that the different concepts are all useful but there are needs to develop both the codes in terms of data handling and visualisation. It is also necessary to continue developing and testing the concepts (Gustafson and Ström, 1995 and Gustafson et al, 1997). The model code intended to be used is PHOENICS, which has been used in regional scale, sites scale and laboratory models (Svensson 1997a,b and 1999b)

The results from the construction phase of the Äspö HRL showed a relatively high number of events with a high inflow rate during drilling. Features with a high transmissivity were drilled through at a number of times and these features were in several cases not a part of the deterministically defined major discontinuities. This has also been seen in boreholes made in the operation phase of the Äspö HRL. These features were called High Permeability Feature (HPF). The spatial distributions of these features, and features with lower transmissivity, has been studied and are a base for modifying the modelling concepts (Rhén and Forsmark, 1999, Rhén et al 1997b).

(High Permeability Features (HPF), as defined in Rhén and Forsmark (1999), consist of a fracture, system of fractures, or fracture zone with an inflow rate (observed during drilling or flow logging) which exceeds 100 l/min or alternatively show a transmissivity $T \geq 10^{-5}$ m^2/s. Some of the conclusions from the study of the data from the pre-investigation and the construction phase of the Äspö HRL (Rhén and Forsmak, 1999))

Scope of work for 2000

The main tasks are:

- Feasibility project A, Flow modelling
- Feasibility project B, Transport
- HPF, part 2

The two first tasks aims at developing and testing the numerical code for the flow and transport calculations, which is made before the models are updated. The third task aims at compiling some site-specific data useful for the updating of the models. The three first tasks are the base for the updating of the models. The tasks are described shortly below and in more detail and in “Test Plan for Groundwater flow modelling – Natural barriers”.

Feasibility project A, Flow modelling

Feasibility project A will probably be divided into three parts: development of the GEHYCO concept, development of gridding technique and boundary conditions for tunnels and finally, testing data exchange with RVS

Feasibility project B, Transport

The objective is to demonstrate the possibilities to simulate transport in the model created according to GEHYCO using PARTRACK and Fluid Population Method for the transport simulations. The transport is studied from smaller to larger scales: Single fracture, fracture zone, a block and site scale. It is expected that the new version of PARTRACK will be a useful tool for simulating transport and dispersion (sorbing and non-sorbing tracers

Feasibility project B will probably be divided into three modelling parts; single fracture model, fracture zone model and block and site scale model.

HPF, part 2

It is planned to update some of the results in Rhén and Forsmark (1999), mainly the distance statistics for conductive features. There are now available more data from new bore holes that are useful for updating of the statistics of the HPFs, and more important, to calculate the distance-statistics for features with transmissivities that are lower than the one defined for the HPF:s in Rhén and Forsmark (1999).

3.3 Tracer Retention Understanding Experiments

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 the computer models for radionuclide transport which will be used in licensing of a repository. The basic concept is that tracer experiments will be performed in cycles with an approximate duration of 3-4 years. At the end of each test cycle, results and experience will be evaluated and the programme revised.

The basic idea is to perform a series of 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, after which epoxy resin will be injected. Subsequently the tested rock volume will be excavated and analysed with regards to flow path geometry, and tracer concentration.

The first test cycle, TRUE-1, which is completed, performed on a detailed scale, was of limited duration in time, and was primarily aimed at technology development. This initial test cycle will be followed by detailed scale tracer tests of longer duration, allowing full address of different retention mechanisms. A block scale tracer test, the TRUE Block Scale Project, is in progress. Together with supporting laboratory studies of diffusion and sorption characteristics made on core samples, the results will provide a basis for integrating data on different scales, and testing of modelling capabilities for radionuclide transport up to a 50 m scale, c.f. Figure 3-1.

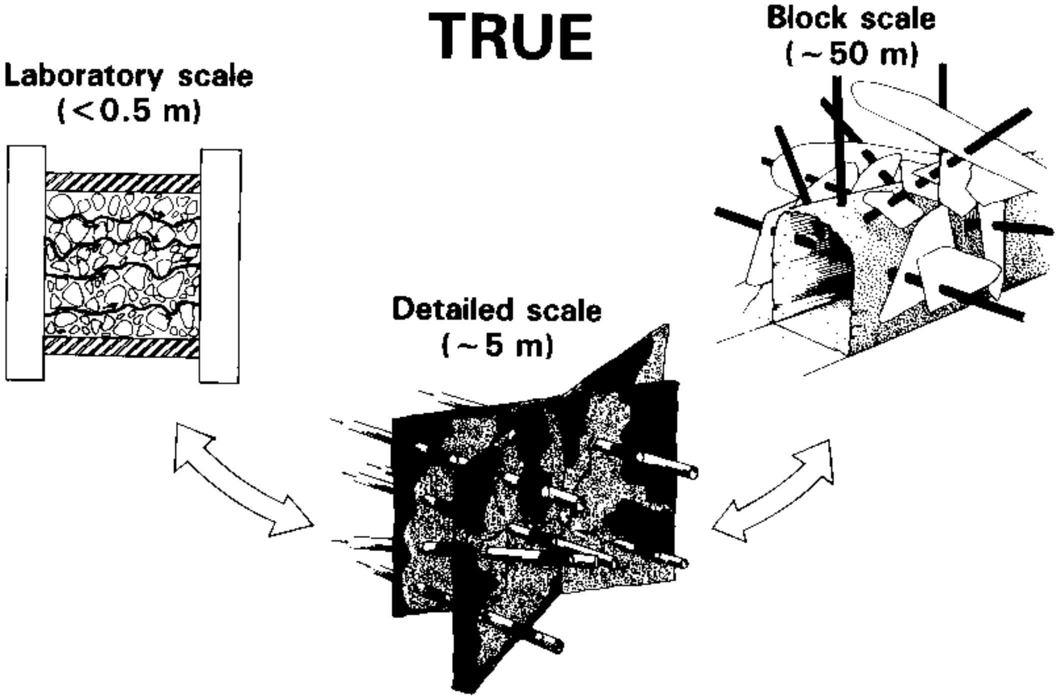


Figure 3-1   *Schematic representation of transport scales addressed in the TRUE programme.*

The tracer 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 1998 USDOE/Carlsbad office signed an agreement with SKB which enables SANDIA/WIPP to collaborate in work related to the TRUE Project. The collaborative work includes comparison and evaluation of multi-rate diffusion and sorption processes in different geological environments and their application to performance assessment. Work during the year has primarily been focused on evaluation of the TRUE-1 experiments using a multi-rate diffusion model within the context of the work within the Äspö Task Force. The work includes development of visualisation of diffusion in low-porosity geological environments using X-ray imaging techniques. Following initial scoping experiments, dynamic experiments are now planned for the year 2000, including experiments on site-specific feature A material. The results are expected to produce imaging of the connected porosity in the samples. Special care is put into not creating damage to the core during sample preparation.

3.3.1 TRUE-1

Basic findings and conclusions

The results of the First TRUE Stage (TRUE-1) is reported by Winberg et al. (2000).

The First TRUE Stage was performed in the detailed scale with the specific objectives of providing data and conceptualising the investigated feature using conservative and sorbing tracers. Further, to improve methodologies for performing tracer tests, and to develop and test a methodology for epoxy resin injection, and necessary techniques for excavation and subsequent analyses.

The experimental site is located at approximately 400 m depth in the north-eastern part of the Äspö Hard Rock Laboratory. The identification of conductive fractures and the target feature has benefited from the use of BIPS borehole TV imaging combined with detailed flow logging. The assessment of the conductive geometry has been further sustained by cross-hole pressure interference data. The investigated target feature (Feature A) is a reactivated mylonite, which has later undergone brittle deformation. The feature is oriented Northwest, along the principal horizontal stress orientation, and is a typical conductor for Äspö conditions. Hydraulic characterisation shows that the feature is relatively well isolated from its surrounding. The near proximity to of the experimental array to the tunnel (10-15 m) implies a strong gradient (approximately 10%) in the structure, which has to be overcome and controlled during the experiments.

A methodology for characterising fracture pore space using resin injection, excavation using large diameter coring and subsequent analysis with photo-microscopic and image analysis techniques was developed and tested at a separate site. The results show that epoxy resin can be injected over several hours hour, and that the estimated areal spread is in the order of square metres. The mean apertures of the two investigated samples were 239 and 266 microns, respectively. Assessment of spatial correlation show ranges in the order of a few millimetres.

Performed tracer tests with conservative tracers in Feature A show that the feature is connected over its interpreted intercepts in the array. The parameters evaluated from the conservative tests; flow porosity, dispersivity and fracture conductivity are similar, indicating a relative homogeneity.

Previous work has identified cationic tracers, featured by sorption through ion exchange, as the most suitable tracers for sorbing tracer experiments at ambient Äspö conditions. Laboratory experiments on generic Äspö material and site-specific material included batch sorption experiments on various size fractions of the geological material, and through diffusion experiments on core samples of variable length on a centimetre length scale. The sorbtivity was found to be strongly affected by the biotite content and the sorption was also found to increase with contact time. The sorbtivity was found to follow the relative order; $^{22}Na^{+} < {}^{47}Ca^{2+} \approx {}^{85}Sr^{2+} << {}^{86}Rb^{+} \approx {}^{133}Ba^{2+} < {}^{137}Cs^{+}$.

The field tracer tests, using essentially the same cocktail of sorbing tracers as in the laboratory, were found to show the same relative sorbtivity as seen in the laboratory. A test using ^{137}Cs showed that after termination of the test, some 63 % of the injected activity remained sorbed in the rock.

The main interpretation of the in situ tests with sorbing tracers was performed using the LaSAR approach, developed as a part of the TRUE project. In this approach the studied flow path is viewed as a part of an open fracture. Key processes are spatially variable advection and mass transfer. The evaluation shows that laboratory diffusion data are not representative for in situ conditions, and that a close fit between field and modelled breakthrough is obtained only when a parameter group, which includes diffusion, is enhanced with a factor varying between 32-50. Our interpretation of the enhancement is higher diffusivity and porosity in the wall rock of the fracture compared to the data obtained from core samples in the laboratory, which in the case of Feature A is dominated by low-porosity mylonite.

Combined diffusion/sorption in the rock matrix was interpreted as the dominant retention mechanism in the TRUE-1 in situ experiments. This is particularly true for the more strongly sorbing tracers, eg. Cs. The effects on tracer retention by surface sorption and sorption onto gouge material were found to be observable, but of secondary importance. Similarly, the effect of sorption into stagnant water zones was identified to be limited.

The results and conclusions of the TRUE-1 experiments will be discussed at an international seminar to be held in September, 2000, in conjunction with the 5th GEOTRAP meeting, both to be held at the Äspö Hard Rock laboratory.

3.3.2 TRUE-2

Background

The Second TRUE Stage, TRUE-2, will constitute a second test in a detailed scale. The focus of the experiments will be on retention processes in a single fracture, their identification and discrimination. Modelling work associated with the experiment will involve different model concepts, including e.g. an application of the evaluation framework applied during the First TRUE Stage, cf. Section 3.2.1. A challenging feat will be to locate and characterise yet another single fracture, similar to Feature A at the TRUE-1 site.

Site selection of TRUE-2 and LTDE, cf. Section 3.3, is furnished by the performed site selection programme (SELECT-2), similar to the SELECT programme which constituted the basis for selection of the TRUE-1 and REX projects. The programme comprised drilling of 3-4 boreholes at four sites defined by a preliminary study conducted during the fourth quarter 1998. Characterisation included BIPS borehole TV imaging and POSIVA flow logging in continuous mode.

Objectives (tentative)

The objectives of the second tracer test cycle (TRUE-2) are to;

- conceptualise transport in a single fracture on a detailed scale (L=5m) using conservative and sorbing tracers in a simple test geometry,
- conduct tests with sorbing tracers over time scales and flow rates such that diffusion becomes a measurable process,
- apply various model concepts in the modelling of the experiments including usage of e.g. the LaSAR evaluation framework and the multi-rate transport concept,
- apply the developed technology for injection of epoxy resin in order to obtain conditional information on the pore space in which the tracer test have been run.

- perform sorption and diffusion laboratory experiments on site-specific material, and improve knowledge of the transport parameters of gouge material.

Experimental concept

Performance of transport experiments using radioactive sorbing tracers. Evaluation (identification and discrimination of mass transfer processes) using eg. the LaSAR and multi-rate frame frameworks. The experimental work will be supported by laboratory experiments on site-specific material and will be completed with injection of epoxy resin in the studied rock volume followed by excavation and evaluation of pore space.

As part of the work, a laboratory study of the mineralogy, geochemistry and transport characteristics of fault gauge will be conducted. In order to obtain a broader picture, fault gouge material available from various structures at Äspö of variable dignity/magnitude, will be used. Material from EW-1, NE-1, the “REDOX zone”, and various minor structures in the TRUE Block Scale site, will be analysed.

Scope for 2000

The schedule for the start up of TRUE-2 has been further postponed by SKB in relation to what was been indicated in Planning Report for 1999. The main reason being that the TRUE team during the later half of 1999 and the first half of 2000 will be involved in planning and performance of feasibility and field studies related to the SKB site characterisation programme. In December 1999, SKB presented a new safety analysis, SR 97, of the KBS-3 system based on site-specific data from three sites in Sweden. The SR 97 report is currently subject to a national review by SKI and an international review organised by OECD/NEA. Before committing to a new large tracer experiment SKB would like to obtain input on research priorities from the review of SR 97 and to further evaluate the results from the TRUE-1 experiment in the context of future research needs.

- The plan for future tracer experiments will be discussed in conjunction with the TRUE-1 Seminar in September 2000. If a decision is taken to proceed with the TRUE-2 experiment a test plan will be written.

- Detailed site characterisation will possibly be started in November/December 2000. This would including drilling of additional boreholes and associated characterisation.

3.3.3 TRUE Block Scale Experiment

Background

The block scale (10-50 m) completes the sequence of scales addressed within the TRUE programme which in addition include detailed scale (0.5-10 m) and laboratory scale (≈ 0.5 m). The TRUE Block Scale project is an international partnership funded by ANDRA, ENRESA, Nirex, POSIVA, JNC and SKB. The TRUE Block Scale project is divided into five basic stages comprising;

- Scoping stage (1996-1997)

- Preliminary Characterisation stage (1997-1998)
- Detailed Characterisation stage (1998-1999)
- Tracer test stage (1999-2000)
- Evaluation *stage (2000)*

The objectives and a basic experimental strategy are defined outlined in a test plan (Winberg, 1997).

Objectives

The specific objectives of the TRUE Block Scale Experiment, listed in the test plan for the experiment (Winberg, 1997), are to;

1. increase understanding and the ability to predict tracer transport in a fracture network,
2. assess the importance of tracer retention mechanisms (diffusion and sorption) in a fracture network,
3. assess the link between flow and transport data as a means for predicting transport phenomena,

Results

During the period 1996 through 1999 five boreholes have been drilled, characterised and completed with multi-packer systems. The characterisation in single holes has included basic geological and structural logging, borehole TV imaging (BIPS), borehole radar, various types of flow logging (including POIVA flow logging), flow and pressure build-up tests. Cross-hole tests included collection and analyses of pressure responses due to drilling, cross-hole seismic surveys and cross-hole hydraulic interference tests. The latter type of tests performed during the Spring of 1998 and tracer Pre-tests performed during the Spring of 1999 included simultaneous tracer dilution tests, which enabled, apart from drawdown due to the pumping, assessment of change in flow rate in selected packer intervals, and selection of suitable injection sections. The possibility to perform well-controlled (high mass recovery) block scale tracer tests in a fracture network (> 1 structure) has been demonstrated. The results of the performed characterisation has resulted in a focus on the fracture network defined by Structures #20, #13, #21 and #22, cf. Figure 3-2.

During the course of the project the deterministic model of the major structures within the studied block has been updated four times, cf. Figure 3-2. In the updating the introduced classification scheme for structures is employed in the classification, where the identified structure intercepts in four different categories; fractures, faults, swarms of fractures and fracture zones. In the building of these models existing geological, geophysical and hydraulic information is utilised. The studied block is characterised by a predominant set of structures that are oriented in the Northwest. In addition, a few north-easterly structures and three sub-horizontal structures have been interpreted. The

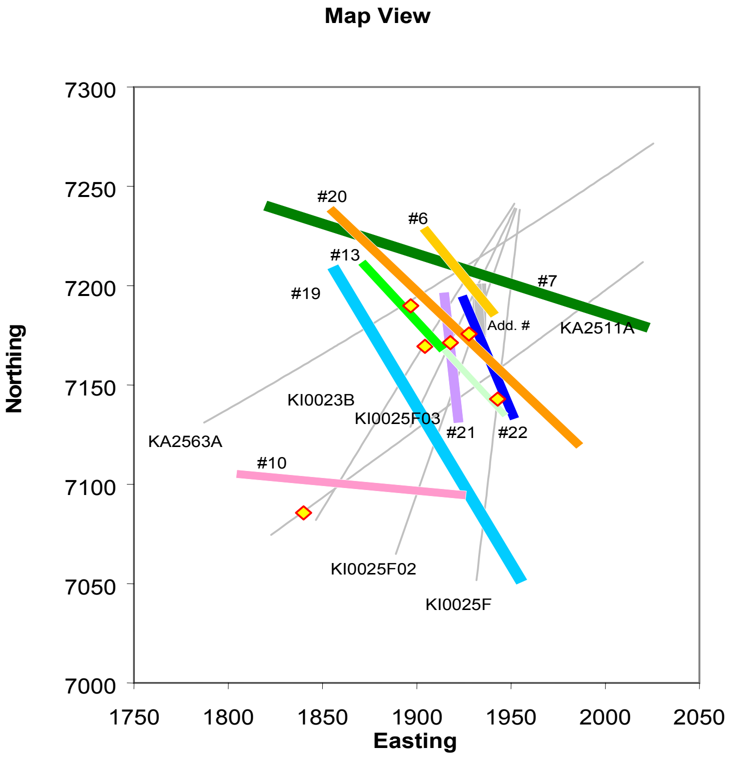


Figure 3-2*Plan view of the reconciled March´99 structural-.geological conceptual model of the TRUE Block Scale rock volume (Plan view of a horisontal section at Z=-477 masl).*

performed seismic and hydraulic cross-hole studies both show that these latter two sets are subordinate, most importantly from the hydraulic standpoint.

Numerical modelling during 1999 has involved discrete fracture network (DFN) modelling work on a site scale, primarily to produce boundary conditions for developed models of the volume of interest. The channel network (CN) modelling has focused on scoping calculations on the possibility to identify effects of fracture intersections. The results show that the intersections are difficult to identify from conservative tracer tests. However, use of sorbing tracers may give a chance to identify these effects for selected test configurations. In addition the model has been used to predict the concluding tracer test as part of the Spring 1999 Pre-tests. During the last quarter of 1999 the stochastic continuum (SC), DFN and CN models have been updated with the most recent information to enable prediction of the Phase A tracer tests.

A tentative planning document for the Tracer Test Stage was presented in late June 1999. The document was further updated and presented at a Review meeting in late October 1999. The final document presents the results of the performed tracer pre-tests and identified the basic issues/questions to be addressed by the planned tracer tests. The issues identified were;

Q1 “What is the conductive geometry of the defined target volume for tracer tests within the TRUE Block Scale rock volume? Does the most recent structural model reflect this geometry with sufficient accuracy to design and interpret tracer tests?”

Q2 “What are the properties of fractures and fracture zones that control transport in fracture networks?”

Q3 “Is there a discriminating difference between breakthrough of sorbing tracers in a detailed scale single feature, as opposed to that observed in a fracture network in the block scale?”

On the basis of the identified issues/questions, a set of hypotheses were developed.

In addition it was proposed to drill yet another characterisation borehole to allow shorter transport paths for radioactive sorbing tracers, and as a means of verification of the model of the conductive geometry. The new borehole, KI0025F03, has been drilled and characterised.

Subsequently, the first phase, Phase A, of the tracer Test Stage has been performed including use of KI0025F03. The objectives of these tests are to provide a basis for selecting the best sink section for the continued testing. Further, to provide complementary pressure drawdown and tracer dilution data. The phase is concluded with a tracer test with injection in a limited number (4-5) of sections.

Scope for 2000

The following activities are planned for 2000:

- Definition of reports and report structures
- Tracer tests with conservative and weakly sorbing tracers (Phase B and Phase C)
- Detailed mineralogy and geochemistry focused on structures of the target fracture network.
- Continued development of numerical models, where the main task will be the prediction and evaluation of the Phase C tests, the latter, which includes tests with radioactive tracers.
- Evaluation
- Reporting

3.4 Long Term Test of diffusion in the rock matrix

Background

A deep granitic rock repository for radioactive waste will not only serve as a long term physical barrier sheltering the waste containment in geological time scales, it will also act as a chemical barrier preventing migration of several radionuclides. A chemical barrier could be of significance in the case of waste containment failure releasing radionuclides to the water. Transport of radionuclides by water will occur by water flow in fractures and by diffusion in the rock matrix. Transport of radionuclides in rock fractures is studied within the current TRUE experimental programme, whereas matrix diffusion studies will require a somewhat modified experimental approach. Based on results from laboratory experiments, the expected low matrix diffusivities for different radionuclides will be difficult to observe in the ongoing and planned dynamic experiments in the TRUE programme, given the practical time constraints of the planned experiments. Hence, a static long-term diffusion experiment is proposed. It should however be stated that diffusion into the matrix with subsequent sorption on inner surfaces are included in evaluation concepts used by most teams analysing the TRUE-1 experiment within the context of the Äspö Task Force, including the evaluation concept used by the SKB TRUE team.

The chemical reactions involved in sorption of radionuclides can according to a simple view be divided in ion exchange, inner-sphere complexation and outer-sphere complexation. The mobility of radionuclides is strongly affected by the interaction with geologic materials. The transport of dissolved solutes can be regarded as a distribution between species in solution (ionic species, inorganic- and organic-complexes), mobile solid phases (particulate matter, colloids, precipitates etc.) and stationary solid phases (minerals). The distribution is often expressed as a distribution coefficient, K_d, which is an equilibrium constant for a reversible sorption process. Kinetic effects and irreversible sorption mechanisms are thus not included in a K_d value. Since most of the radionuclides in nuclear waste are influenced by any of the sorption mechanisms mentioned above during their transport in the rock matrix it is possible to take advantage of a combined diffusion and sorption experiment. By using sorbing radionuclides in a diffusion experiment one will automatically have a fixation of the tracer in the diffusion pathways. It is however important that one knows the sorption behaviour of the tracers, (e.g. specific sorption mechanisms, ”sites” and reversibility or kinetics) in order to evaluate the diffusion pathways.

Matrix diffusion studies of radionuclides have been performed in several laboratory experiments and also *in situ.* Some experimental conditions such as pressure and natural groundwater composition are however difficult to simulate in laboratory experiments. Investigation of rock matrix diffusion in laboratory scale implies 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. Investigation of matrix diffusion in non-disturbed rock is therefore preferably investigated *in situ.* Through the proposed experimental technique one will also get some information of the adsorption behaviour of some radionuclides on fresh granitic rock surfaces, which is of interest for the short term safety in a repository, i.e. exposure of leaked radionuclides on to fresh rock surfaces in canister holes and the tunnel system in a repository.

Scooping calculations for the planned experiment have been performed (Haggerty, 2000) using the multi-rate diffusion concept which accounts for pore-scale heterogeneity. A draft 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 tom its final form (Byegård et al. 1999)

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 and hydraulic pressure and groundwater chemical conditions.
- To obtain data on sorption properties and processes of 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

The experiment is planned to be focused on a fracture which has been identified in a pilot borehole drilled within the context of the SELECT-2 project. A telescoped large diameter borehole (300/196.5 mm) will be drilled sub-parallel to the existing pilot borehole in such away that it intercepts the identified fracture some 10 m from the tunnel wall and at an approximate separation of 0.3 m between the mantel surfaces of the two boreholes. The

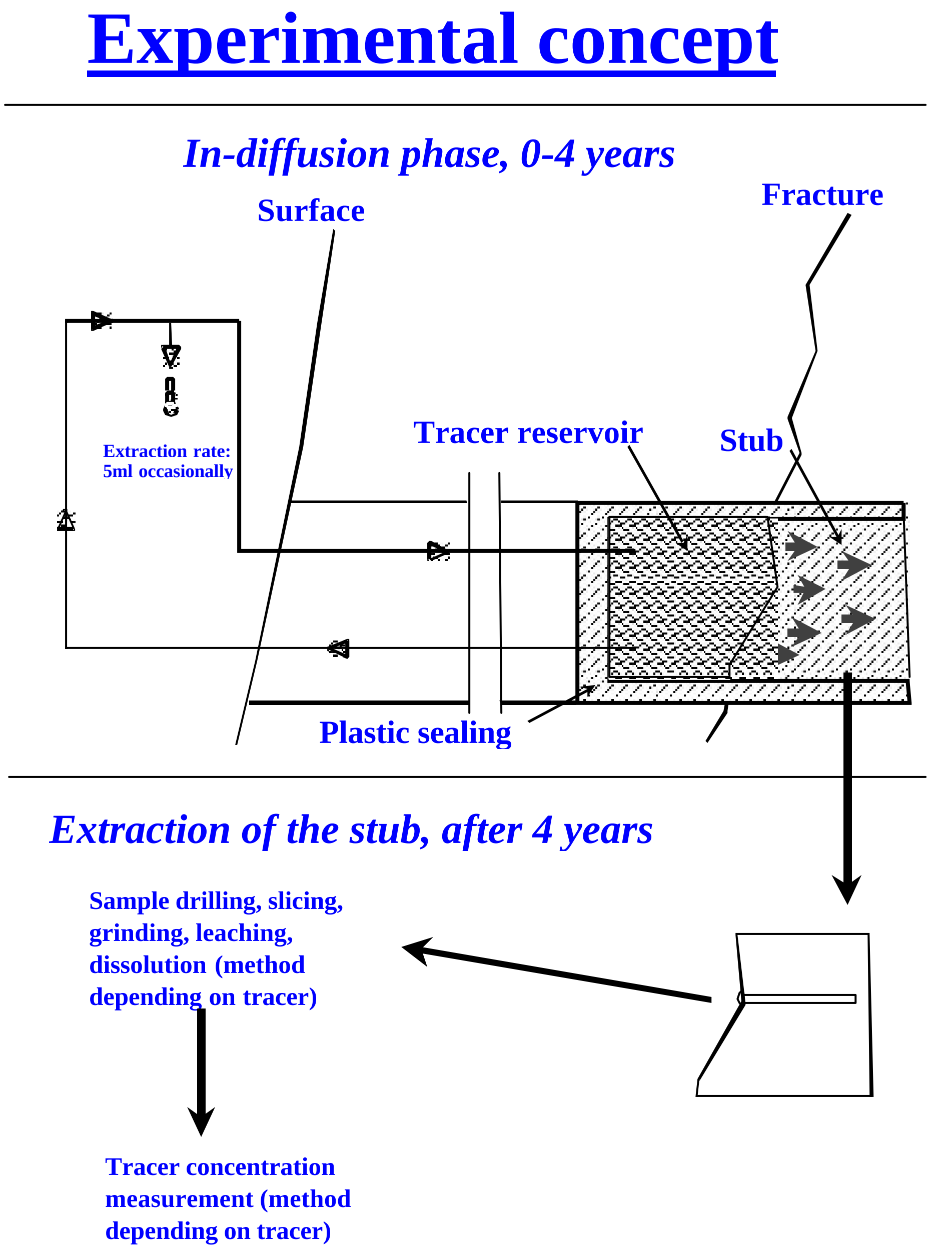


Figure 3-3 *Experimental concept of the Long-Term Diffusion .Experiment (Byegård, et al., 1999)***.**

fracture is passed in such a way that an approximately 50 mm long "stub" remains in the borehole. A controlled passage of the target fracture is furnished by a careful iterative drilling process where interactive BIPS borehole TV imaging with subsequent revision of the existing structural RVs model is performed. The obtained stub remaining at the bottom of the hole will be sealed off using a "cup-like" packer, cf. Figure 3-3. The remainder of the borehole will be packed off with a system of mechanical and inflatable packers such that a hydraulic gradient along the borehole is avoided. The packed off section is connected to the borehole collar and a regulation and sampling system, cf. Figure 3-4. A slowly circulating system will be used to expose the surface of the stub with a cocktail of various radioactive sorbing tracers over a period of 3-4 years. Performed scoping calculations indicate that diffusion depths up to 0.3 m are feasible. Samples of water will be collected at various times over the duration of the experiment. After terminating the tracer circulation, the inner part of the borehole will be overcored. The core will subsequently be subject to analyses for tracer concentration/activity.

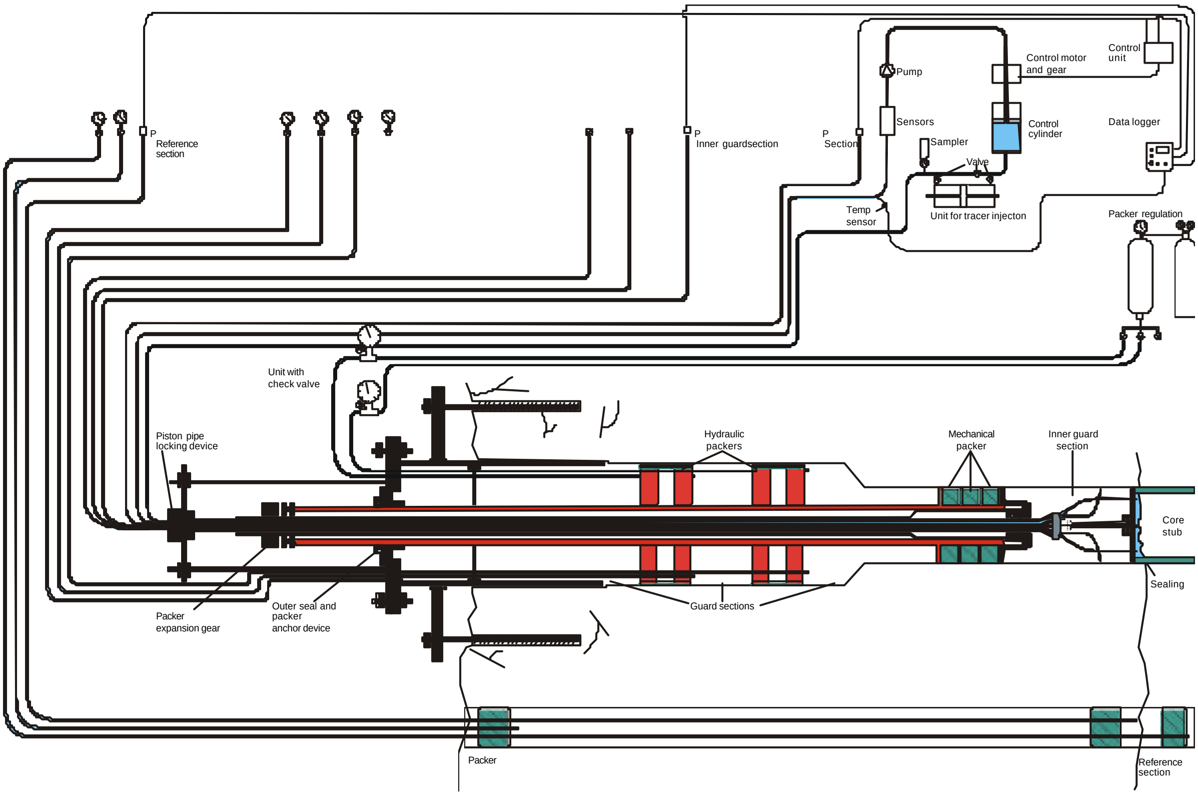


Figure 3-3 *Schematic drawing showing the surface and down-hole equipment in the telescoped larger diameter LTDE borehole and the adjacent pilot borehole.*

The project involves a variety of mineralogical, geochemical and petrophysical analyses. In addition, as in the REX project, a "replica" laboratory through diffusion experiment is planned

Scope for 2000

- Drilling of telescope borehole
- Characterisation of borehole and drillcore
- Construction of equipment (downhole/regulation/sampling)
- Installation of equipment
- Check of installation (pre-tests)
- Start of tracer circulation
- Start-up of replica experiment

3.5 Radionuclide retention

Background

The retention of radionuclides in the rock is the most effective protection mechanism if the engineering barriers have failed and the radionuclides have been released from the waste form. The retention is mainly caused by 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 on solubility and migration of the long lived nuclides e.g. Tc, Np, and Pu indicate that these elements are so strongly sorbed on the fracture surfaces and into the rock matrix that they will not be transported to the biosphere until they have decayed. In many of these retention processes the sorption could well be irreversible and thus the migration of the nuclides will stop as soon as the source term is ending.

Laboratory studies under natural conditions are extremely difficult to conduct. Even though the experiences from different scientists are uniform it is of great value to demonstrate the results of the laboratory studies in situ, where the natural contents of colloids, organic matter, bacteria, etc. are present in the experiments. Laboratory investigations have difficulties to simulate these conditions and are therefore dubious as validation exercises. The CHEMLAB borehole laboratory probe has been constructed and manufactured for validation experiments in situ at undisturbed natural conditions. Figure 3-5 illustrates the principles of the CHEMLAB 1 and CHEMLAB 2 units.

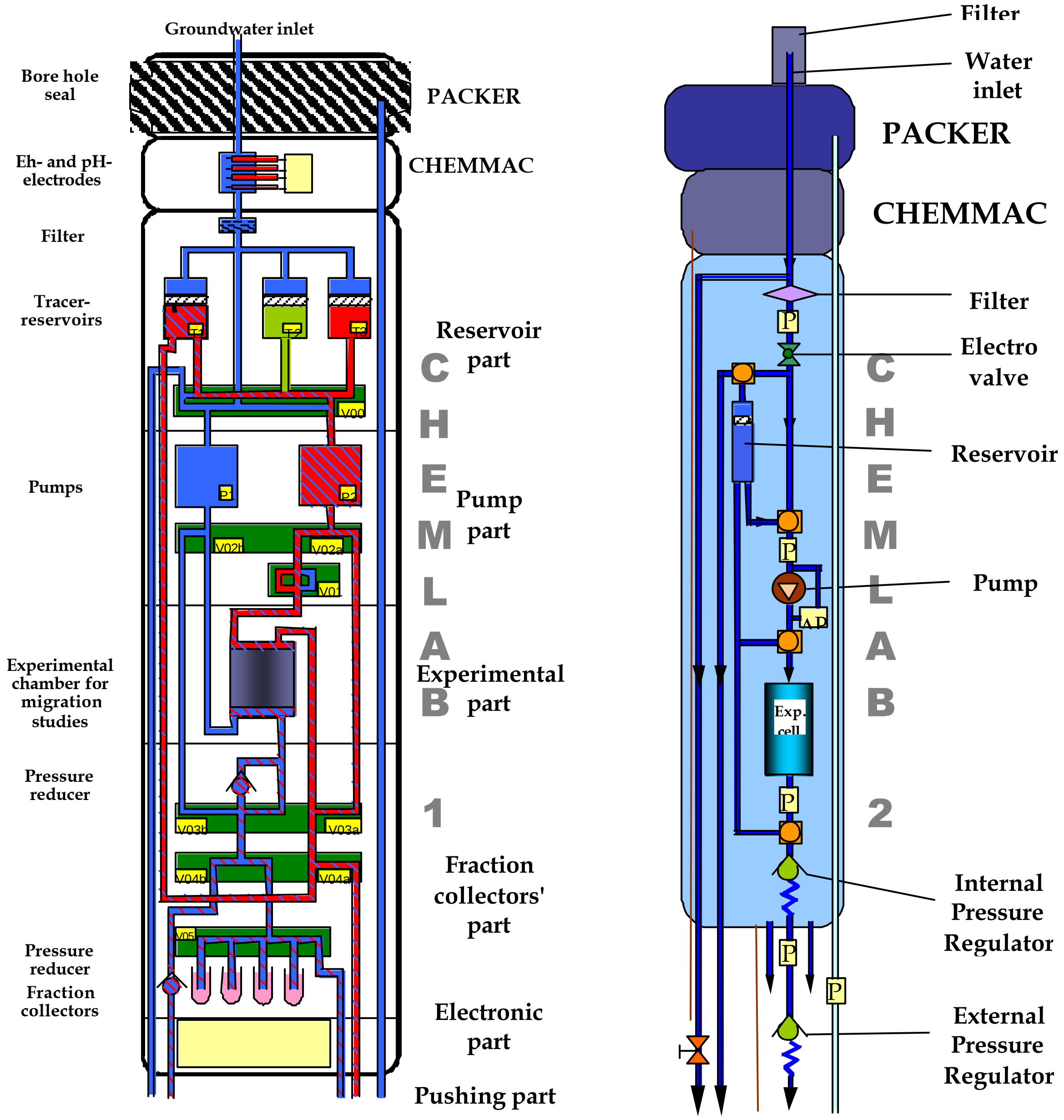


Figure 3-4 *Schematic illustration of CHEMLAB 1 and 2.*

Objectives

The objectives of the Radionuclide Retention (CHEMLAB) experiments are:

- To validate the radionuclide retention data which have been measured in laboratories by data from in situ experiments in the rock
- 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 is a borehole laboratory built in a probe, in which migration experiments can be carried out under ambient conditions regarding pressure and temperature and with the use of the formation groundwater from the surrounding rock.

Initially one “all purpose” unit was constructed in order to meet any possible experimental requirement. This unit CHEMLAB 1 has been used for the “diffusion in bentonite” experiments and will now be used for similar experiments including the effects of radiolysis. Others to follow are:

- Migration from buffer to rock
- Desorption of radionuclides from the rock
- Batch sorption experiments

The CHEMLAB 2 unit is a simplified version of CHEMLAB 1, designed to meet the requirements by experiments where highly sorbing nuclides are involved. These are:

- Migration of redox sensitive radionuclides and actinides
- Radionuclide solubility
- Spent fuel leaching

Scope of work for 2000

A new site for the CHEMLAB experiments was selected and prepared during 1999. All future experiment will be conducted in the J niche at 430 m depth.

The different experiments are defined as separate projects within the programme of Radionuclide Retention. Figure 3-6 illustrates the organisation.

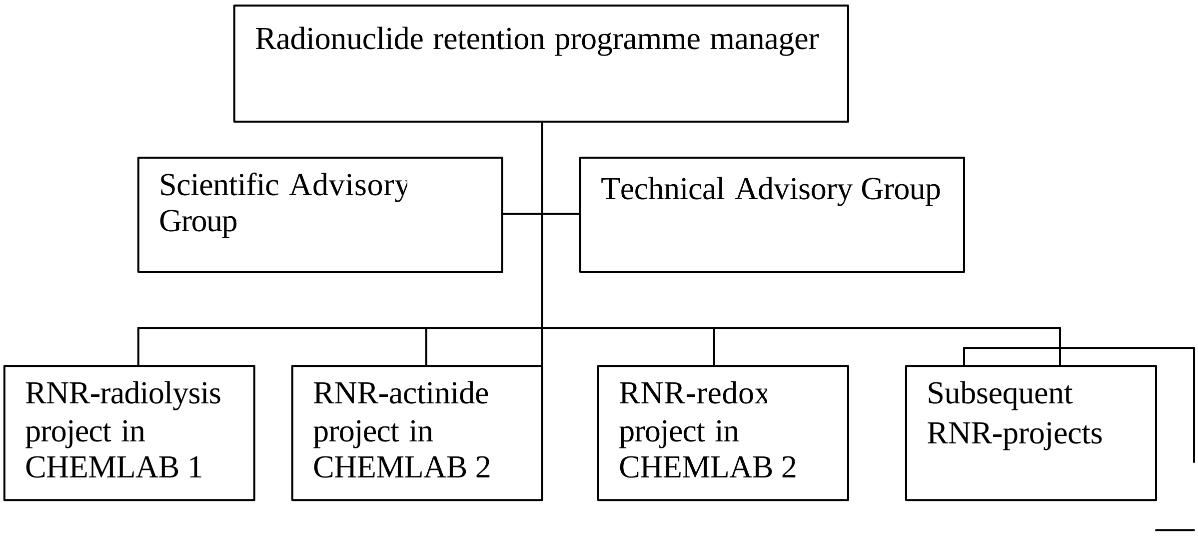


Figure 3-5 *Organisation of the experiments within the RNR .programme.*

The experiment with radiolysis was prepared in 1999 and will be conducted and completed within 2000. The execution of the experiment is similar to the previous diffusion experiment.

The first experiment to be carried out in CHEMLAB-2 is the migration of actinides, Americium, Neptunium and Plutonium, in a rock fracture. Planning and pre-testing is done by Institut für Nuklear Entsorgung in Karlsruhe. INE is also carrying out the experiment at Äspö in cooperation with SKB staff and Nuclear Chemistry at KTH.

The RNR-redox project involves a similar experiment as the actinide project. Preparations for that are started during 2000.

The final reporting from the diffusion experiments is delayed due to difficulties in analyses of the Technetium profile in the bentonite plug. The report is expected to be available by mid 2000.

3.6 Degassing of groundwater and two-phase flow

Background

Two-phase flow conditions, i.e. a mixed flow of gas and water, may develop in the vicinity of a repository situated in a regionally saturated rock mass. The main sources of two-phase flow conditions are 1) gas generation in the repository due to corrosion or biological processes, 2) exsolution of gas (bubble generation) due to pressure decrease, and 3) entry of gas (air) into the rock mass from ventilated tunnels. The presence of a gas phase in the repository before and after closure must be understood in relation to its effect on repository performance. Waste-generated gas may affect repository integrity and hazardous material may be transported in the gas phase.

Understanding evolution and characteristics of two-phase flow conditions near drifts is essential for understanding observations of hydraulic conditions made in drifts, interpretation of experiments performed close to drifts, and performance of buffer mass and backfill, particularly during emplacement and repository closure.

Objectives

The objectives for the project on degassing and two-phase flow are:

- To show if degassing of groundwater at low pressures has significant effects on measurements of hydraulic properties in boreholes and drifts.
- To study and quantify other processes causing two-phase flow near excavations such as air invasion due to buoyancy and evaporation.
- To show under what conditions two-phase flow will occur and be significant. Conditions expected to be of importance are gas content, chemical composition of groundwater, fracture characteristics (aperture distribution and transmissivities), and flow conditions.
- To get an idea of the time scales required for resaturation of a repository.

- To develop technology for measurement of saturation.

Experimental concept

Two-phase flow effects in fractured rocks are generally not well understood and it is essential that the in-situ experiments are supported by theoretical studies, numerical model development and simulations. In-situ testing of degassing and changes in hydraulic conductivity have been performed by measuring the inflow to a borehole at different pressures. Degassing should affect groundwater flow only at low pressures. Non-linearities in the flow-pressure relationship should be indicative of two-phase flow effects. Laboratory studies of two-phase flow in fractures and fracture replicas have been included to yield a better understanding of the microscopic effects. Models have been developed for the estimation of the resulting degree of fracture gas saturation and the associated transmissivity reduction due to groundwater degassing in fractured rock. Both model and experimental degassing studies imply that boundary pressure conditions, gas contents and flow geometry are influential on the degree of flow reduction due to degassing.

Results also show that the conceptualisation of gas and water occupancy in a fracture greatly influences model predictions of gas saturation and relative transmissivity. Images from laboratory degassing experiments indicate that tight apertures are completely filled with water, whereas both gas and water exist in wider apertures under degassing conditions; implementation of this relation in our model resulted in the best agreement between predictions and laboratory observations. Model predictions for conditions similar to those prevailing in field for single fractures at great depths indicate that degassing effects in boreholes should generally be small, unless the gas contents are elevated above the range of natural gas contents at Äspö HRL; these results are consistent with field observations in boreholes. The modelling also shows that the conditions for the occurrence of degassing are more favourable around drifts.

Scope for 2000

During 1999, we considered all available degassing-related experimental investigations, and tested various hypotheses underlying a theoretical degassing model for a wide range of boundary conditions. In parallel with the interpretation of the experimental investigations, a final summarising degassing report was prepared, synthesising results from both experimental and theoretical degassing studies.

The finalisation of this summarising technical report was delayed and is now scheduled for the end of March, 2000. This report will also include findings regarding the relevance of various two-phase flow relations for fractured rock applications, in a more general sense (including the relations originally developed for degassing applications). This latter work is carried out within the German-Swedish programme at the Äspö HRL, mainly in cooperation with the group of R. Helmig at the Institute for Computer Applications in Civil Engineering (CAB), Braunschweig, Germany.

3.7 Hydrochemical modelling/Hydrochemical stability

Background

The chemical properties of the groundwater affect the canister and buffer stability and the dissolution and transport of radionuclides. It is therefore important to know the possible changes and evolution of the groundwater chemistry during the repository life time. Important questions concern the understanding of the processes which influence and control the salinity, occurrence, character and stability of both saline and non-saline groundwater.

At present this project is carried out within the framework of the Äspö agreement between SKB and Posiva. It also covers the technical parts of the participation in the EC EQUIP project and the modelling Task #5 within the framework of the Äspö Task Force for modelling of groundwater flow and transport of solutes.

Objectives

The objectives of this project are:

- To clarify the general hydrochemical stability (= groundwater chemistry of importance for canister and bentonite durability and radionuclide solubility and migration)
- To describe the possible scenarios for hydrochemical evolution at Äspö over the next 100.000 years, separated into time slabs of 0-100, 100-1000, 1000-10000 and 10.000-100.000 years.
- To develop a methodology to describe the evolution at candidate repository sites, e.g. Olkiluoto.

Model concepts

Geochemical interpretation of groundwater-rock interaction along flow paths makes use of the results from groundwater chemical investigations, i.e. chemical constituents, isotopes and master variables pH and Eh in combination with the existing mineralogy, petrology and thermodynamic data. Useful tools for these calculations are reaction path codes like NETPATH and equilibrium-mass balance codes like EQ 3/6. These codes are frequently used in hydrochemical studies.

A newly developed concept and code, M3, start from the assumption that it is mixing and not chemical reactions that is the dominating process affecting the chemical composition of the groundwater within the investigated system. The principal assumptions behind this concept is that the varying hydraulic conditions of the past have created the complex mixing pattern presently observed. When the effects of mixing has been evaluated, mass balance calculations (resulting from chemical reactions) are then made to explain the difference between the ideal mixing and the observations.

The modelling strategy for the Hydrochemical Stability project involve:

- Identification of the dominant (chemical) processes for Finnish and Swedish sites.

- Geochemical mixing for Äspö and Olkiluoto.
- Site intercomparison and comparison between the M3 and NETPATH techniques based on data from Olkiluoto.
- Transient hydrodynamic modelling for Äspö and Olkiluoto.

The intention with the strategy is to be able to compare the results of the traditional hydrochemical modelling with the results from M3 and to compare the outcome of the hydrodynamic modelling with the results from M3. The latter comparison is done within the Task #5 of the Äspö Task Force for modelling of groundwater flow and transport of solutes.

The Equip project has the specific objective to trace the past hydrochemical conditions through investigation of (calcite) fracture filling minerals. The outcome will be used to check the conclusions from hydrogeological and hydrochemical models.

Scope of work for 2000

The integrated modelling effort within Task#5 was prolonged and will be reported by the different modelling teams in February. The evaluation of the entire Task#5 will start as well as the review of the outcome. Task#5 will be ended in 2001.

EQUIP, which is an EC project, is completed and will be reported during 2000.

Hydrochemical Stability will also be reported during 2000. In addition to the individual modelling efforts, the final report will assess the stability/variability with respect to the potential danger in the waste in the different time slabs. That reporting will then identify possible further needs for model development.

3.8 Matrix Fluid Chemistry

Background

Groundwater sampled from the Äspö site has been collected from water-conducting fracture zones with hydraulic conductivities greater than $K = 10^{-9}$ ms^{-1}. The chemistry of these groundwaters probably results from mixing along fairly rapid conductive flow paths, being mainly determined by the hydraulic gradient, rather than by chemical water/rock interaction. In contrast, little is known about groundwater compositions from low conductive parts ($K < 10^{-10}$ ms^{-1}) of the bedrock (i.e. matrix fluids), which are determined mainly by the mineralogical composition of the rock and the result of water/rock reactions. As rock of low hydraulic activity constitutes the major volume of the bedrock mass in any granite body, matrix fluids are suspected to contribute significantly to the salinity of deep formation groundwater. It is considered expedient therefore to sample and quantify such fluids and to understand their chemistry and origin.

Knowledge of matrix fluids and groundwater from rocks of low hydraulic conductivity will complement the hydrogeochemical studies already conducted at Äspö. It can also provide a more realistic chemical input to near-field performance and safety assessment calculations, since deposition of spent fuel will be restricted to rock volumes of similar hydraulic character.

Objectives

The main objectives of the task are:

- to determine the origin and age of the matrix fluids,
- to establish whether present or past diffusion processes have influenced the composition of the matrix fluids, either by dilution or increased concentration,
- to derive a range of groundwater compositions as suitable input for near-field model calculations, and
- to establish the influence of fissures and small-scale fractures on fluid chemistry in the bedrock.

Experimental concept

The experiment has been designed to sample matrix fluids 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. Special equipment has been designed to sample the matrix fluids 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 fluids (and gases) under pressure, and g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

Migration of matrix fluids will be facilitated by small-scale fractures and fissures. Therefore the matrix fluid chemistry will be related to the chemistry of groundwaters present in hydraulically-conducting minor fractures ($K= 10^{-10}-10^{-9} ms^{-1}$), since it will be these groundwaters that may initially saturate the bentonite buffer material.

Scope of work for 2000

Fluid inclusion studies

The nature of the matrix fluid may be strongly influenced by leakage of saline fluids from fluid inclusions which are commonly included in matrix quartz. Four groups will participate in characterising the fluid inclusions; this collaboration will also function as an inter-laboratory exercise with the intention of deriving a common methodology for the description, analysis and interpretation of fluid inclusion populations.

Some preliminary fluid inclusion studies have already been reported to the project group. For this present study the drillcores were sampled collectively (last December at the University of Stockholm) to ensure close integration of interests and to maximise available resources. For example, petrophysical measurements (e.g. interconnected porosity) will also be carried out on the same sample splits selected for the fluid inclusion studies. Core samples from borehole Sections 4 (sampled for matrix fluid) and 2 (to be sampled) will be investigated. The drillcore material will be archived at the University of Stockholm.

The four participating groups represent the Universities of Stockholm, Bern and Waterloo, together with a group from Kivitieto, Oulu, Finland, sponsored by Posiva. The administrative procedures to set these studies in motion should be cleared by mid-January, 2000.

Matrix fluid and groundwater analysis

Outstanding groundwater analysis from the previous quarter (i.e. from the Prototype Experiment campaign) and the present analysis of the matrix waters should be available by early February, 2000.

Further matrix fluid sampling

Sampling Section 2 (8.85-9.55 m) has been showing a small, but steady pressure increase. This will be allowed to continue until adequate matrix fluid has accumulated (total section volume of 245 mL). Sampling will then be carried out; this time a more sophisticated sampling approach will be planned, including gas analysis. The much slower accumulation of fluid in this section, plus the absence of large fluid volumes in the adjacent Section 1 (already opened), may suggest a more representative matrix fluid composition than collected from Section 4.

Additional boreholes

No decision has been made yet to drill additional boreholes to sample low transmissive fractures adjacent to the matrix block, or for potential in- and out-diffusion studies between more highly transmissive fractures and the rock matrix. Any action within these tasks will depend on the future status of the budget.

Reporting

A status report will be produced when the results from chemical analyses of the first matrix fluid sample are completed. Available results from the fluid inclusion studies will also be included.

3.9 Colloids

Background

Colloids are small particles in the size range 10^{-3} to 10^{-6} mm these colloidal particles are of interest for the safety of spent nuclear fuel because of their potential for transporting radionuclides from a faulty repository canister to the biosphere.

Therefore, SKB has for more than 10 years conducted field measurements. The outcome of those studies performed nationally and internationally concluded that the colloids in the Swedish granitic bedrock consist mainly of clay, silica and iron hydroxide 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 large attachment factor to the rock which reduces stability and the transport capacity of the colloids in the aquifer.

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 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). Based on these results SKB decided to initiate a project in the Äspö-HRL to study the Stability and Mobility of Colloids (SMC).

Objectives

The objectives of the SMC project is to:

- Verify the colloid concentration at Äspö-HRL
- Investigate the potential for colloidal transport of nuclides in natural groundwater flow paths
- Study the role of bentonite clay as a source for colloid generation

Experimental concept

Two nearby boreholes at HRL will be selected for the SMC experiment. One of the boreholes will be used as an injection borehole and the borehole downstream will be used as a monitoring borehole. The boreholes intersect the same fracture and have the same basic geological properties. The experiment will be performed in association with the TRUE-trace experiment programme

The boreholes and the optimum time for the experiment will be selected in co-operation with the co-ordinator for the TRUE experiment.

The natural background colloid content will be measured on-line from both boreholes by using a modified laser based equipment which has been developed by INE in Germany. The advantage is that the resolution of this equipment is higher compared with standard equipment of this type. It is therefore possible to detect natural colloid contents at much lower concentrations than previously possible. The outcome of these measurements will be compared with standard type of filtration performed on-line at the boreholes in order to be able to compare/transform these results to all the earlier colloid sampling campaigns at Äspö.

After assessing the natural colloid content in the groundwater bentonite clay will be dissolved in ultra pure water to form colloidal particles. These clay colloids will be labelled with a nuclide together with a water conservative tracer. The mixture will be injected into the injection borehole. From the monitoring borehole the colloidal content will be measured with the laser, the water will be filtered and the amount of tracers will be measured. The following results are of interest 1) is the colloid content lower after the transport, 2) is the nuclide association irreversible on the colloids and 3) is the bentonite clay a potential source for colloid generation. The outcome of this exercise is used to check the calculations in the safety assessment report TR 91-50 to be used in future colloid transport modelling.

Scope of work for 2000

The work will be planned during year 2000 together with SKB personnel and SKB consultants. Relevant work performed internationally will be reviewed. The possible interest from foreign experts and organisation to participate in the SMC project will be examined. The preparation and the experiment will be performed during the time period 2000-2003.

3.10 Microbe

Background

A set of important microbiology research tasks for the performance assessment of high level nuclear waste (HLW) disposal has been identified in by Pedersen and Karlsson (1995) and Pedersen (1997). They are:

1. Microbial influence on radionuclide migration. To what extent can bacterial dissolution of immobilised radionuclides and production of complexing agents increase radionuclide migration rates?

2. Microbial corrosion of copper. Bacterial corrosion of the copper canisters, if any, will be a result of sulphide production. Two important questions arise: Can sulphide producing bacteria survive and produce sulphide in the bentonite surrounding the canisters? Can bacterial sulphide production in the surrounding rock exceed a performance safety limit?

3. Microbial production and consumption of gases. Will bacterial production and consumption of gases like carbon dioxide, hydrogen, nitrogen and methane influence the performance of repositories?

4. The subterranean biosphere. Is there a deep subterranean biosphere and how does it sustain its life processes? What energy sources and fluxes of energy will be available for microorganisms in and around a HLW repository?

5. Microbial reducing activity. Will bacterial oxygen consumption significantly contribute to oxygen removal from a HLW and to what extent may bacterial production of reduced compounds such as organic material, methane, sulphide and ferrous iron contribute to keeping the repository host rock reduced?

6. Microbial recombination of radiolysis products. Will bacterial recombination of radiolysis products significantly contribute to the removal of unwanted oxidised molecules such as oxygen?

7. Alkaliphilic microbes and concrete. Do relevant microorganisms survive at pH equivalent to that of repository concrete and can they possibly influence repository performance by concrete degrading activities such as acid production?

These tasks have been addressed in a range of projects, of which several is ongoing. Important conclusions have been obtained based on laboratory and field data (Pedersen, 1997, 1999). While some results seem very solid with general applicability, others are pending inspection at in situ conditions. This is especially true for data generated at the laboratory only. In situ generated data must be obtained for microbial activities in the far- and near-field environment at realistic HLW repository conditions. This can only be achieved at an underground site, developed for microbiological research, using circumstantial protocols for contamination control during drilling and operation. An in situ site allows experiments at natural pressure with correct gas content in groundwater which is of great importance for microbial activity and very difficult to obtain in vitro. Such a site was drilled in May 1999 in the J-niche at Äspö HRL, 450 m underground. Three boreholes were produced.

Objectives

The demands on a high level nuclear fuel waste (HLW) include reaching reduced conditions before significant oxygen corrosion of the copper canisters occurs. It is also important that sulphate reducing bacteria do not produce sulphide in the buffer in amounts that may threat the canister integrity. Reducing conditions will also be necessary for correct functioning of the third barrier, the host rock. Several radionuclides fail to sorb to the rock at oxidising conditions. Microorganisms will contribute to the reduction of the repository environment, thereby providing better conditions for HLW disposal compared to conditions without microbes. Their ability to do so is very much related to available energy sources in rock, groundwater, buffer and backfill. Hydrogen produced in very deep rock environments is expected to support a sustainable energy source for the indigenous microbial populations at repository depth. Earlier research concerning microbiology and nuclear waste disposal have included investigations at laboratory and at various sites during the pre-investigation and constructions phases of Äspö hard rock laboratory. The microbe site will significantly help to clarify and demonstrate to what extent microbial reactions may support, or threat, the repository concept.

The major objectives for the microbe site are:

- To assay microbial activity in groundwater at in situ conditions. Influence on redox conditions, radionuclide migration and gas composition and consumption will be in focus.

- To establish data on hydrogen generation and flow in granitic rock environments. The flow of hydrogen form where it is produced will determine the possible rate of long term microbial subterranean activity.
- To enable experiment where the engineered barriers, bentonite, backfill and copper can be investigated for the influence of microorganisms at realistic and controlled conditions with a significant knowledge about the microbiology of the groundwater used.
- To generate accurate data about rates of microbial reactions at repository conditions for performance assessment calculations.

Experimental concept

The microbe site consists of three core drilled boreholes, KJ0050F01, J0052F01 and KJ0052F03, intersecting water conducting fractures at 12.7, 43.5 and 9.3 m respectively. Each borehole will be equipped with packer systems in January 2000 that allow controlled sampling of respective fracture. Special attention will be directed towards the use of clean, non-contaminating instrumentation. An underground laboratory, approximately 7 x 2.5 m will be installed in January 2000 close to the site and will be equipped with a large anaerobic chamber and possibility for set up of on line GC measurement of dissolved gases. Tubing from the boreholes will be connected to the box, allowing for anaerobic sampling in the box. The microbe site will, to the extent possible, simulate real aquifer conditions.

Scope of work for 2000

Instrumentation

The microbe site will be instrumented during January. An underground container will be equipped for microbiological field work. It will have an anaerobic chamber and will be connected to the boreholes via circulation systems.

Chemical characterisation

The first task will be a chemical and microbiological characterisation of the groundwater at the site. Groundwater will be sampled after the boreholes have been instrumented. The groundwater composition in the packed off sections will be analysed applying ÄHRL class 5 analysis. The following optional class 5 analyses will be performed once for each borehole: HS^-, F, NH_4, NO_2, NO_3, PO_4, NH_4, TOC, ^{14}C-age, PMC, $\delta^{13}C$ per mill PDB, INAA-analysis of listed elements, 226Ra 228Ra 222Rn + U Th isotopes, ICP analysis of VI + U, Th + other trace elements + I. The results should be available before end of May. A PCA comparison of the obtained data with earlier obtained ÄHRL will give important information about the geochemical situation of the site.

Microbiological characterisation

The total numbers of microorganisms and the most probable numbers of iron reducing bacteria (IRB), manganese reducing bacteria (MRB) sulphate reducing bacteria (SRB), heterotrophic and autotrophic acetogens and heterotrophic and autotrophic methanogens will be analysed (For methods, see Haveman, Pedersen and Routsalainen, 1999). Solid phase reactors will be installed in circulation systems and the potential for attachment and growth of microbes will be assayed. Nucleic acid probes will be applied for the determination of the proportion of Bacteria, Archaea and Eukarya. Species diversity will also be addressed, especially when SRB are detected. This work will need time until August, approximately.

Set up of circulation systems

A system that allows circulation of groundwater under full formation pressure will be developed and installed. This system should enable work with microbes at very close to in situ conditions.

Set up of buffer mass tests

The site will enable a continuation of buffer tests (Motamedi, 1999), including the possibility of studying the potential for microbial copper corrosion at natural environmental conditions. The possible start of this experiment is still pending additional planning and the proper functioning of the microbe site.

3.11 The Task Force on modelling of groundwater flow and transport of solutes

Background

The Äspö Task Force on modelling of groundwater flow and transport of solutes was initiated in 1992. The group consists of nine organisation from eight countries. Each participating organisation is represented by a Task Force delegate 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 defined as Modelling Tasks and so far the focus has been on the following:

Task No 1: The LPT-2 long term pumping and tracer experiments.

Task No 2: Scoping calculations for some of the planned detailed scale experiments at the Äspö site.

Task No 3: The hydraulic impact of the Äspö tunnel excavation.

Task No 4: TRUE - The Tracer Retention and Understanding Experiment, 1st stage.

Task No 5: Coupling between hydrochemistry and hydrogeology

Objectives

The Äspö Task Force shall be a forum for the organisations supporting the Äspö Hard Rock Laboratory 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 assessment.

Scope for 2000

The main objectives targeted to be accomplished during 2000 are summarised below:

- Arrange the 13th International Task Force meeting, hosted by DOE/Sandia NL, Carlsbad, NM, USA.
- Arrange a Workshop for modellers on an interesting modeling issue.
- Arrange Workshop for Task Force Delegates – take stock of past accomplishments and set the future direction of the Task Force.
- Define and implement sub-task 4G,- to resolve discrepancies identified in Task’s 4A-4F.
- Produce the Deconvolution report for Task 4E
- Produce the final report of Task 4E&F
- Produce the Evaluation report of Task 4E&F.
- Produce the final report of Task 4G.
- Produce the final report on prediction 2900-3600m for Task 5
- Produce a preliminary summary report on all Task 5 modelling
- Define and implement a new modelling task, Task 6.
- Arrange the 14th International Task Force meeting.
- Arrange a Workshop on the final evaluation of Task 4.

4 Demonstration of technology for and function of important parts of the repository system

4.1 General

Stage goal 4 of the 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, is conducted under realistic conditions and at appropriate scale. A number of large-scale field experiments and supporting activities are therefore planned to be conducted at Äspö HRL. The experiments focuses on different aspects of engineering technology and performance testing, and will together form a major experimental program.

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

- To furnish methods, equipment and procedures required for excavation of tunnels and deposition holes, near-field characterisation, canister handling and deposition, backfilling, 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*, objectives are:

- To test and demonstrate the function of components of the repository system.
- To test and demonstrate the function of the integrated repository system.

4.2 Prototype repository

Background

Many aspects of the repository concept (KBS-3) 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 during 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 and in full-scale and 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 Äspö Prototype Repository is a dress rehearsal of the actions needed to construct a deep repository from detailed characterisation to resaturation of deposition holes and backfilling of tunnels. The Prototype 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 should demonstrate that the important processes that take place in the engineered barriers and the host rock are sufficiently well understood.

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 models and assumptions.
- To develop, test and demonstrate appropriate engineering standards and qualify assurance methods.
- To simulate appropriate parts of the repository design and construction processes.

The Prototype Repository is set up to simulate a part of the KBS-3 type repository under what can be described as normal conditions, which is essentially the same as the reference scenario described in SR-95. The Prototype Repository will differ from a real repository in that the canisters will contain electrical heaters to simulate heat generation instead of spent nuclear fuel.

The evolution of the Prototype Repository should be followed for a long time, possibly 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 stage operation of the real deep repository. The Prototype Repository will in this context provide operating experience for 10-20 years longer than have been achieved with deposited canisters containing spent fuel.

Experimental concept

The Prototype Repository should, to the extent possible, simulate the real deep repository system, regarding geometry, materials, and rock environment. This calls for testing in full-scale and at relevant depth. The test arrangement should be such that artificial disturbance of boundary conditions or processes governing the behaviour of the engineered barriers and the interaction with the surrounding rock are kept to a minimum.

Important limitations with respect to the possibilities to simulate a repository situation are:

- The test site area is given and the location in conjunction with certain conditional criteria is therefore limited.

- No spent fuel, or any other form of nuclear waste, will be used. Canisters equipped with electrical heaters will be used to simulate encapsulated spent fuel.
- The Prototype Repository cannot demonstrate long-term safety, since the experiment considered will be extended in time at most tens of years.
- The Prototype cannot demonstrate final handling and installations of components in the deep repository due to practical considerations, such as installation of instruments etc.

In the deep repository, localisation of the repository, deposition tunnels and final canister positions is planned to be determined by a step-by-step characterisation system followed by a detailing of the repository layout. The site of the Prototype Repository is given. However, methods for characterisation of the rock mass in the test site are expected to contribute to the assessment of methods for characterisation of the rock mass and the canister positions in a real deep repository.

Different alternatives as regards location and layout of the prototype Repository have been considered. The test location chosen is the innermost section of the TBM tunnel at 450 m depth. The layout involves six deposition holes with a centre distance of 6 m (Figure 4-1). The 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. The distance between the plugs and the nearest deposition holes are 9 m. 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 material (Figure 4-2). The tunnel will be backfilled with a mixture of bentonite and crushed rock (30/70).

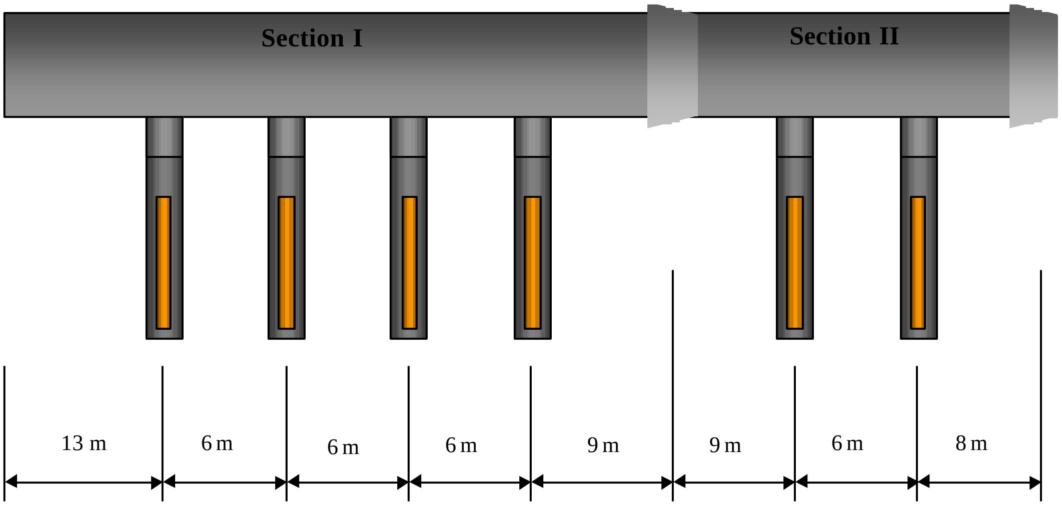


Figure 4-1 *Schematic view of the layout of the Prototype Repository .(not to scale)*

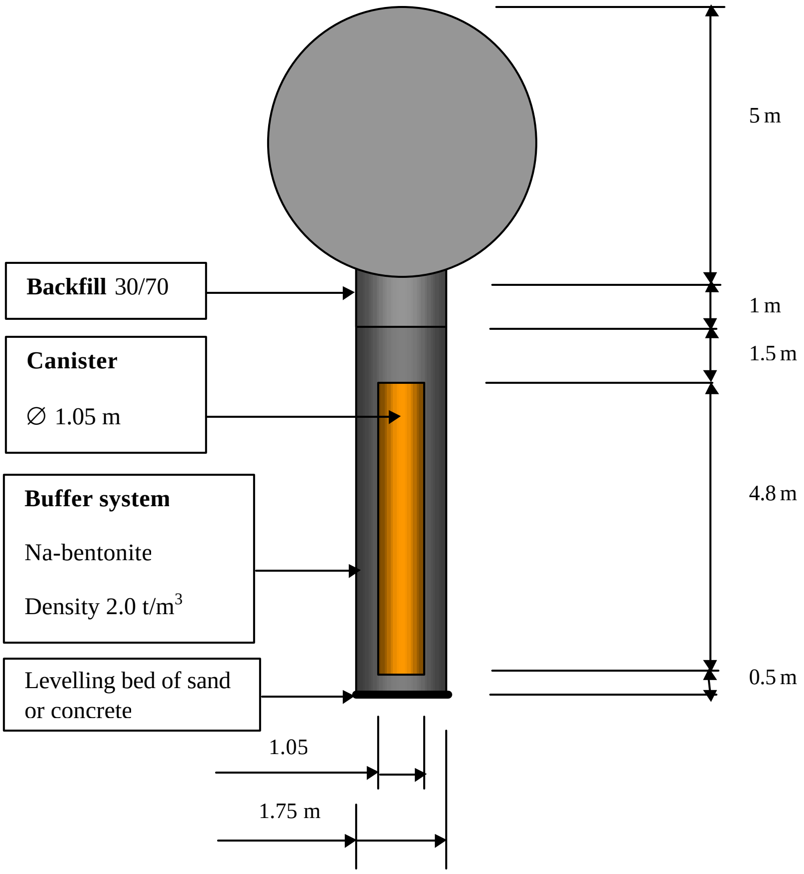


Figure 4-2 *Schematic layout of the deposition holes (not to scale)*

A massive concrete plug designed to withstand full water- and swelling pressures will separate the test area from the open tunnel system. A second plug will be placed such that it divides the test into two sections, comprising four and two canister holes. This layout will in practice provide two more or less independent test sections.

Operation time for the experiment is envisaged to be at least 10 years, possible up to 20 years. Decision as to when to stop and de-commission the test will be influenced by several factors, including performance of monitoring instrumentation, results successively gained, and also the overall progress of the deep repository project. It is envisaged that the outer test section will be de-commissioned after approximately five years to obtain interim data on buffer and backfill performance through sampling.

Instrumentation will be used to monitor processes and properties in the canister, buffer material, backfill and the near-field rock. The intention to minimise disturbance will however add restrictions to the monitoring possible.

Processes that will be 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
- Tracer transport
- Bacterial growth and migration in buffer and backfill

Scope for 2000

During year 1999 an application for EC funding of the Prototype Repository project was submitted concerning the time from April 1 of 2000 up to December 2003. The application included eight other organisations and asked for 50% funding of SKB´costs during that period and between 10% and 100% funding for the other organisations contributions. Besides SKB the group consists of:

- POSIVA, Finland
- ENRESA, Spain
- AITEMIN, Spain (associated with ENRESA)
- CIMNE, Spain (associated with ENRESA)
- GRS, Germany
- BGR, Germany
- UWC (University of Wales)
- JNC, Japan

Now in January 2000 it has been public that the application is selected by EC for funding but only to a smaller extent than was asked for, approximately half of the asked sum. This will require modification of the planning of the EC part of the Prototype Repository and possibly also modifications of the programme if not all participants will find other sources of funding. This, however, is only expected to cause minor changes, if any. The planning aims at submitting the modified application in March and sign the contract with EC in June.

Minor parts of the characterisation work, that remains, will be carried through and the reporting of the results from all the characterisation work carried out will be completed. Eventually the core of the findings is compiled in one characterisation summary report.

The remaining field work is to measure the elastic properties of the rock in the Prototype Repository tunnel in situ and to measure the magnitude and direction of in situ stresses with another method than the overcoring method earlier used, in order to get a second observation. Detailed hydraulic characterisation of the six bored deposition holes has started and will continue during the year, the aim being to establish the inflow regime as boundary conditions for the THM modelling on buffer saturation and swelling.

Water samples will be taken with the new tool for determination of the in situ redox conditions.

Analysis of rock samples in the laboratory will be completed by determination of the thermal expansion of the rock in the tunnel.

The main reporting as basis for the mentioned final report, is

- Geological characterisation using the Rock Visualisation System (RVS) as modelling tool
- Thermal properties of the rock
- Hydraulic predictions of inflow based on Discrete Fracture Network modelling
- Results from acoustic emissions measurements during boring
- Rock mechanical properties, in situ stresses and mechanical response to the boring of the deposition holes
- Redox conditions in the rock

Design as well as detailed planning continues. All work for Section I has to be ready during year 2000. Main design is the design of the plugs and the slots these need and the design of all handling of cables and tubes including lead-throughs.

Remaining rock work prior to installation of bentonite blocks and canisters are excavation of the two slots for the plugs and boring of lead-throughs to the adjacent G-tunnel for cables and tubes from all instruments, gas and water sampling unit, and heaters in the canisters. These two activities are interconnected as the excavation requires dismantling of the roadbed at the places for the slots, which also requires disconnection of tubes from the hydraulic measurement sections in the 31 different exploration holes in the tunnel. And the hydraulic responses will have to be registered during drilling of the lead-throughs, as the pillar between the Prototype Repository tunnel and the G-tunnel most certainly contains main water conducting features. In addition small spaces are needed in the tunnel wall at the mouth of the lead-throughs for hosting the water and gas tight interfaces between the Prototype Repository and the monitoring, sampling and supervision facility.

Preparations prior to start of installations will comprise installation of instruments in the rock, which in some cases also requires drilling of holes for the instruments. During year 2000 basically work in Section I is made but in some cases the short time between ending of installations in Section I and start in Section II calls for preparations also in Section II during year 2000. The main activities during year 2000 are:

- Installation of temperature sensors in the rock in Section I (new instrument holes are needed)
- Installation of estimated 24 packers in 2 m deep holes in the tunnel wall (new instrument holes are needed)
- Installation of new bentonite packers in Section I and old mechanical packers in Section II
- Installation of resistivity sensors in Section I and II (new instrument holes are partly needed)

Preparation work also addresses the casting of the bottom pad in the inner four deposition holes of Section I.

Design of canisters with heaters will be finalised and four of the canisters manufactured and assembled. The design will be very much like the design of the canisters to the Canister Retrieval Test, with the exception of the concern and consequent design measures for the long time span heaters and power supply shall be active.

Bentonite blocks to Section I are compacted in the press at Ystad with the technique used to produce the blocks to the Canister Retrieval Test.

Detail planning for the deposition sequence will be made. The installation equipment for handling the canisters, bentonite blocks and buffer material and techniques for installation, including instrumentation will be ready for operation in the Äspö HRL in early 2000. The programme is to start with testing of the different installation sequences in the deposition hole in the Assembly Hall at 420 m level in the project named “Test of Deposition Process”. When completed, the installation of the holes in the Canister Retrieval Test is carried out before the installation in the Prototype Repository starts.

The late delivery of the equipment combined with delaying modification of the deposition machine has postponed the start of installation. At the end of 1999 the decision was taken to plan for a start of the installation of the first block in the innermost hole in Section I during January 2001, which is twelve months later than was presented in the Planning Report for year 1999. The start of installation in Section II is postponed until October 2001, which also is a delay of twelve months. With this plan all six heaters are turned on during year 2001. This postponement also adopts to the planning of the EC project as the EC funding starts first when the signing of the contract has been made.

4.3 Backfill and plug test

Background

The *Backfill and Plug Test* is a test of different backfill materials and emplacement methods and a test of a full-scale plug. It is a test of the hydraulic and mechanical function of the backfill materials and their interaction with the near field rock. It is also a test of the hydraulic and mechanic functions of a plug and will be the basis for the design of temporary plugs in a repository. The test is partly a preparation for the *Prototype Repository*.

Objectives

The main objectives of the test are:

- to develop techniques and test techniques and materials for backfilling tunnels.
- to develop and test techniques for temporary plugging of deposition tunnels and to test the mechanical and hydraulic function of such a plug

- to test the integrated mechanical and hydraulic function of the backfill and near field rock in a tunnel excavated by blasting

Experimental concept

Figure 4-3 shows an overview of the test. The test region, which is located in the old part of the ZEDEX drift, can be divided into the following three test parts:

1. The *inner part* filled with backfill containing 30% bentonite (sections A1-A5 and B1).
2. The *outer part* filled with backfill without bentonite (sections B2-B4).
3. The *plug*.

The backfill sections have been 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.

ÄSPÖ HARD ROCK LABORATORY- BACKFILL AND PLUG TEST IN ZEDEX DRIFT

Layout of the test
Numbering of backfill sections and permeable mats

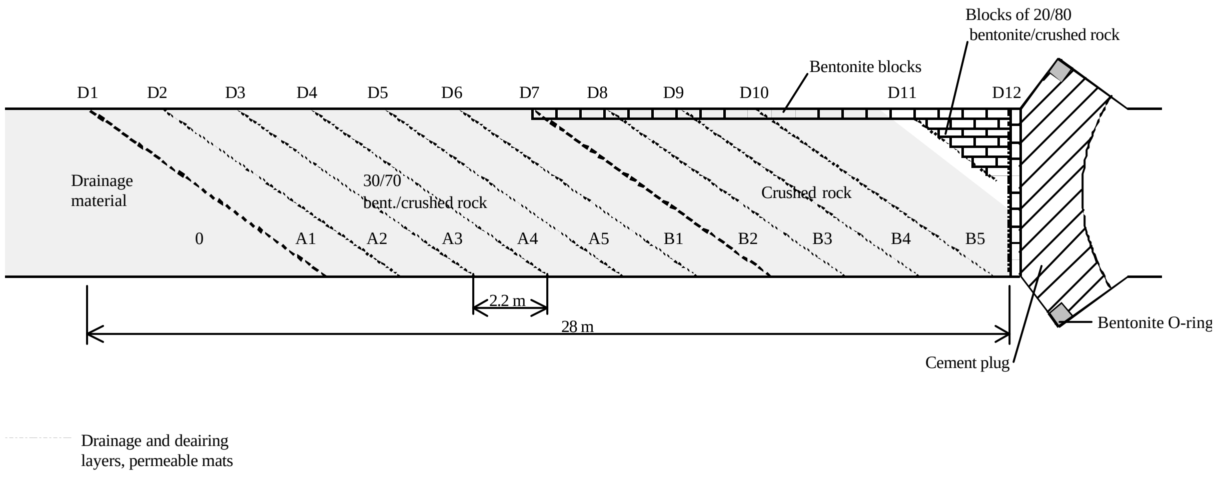


Figure 4-3 *An overview of the Backfill and Plug Test*

The inner test part has been filled with a mixture of bentonite and crushed rock with a bentonite content of 30%. The composition has been based on results from laboratory tests and field compaction tests. The outer part has been 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.

The two parts are about 14 meter long and split 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 nearfield rock. They will also be used for the water saturation of the backfill by applying water pressure in every second mat and lead out air in every other. The mats have been installed in both backfill parts with the individual distance 2.2 m. Each mat section was split 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 section ends with a wall made of prefabricated bars 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 be filled with blocks of bentonite/sand mixture with 20% bentonite content.

The backfill and rock have been 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 have been led through the rock to the data collection room in bore holes drilled between the test tunnel and the neighbouring Demo-tunnel.

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 saturation is expected to take about 1 year and the subsequent flow testing about 1 year. The flow testing in the backfill is planned to start after saturation, when steady state flow and pressure have been reached. The tests will be made by decreasing the pressure in the filters one by one starting with the outer filter and after equilibrium continue with the next filter.

Scope for 2000

During 1999 the experimental setup was finished with the following main work:

- blocks for the backfill and for the bentonite o-ring in the plug have been compacted
- the data collection house, the data collection system and the water pressure and water flow measuring system have been installed
- the test sections have been backfilled by inclined compaction and filter mats installed etc.
- all instruments in the backfill have been installed and all cables and tubes led through the through connection holes to the data collection house
- the bentonite o-ring has been installed and the final part of the plug has been built
- water saturation of the backfill has started by filling up the mats with water and applying a low water pressure

During 2000 the water saturation will proceed. The following main activities will take place:

- Three months wetting with low water pressure applied in the mats
- Evaluation of the saturation rate and decision on if the water pressure in the mats need to be increased
- Continued wetting until completed saturation
- Continuing data collection of measured water pressure, water flow, total pressure and degree of water saturation

4.4 Demonstration of repository technology

The design and testing of equipment for handling and deposition of the buffer material and canisters for the Canister Retrieval Test and the Prototype Repository will be completed during 2000. The development work of the equipment needed in the future deep repository will continue based on experiences from the ongoing work with the demonstration deposition machine now installed at Äspö. The whole system of different machines and equipment needed is expected to be identify and developed to a feasibility stage as part of the ongoing design studies of the deep repository

4.5 Canister retrieval test

Background

The stepwise approach to safe deep disposal of spent nuclear fuel implies that if the evaluation of the deposition after Step I 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 strength that allows the canister to be just pulled out of the deposition hole. First the grip of the bentonite has to be loosened before the canister can be taken up and enclosed in a radiation shielding before being transported away from the deposition area.

Objectives

The objectives of the retrieval test are

- to develop and test methodology and equipment for freeing of canister from the grip of the swollen bentonite,
- to show in a perceptible way that a free canister can be safely retrieved in an underground environment

but also

- to develop methodology and equipment for boring of full size deposition holes.

Experimental concept

The Canister Retrieval Test is located in the main test area at the 420 m level, and is separated into three stages:

Stage I: Boring of deposition holes and installation of bentonite blocks and canisters with heaters. The holes are covered in the top with a lid of concrete and steel, which is bolted to the rock around the hole. The tunnel is maintained unfilled.

Stage II: Saturation of the bentonite and evolution of the thermal regime.

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).

As two holes are used in the test there is a possibility to test two different methods for freeing of the canister. The development up till today has listed disintegration of the bentonite with salt solution and pumping of the slurry as the prime alternative. An alternative method is being selected by means of evaluation and analysing a number of listed methods

Scope for 2000

The installation of bentonite blocks is scheduled to start in August, 2000, the sensitive parts of the deposition sequence are going to be tested prior to that in “Test of Deposition Process”.

Design and planning prior to start of the installations are basically done and, if not already reported, in the reporting phase. Main objects, which will be finished early 2000, are:

- Plug design
- Mats for artificial addition of water
- Routes for cable bundles from buffer and canister
- Location of temperature sensors

Preparations in the test area prior to start of installation will address:

- Surveying
- Drilling of holes for temperature sensors and for cable bolts to the plugs
- Arrangements for drainage (although the inflow is presently negligible)
- Casting of the bottom pads in the deposition holes
- Installation of a climate control system

Compaction of the last series of bentonite blocks will be made in the plant at Ystad after homogenisation and mixing the MX-80 quality with water in the plant at Lidköping (Rörstrand). Bentonite pellets are fabricated in France.

A complete canister with heater will be manufactured and assembled in Malmö. The canister is furnished with temperature sensors and strain gauges inside as well as outside.

Instrumentation of the buffer follows the instrument plan published. Instruments are partly to be ordered. Once they arrive they are made objects for calibration before installation.

Eventually the outer hole is installed first with the canister without instruments in the interior. Starting with lowering of the first block in May the plug can be in place so that the heaters as well as the artificial watering system can be turned on before the summer vacations start. The second hole is installed during the fall resulting in completed installation during September year 2000.

The heaters are regulated so that the temperature on the canister´s surface reaches 90°C, and is maintained at that level. Water is added to the mats so that enough water is supplied for the diffusion into the bentonite. The movement of the plug is registered and the force on to the bolts is progressively increased in accordance with the increased swelling of the bentonite.

The monitoring system is taken into operation with a schedule to be in operation for about five years.

The test is a first test of the quality system that is planned to be adopted in the Prototype Repository, one part being the planning and documenting of activities in quality plans, followed by evaluation and documentation of the actual outcome. This means that main work is dedicated to the compilation of the quality documents needed in the system as well as to follow-up later, after completion of installations.

4.6 Long term test of buffer material

Background

Bentonite clay has been proposed as buffer material in several concepts for HLW repositories. In the Swedish KBS3 concept the demands on the bentonite buffer are to serve as a mechanical support for the canister, reduce the effects on the canister of a possible rock displacement, and minimise water flow over the deposition holes.

The decaying power from the spent fuel in the HLW canisters will give rise to a thermal gradient over the bentonite buffer by which original water will be redistributed parallel to an uptake of water from the surrounding rock. A number of laboratory test series, made by different research groups, have resulted in various buffer alteration models. According to these models no significant alteration of the buffer is expected to take place at the prevailing physico-chemical conditions in a KBS3 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 KBS3 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 KBS3 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 transport and gas penetration.
- Check of existing models concerning buffer-degrading processes, e.g. illitisation and salt enrichment.
- Information concerning survival, activity and migration of bacteria in the buffer.
- Check of calculation 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 philosophy for all tests in the series (Table 4-1) is to place prefabricated units of clay blocks surrounding heated copper tubes in vertical boreholes (Figure 1). The test series are performed under realistic repository conditions except for the scale and the controlled adverse conditions in three tests.

The test series have been extended, compared to the original test plan, by the A0 parcel in order to replace the part which was lost during the uptake of the previous A1 parcel.

Table 4-1. Lay out of the ongoing Long Term Test series.

Type	No.	T °C	Controlled parameter	Time years
A	0	120<150	T, $[K^+]$, pH, am	1
A	2	120<150	T, $[K^+]$, pH, am	5
A	3	120<150	T	5
S	2	90	T	5
S	3	90	T	>>5

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

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

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 effect of 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. Test ”parcels” containing heater, central tube, clay buffer, instruments, and parameter controlling equipment are placed in boreholes with a diameter of 300 mm and a depth of around 4 m.

Temperature, total pressure, water pressure and water content, are measured during the heating period. At termination of the tests, the parcels will be extracted by overlapping core-drilling outside the original borehole. The water distribution in the clay will be determined and subsequent well-defined chemical, mineralogical and physical testing will be performed.

Scope for 2000

The official test start, i.e. full ground-water pressure and beginning of heating, will take place at the end of January, 2000. Chemical analyses of ground-water, and if possible of water from the “passive” filters in the bentonite, will be made regularly during the test period. The monitored water pressure, total pressure, temperature and moisture in the 5 parcels will continuously be analysed and regularly reported during the test period. Supplementary laboratory work will be made concerning technique for measurement of gas penetration pressure, and characterisation of the original bentonite material. During the end of the year planning for the uptake, and analysing of material from parcel A0 will start. The uptake is preliminary scheduled to take place in March 2001.

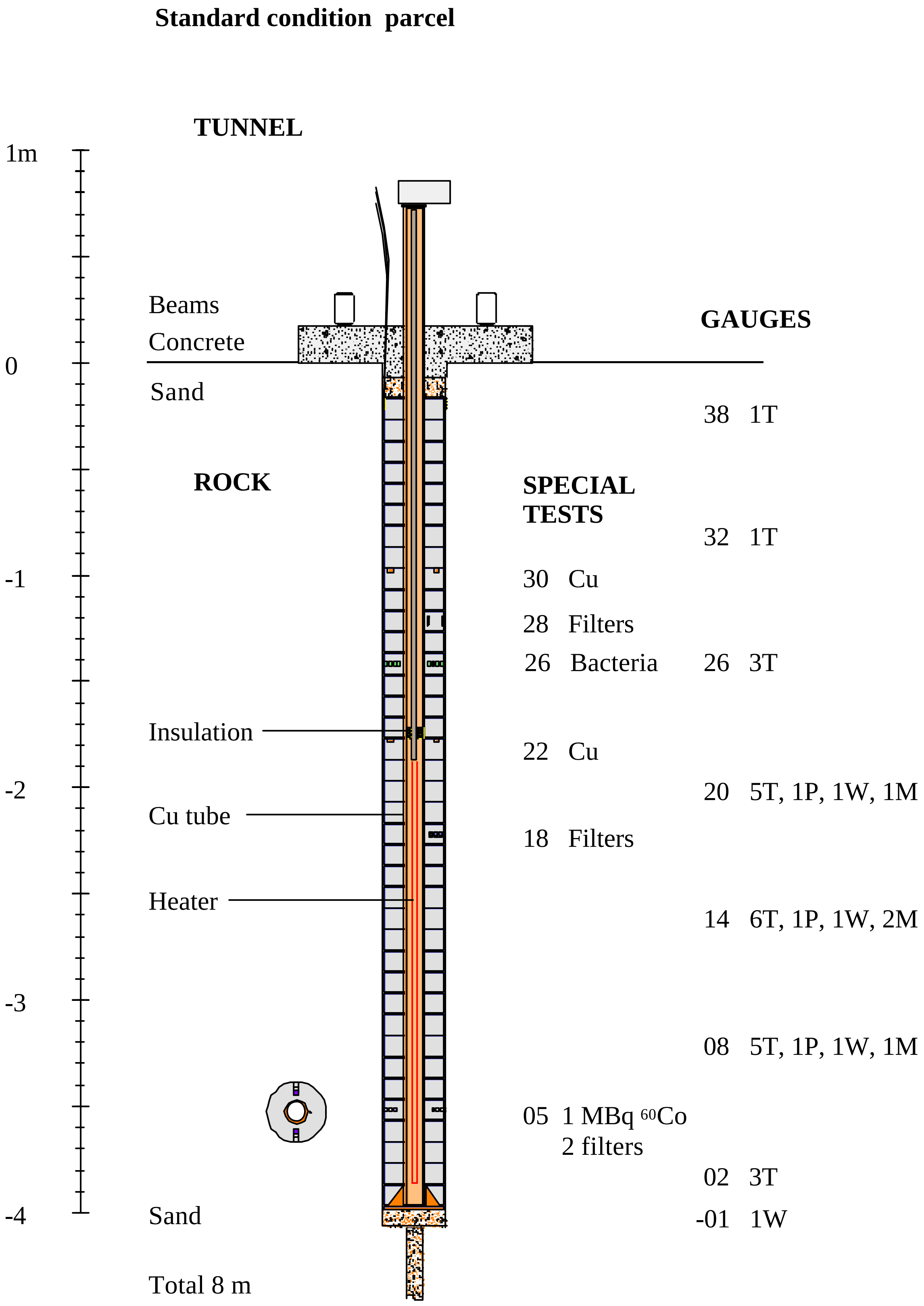


Figure 4-4 *Principle parcel layout. Numbers show bentonite block notation and the number of gauges at each level. T indicate thermocouples, W indicate water pressure gauges, P indicate total pressure gauges, and M indicates moisture gauges.*

4.7 Development and test of grouting technology

The work with development and testing of grouting technology will continue during year 2000. The project consists of three main parts:

- Characterisation of the rock for grouting purpose;
- Mechanisms controlling the spreading of grout;
- Different studies on cement grouts.

This project started in 1996 and the Phase I was completed mid 1998. Phase II of the project was completed end 1999. Phase III of the project is still in the planning stage but the plans are to perform a small field test with sealing tests at Äspö as part of Phase III.

4.8 Task Force on engineered barriers

Background

In the large to full scale experiments SKB is promoting in the Äspö Hard Rock Laboratory processes taking place in the bentonite, backfill and surrounding rock (Engineered Barrier System, EBS) during saturation and thereafter are in focus.

SKB is also conducting a fairly extensive programme on laboratory investigations of unsaturated behaviour of MX-80 bentonite as input for development and verification of the numerical codes for calculating the performance of an unsaturated buffer.

Similar to SKB´s work laboratory work as well as validation/verification experiments and code development are going on as part of many organisation’s core programme.

Following the recommendation of the International Joint Committee (IJC) a proposal for a Task Force on EBS has been distributed.

Objectives

The proposal is focusing on the objectives to increase the understanding and to build confidence in the capability of modelling various thermo-hydro-mechanical-chemical-biological (THMCB) processes of importance for the long term safety of a deep repository, their interaction and consequent need of coupling.

Task Force concept

The proposed Task Force is intended to be a forum for the organisations supporting Äspö HRL Project for interaction in the area of conceptual and numerical modelling of the EBS performance. In particular, the Task Force shall propose, review, evaluate and contribute to such work in the Äspö HRL Project. The Task Force shall interact with the Project Managers and Principal Investigators responsible for carrying out experimental and modelling work for the Äspö HRL in areas of particular interest to the members of the Task Force. These are the same principles that guide the Task Force on Modelling of

Groundwater Flow and Transport of Solutes, and also in other matters of administrative or strategic nature is the intention to apply the already developed principles to the proposed new Task Force concept.

Scope for 2000

The proposal comprises three tasks, which will be discussed in a preparatory meeting on March 14-15, 2000. The outcome is expected to be a proposal on tasks, the proposed ones with possible supplement of new ones, to be studied as well as time plans and activity lists for each organisation taking part in the Task Force on EBS. This proposal is submitted to the IJC for decision.

The proposed tasks are.

***Task A*: Selection of conceptual and mathematical models and identification of parameters these need for calculations**

The aim is to select and describe the conceptual and mathematical models that are planned to be the basis for each participant in the work. In addition a number of parameters are expected to be defined which are not known or known with low accuracy, and thus can call for new laboratory experiments.

Task A1: Selection of conceptual and mathematical models for THMCB processes in the EBS

The whole spectrum of THMCB processes is not assumed to be covered in the Task Force work but assumed to be considered in the selection of Tasks for the Task Force work. The acronym may thereafter be adjusted to only the processes selected.

Duration: Half a year starting July 2000.

Task A2: New laboratory experiments

Although new laboratory work may be needed for the models it is, until other information is available, assumed that the need of the Task Force on EBS is covered by the work conducted within other projects.

Task B: *Validation/verification of codes/models that describe the THMCB behaviour of EBS.*

The aim is to establish a process by which the repository developers may demonstrate a level of confidence in models that are used to estimate the probable behaviour of EBS. Work is done in steps concerning:

1. Determination of the fundamental processes and their interactions, and descriptions of these within the mathematical models

2. Evaluation of the numerical models by comparison with actual laboratory and bench-scale experiments

3. Application of the models for prediction of long term behaviour of the engineered barrier

Task B1: Identification and conceptualisation of processes and phenomena

Identification and conceptualisation of processes and phenomena which have not been properly addresses yet and which are considered to be of importance for the safety assessment or other means of investigating the quality of the EBS performance. With the experience of the work in the VALUCLAY Project (VALidation of codes/models that describe the Unsaturated behaviour of engineered CLAY barriers) the following items need further investigation:

- Dehydration and cracking of the bentonite closest to the heater/canister
- Properties of the EDZ (Excavated Damaged Zone) and its impact on the saturation process
- Proper determination of the mechanical properties in the buffer over a range of temperatures and water contents
- Chemical alterations with effect on the physical properties
- Temperature and pressure dependence of different processes

Duration: Half a year starting January 2001.

Task B2: Validation/verification of codes and models by using small to pilot-scale experiments

One example is proposed to be submitted by each organisation supporting Research Team(s) in this Task.

Duration: Two and a half years starting July 2001

Task C: ***THM modeling of the buffer, backfill and near-field rock***.

The aim is to validate/verify coupled mathematical models for THM(CB) processes by applying them on Äspö HRL experiments and to compare the predictions with the actual data obtained from the test.

Task C1: Calculation of buffer/backfill performance with the rock as boundary condition

The saturation process can be predicted for different hydraulic conditions of the rock mass, such as even and large supply of water around the buffer, limited supply, and supply only via fractures. The Canister Retrieval Test offers in-situ observations of saturation under controlled boundary conditions with respect to water supply, as the holes are dry and artificial water supply will be administrated in permeable mats attached to the bore hole wall.

Duration: Half a year starting January 2001.

5 Äspö facility operation

5.1 Plant operation

Background

The main goal for the operation of the facility is to provide a safe facility for all people working or visiting the laboratory. This includes preventive and remedy maintenance on all systems like drainage, ventilation, electricity and different kind of alarms.

The work with improving the facilities safety and function will always be an important part of the operation.

Today the organisation includes two employees. During this year it will be strengthened.

Scope for 2000

A major inspection of the rock- and reinforcement conditions took place last year.

Several recommendations concerning reinforcement was done. This will have the highest priority

The fire alarm will be enlarged to cover all parts of the tunnel system were major activities take place.

A plant supervision system will be taken into operation early year 2000. This will considerably facilitate the possibilities to run the facility in a safe and economic way.

Exchange of non stainless steel components around the shafts, both hoist and ventilation, to stainless material will continue.

As a part of the ”certification work” a lot of instructions are formalised and system hand books are prepared.

Several safety related educations will be held this year.

A new power line to supply the Äspö village with electricity is under construction. This will in a positive way affect the reliability of operation. Specially, the hoist is dependent on electrical supply without interruption.

5.2 Data management and data systems

Background

The regulatory authorities are following SKB’s siting work. Before each new stage, they *examine and review the available data.* A repository will never be allowed to be built and taken into service unless the authorities are convinced that the safety requirements are met. Hence, SKB is conducting *general studies* of the entire country and *feasibilty studies* in 5-10 municipalities. *Site investigations* will then be conducted on a couple of specific sites. With the result of the studies as supporting material, SKB will then apply for permission to carry out *detailed characterisation* of one of the sites. The licence application for detailed characterisation will include a *safety assessment* and the results will be reviewed under the Act on Nuclear Activities and the Act concerning the Management of Natural Resources by the regulatory authorities, the municipality and the Government.

Management of investigation data is a highly demanding and critical task in the presented licensing process. The safety assessment must be based on correct and relevant data sets. Hence, the data management routines need to be focused on the following aspects in a long-term perspective:

- traceability,
- accessibility,
- data security and
- efficiency (system integration and user friendly applications).

A high quality baseline for the safety assessment will be established if the aspects specified above are met.

The parameter data needed in a safety assessment have been reported in Andersson et al /1998/. A set of major data systems have been developed and implemented in order to support and control the management of all investigation data sets and the corresponding parameters. In this report the current plans for SKB's Site Characterisation Database (SICADA), SKB's Rock Visualisation System (RVS) and SKB's Geographical Information System are presented. Other important tools are also improved and adapted continuously, but not treated in this report.

Objectives

SICADA

SICADA is and will be one of SKB’s most strategic database systems. The database should efficiently serve planned investigations activities at the future candidate sites as well as the experiments at Äspö HRL. The database should be user friendly and always guarantee a high degree of quality, traceability and safety. SICADA need to be held modern and also adapted and improved in parallel with the planning of the site investigation program.

RVS

A three dimensional rock model is built by successive collection, processing and interpretation of site data. All site data will be stored in SICADA. Furthermore all geological and geophysical maps will be available in SKB's GIS database.

It is important to have the possibility to test interactively in 3D different possible connections between observations in boreholes, tunnels and on the ground surface. By effectively visualising the rock model, based on available site data in SICADA, it is also possible to optimise new investigation efforts. Finally, during the design of the Deep Repository, the rock model will be the basis for adaptation of the tunnel layout to the different rock characteristics at the site

GIS

Geographical Information Systems are used to visualise any attribute distribution in a geographical area of any scale. By superimposing different sets of data the situation of a piece of land become easy to analyse. This advantage has been used extensively in the feasibility studies performed by SKB. GIS will also be used when the site investigations are planned but also during the site investigations.

System concept

SICADA

Data model

The central data table in the system is the activity_history table. All data rows in this table have a unique activity identifier. This identifier uniquely connects measured data with only one activity in the activity_history table. The activity identifier is located in the first column of the table. Normally the activity identifier is hidden, but it is always present in the background and is handled automatically by the system.

Activity identification numbers was introduced in order to make it possible to link an arbitrary number of investigation data tables to a certain activity. Hence, activity identification numbers are present in all investigation data tables in the whole system.

All data rows in the activity_history table also have a time stamp and an user identification code to show and control when data was inserted into the table and who did the input.

Data structure

A hierarchical data structure was implemented in the former GEOTAB system in order to make it easy to find and retrieve any investigation data. This data structure is also available in the SICADA system. The hierarchy is composed of four levels, viz:

- Science (Level 1)
- Subject (Level 2)
- Method (Level 3)
- Activity (Level 4)

At present time the SICADA data structure contains the sciences *engineering, geology, geophysics, groundwater chemistry, hydrology, meteorology and rock mechanics*. The principal structure with excerpt of contents of information for each hierarchical level within the seven sciences are viewed in Table 5-1.

Table 5-1. The hierarchical data structure of the SICADA system, with all sciences shown, but only an excerpt of subjects, methods and activities. Note, in most cases there is an one to one association between a certain method and an activity, but in some cases a whole group of activities are associated with only one method.

Level 1 Science	**Level 2 Subject**	**Level 3 Method**	**Level 4 Activity**
Engineering	Tunnel excavation etc.	Drill and blast etc.	D&B – Round drilling D&B – Charging D&B – Round D&B – Ventilation etc.
Geology	Tunnel mapping etc.	Tunnel mapping etc.	Tunnel mapping with TMS
Geophysics	Borehole logging etc.	Resistance etc.	Single point resistance logging
G.W. Cheimstry	Analyses etc.	Water etc.	Water sampling, class 1 Water sampling, class 2 Water sampling, class 3 Water sampling, class 4 Water sampling, class 5 etc.
Hydrology	Disturbance tests etc.	Pressure build up etc.	Pressure build up test
Meteorology	Temperature etc.	Temperature etc.	Temperature from SMHI
Rock Mechanics	Insitu stress etc.	Overcoring etc.	Overcoring

RVS

RVS is an advanced visualisation and rock modelling system based on the CAD-system MicroStation/J. MicroStation/J is a modern and powerful 3D-modeling system developed by Bentley Systems Inc in U.S.A, and is running on computers with the most common operating systems as Windows NT and UNIX.

The current version of RVS is designed as a single-user system, and the data exchange link between RVS and SKB's Site Characterisation Database System (SICADA) is based on a client/server technique.

There is also a local database, currently based on MS/Access 97, required on each RVS workstation. An open architecture based on the ODBC data exchange concept is used. Hence, by using ODBC, it will be easy to quit MS/Access 97 if another database system is needed in the future.

In the Rock Visualisation System, in contrast to standard MicroStation, the work is not based on design files (drawing files) and levels but on projects and objects. In order to work in an organised matter, and for practical reasons, it is for *larger projects* highly recommended to separate the visualisation work into three sub-projects:

• Data project	(Containing visualizations of background data)
• Model project	(Containing modeled objects)
• Construction project	(Containing underground constructions)

Hence, data, model and construction can be handled separately which is a great advantage, mainly regarding version handling, when data are updated continuously and much more often than the model. The project with background data is then attached as a background project to the model project. The background data project can be labelled with the attribute *data* by the user to ensure traceability between model and data project.

For *small projects*, limited in time and extension, it could, however, be more efficient to gather all information in one project, but independent of how the total set of objects are managed they can be mixed arbitrary when displayed on the screen.

GIS

As a result of the feasibility studies a huge amount of GIS data has been set up and organised. Some of the information is stored in the ArcInfo databased. The applications ArcView and ArcExplorer are used to display and visualise geographical attribute data.

Scope for 2000

SICADA

A new complementary navigation tool will be developed and implemented.

The SICADA system administration tool, GTADMIN, will be given a graphical user interface.

The user applications SICADA/Diary and SICADA/Finder will be integrated to one application.

Processes for management of investigation data should be identified, documented and implemented during year 2000. This is an important task and a part of the planning of the site investigations.

SICADA needs to be complemented a bit to fulfil the requirements which have been set up by the international PROTOTYPE experiment in the Äspö Hard Rock Laboratory.

We are judging that the number of SICADA users will increase about 50 % during year 2000.

RVS

RVS version 2.1 will be released and implemented in February 2000. Short after this release the programming of RVS version 2.2 will start. Version 2.2 will not include any major new functionality, but a set of very important improvements.

In August 2000 the development of version 2.3 will start. This version will be a major upgrade including functionality for solid modelling of the complete rock mass.

Several seminars and meetings will be planned and performed during 2000 in order to make SKB's Rock Visualisation System known as an powerful rock modelling and visualisation tool for not only the nuclear waste management line of business. Every civil engineering project should take a closer look at the capabilities.

GIS

Efforts will be taken to implement GIS as a general tool in the process of creating illustrations based on geographical information.

About five users in the organisation should be familiar with ArcView or ArcExplorer before the end of year 2000.

5.3 Program for monitoring of groundwater chemistry

Background

During the construction phase of the Äspö Hard Rock Laboratory, 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 the cored boreholes drilled from the ground surface and from percussion and cored boreholes drilled from the tunnel.

Objectives

At the beginning of the operational phase, sampling was replaced by a groundwater chemistry monitoring program, aiming to sufficiently cover the hydrochemical conditions with respect to time and space within the Äspö HRL. This program should provide information for determining where, within the rock mass, the hydrochemical changes are taking place and at what time stationary conditions are established.

Planned work

- Water sampling campaigns are scheduled to take place in April (w. 015-016) and September (w. 038-w. 039), 2000.
- The results from the Monitoring program undertaken in 1999 will be presented in a Technical Document in February 2000.

5.4 Technical systems

Hydro monitoring system

The groundwater monitoring system (HMS) collects data on-line of groundwater head, salinity and, in some boreholes, Eh and pH. The data are recorded by numerous transducers installed in boreholes on Äspö as well as in boreholes located in the tunnel, Figure 5-1.

All data are transmitted to the main office at Äspö, by radio or modems. Weekly quality control of preliminary groundwater head data are performed at the site office. 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 bore-holes, 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 has 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 lover pressure transducers in the tubes or to lover 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 will be done before a new similar system will be set up at candidate sites for the deep repository.

The measuring system is located in the tunnel with substations at sections 690, 1190, 1645, 2162, 2511, 3007, 3107, 3385 and 3510 m is also incorporated in the Hydro Monitoring System (HMS). Groundwater inflow to the tunnel is measured at intervals in the tunnel by dams and weirs.

The inflow of water into the different shafts will be collected with the aid of a weir and a Thomson measuring device for flow determination. At the ramp positions at 220 m, 340 m and 450 m, the measuring stations is installed for data sampling from the substations.

Scope for 2000

The experiment Canister Retrieval Test will be instrumented and connected to the Measurement system during 2000.

A new measuring station at ramp position –420 will be installed to take care of data from the Canister Retrieval Test.

Also new measurement points in the tunnel will be instrumented and connected to the HMS- system.

The presentation system for the HMS-system will be installed during winter 2000 and in full operation to the summer 2000.

Installation of the Measurement System for the Prototype Repository will start in the autumn.

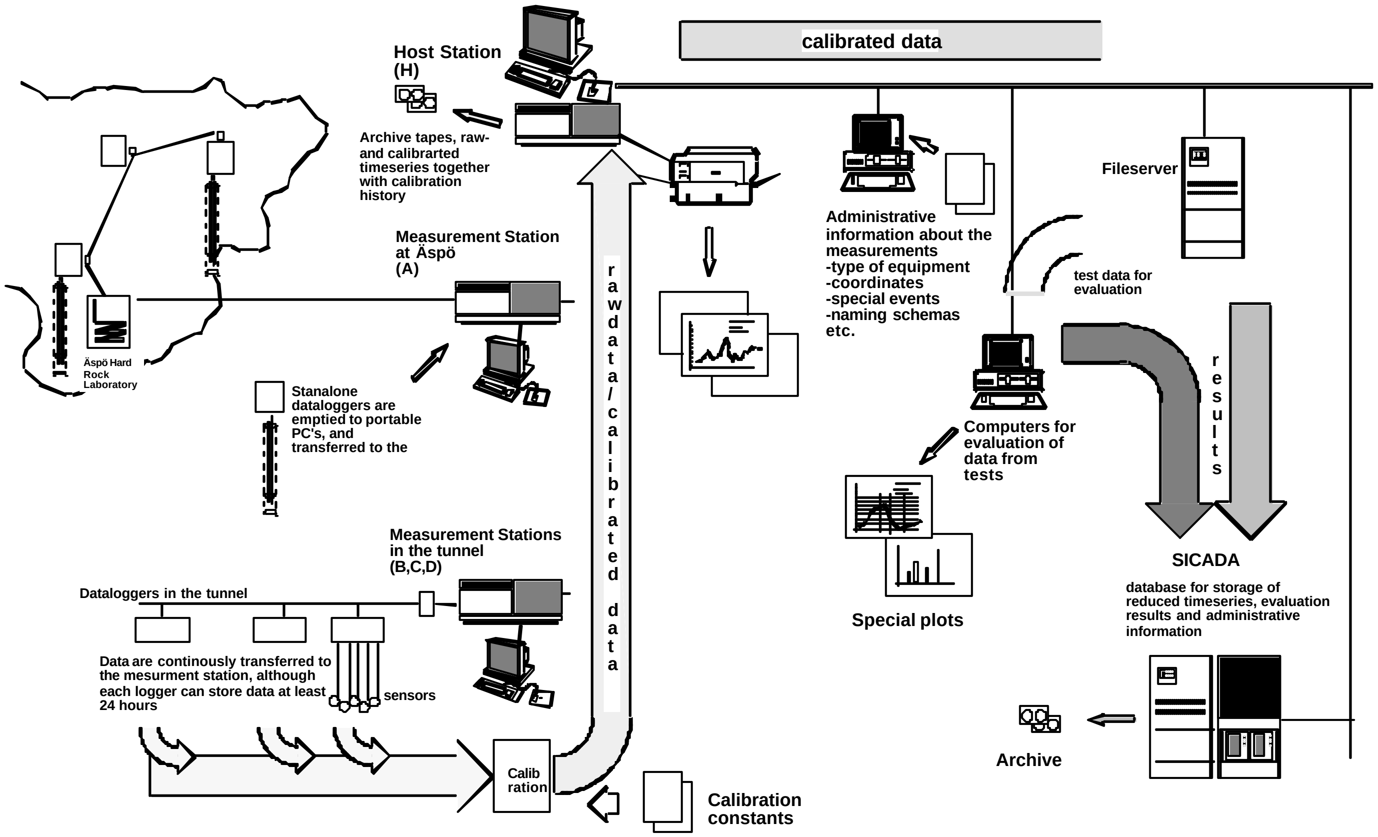


Figure 5-1 *Borehole system for groundwater monitoring*

6 International cooperation

6.1 Current international participation in the Äspö Hard Rock Laboratory

Nine organisations from eight countries are currently (December 1999) participating in the Äspö Hard Rock Laboratory.

The participation by JNC and Criepi is regulated by one agreement and the two companies are represented by one delegate in the International Joint Committee.

Discussions are going on concerning the future cooperation between SKB and Canadian organisations.

In each case the cooperation is based on a separate agreement between SKB and the organisation in question. Table 6-1 shows the scope of each organisation's participation under the agreements.

Most of the organisations are interested in groundwater flow, radionuclide transport and rock characterisation. Several organisations are participating in the Äspö Task Force on groundwater flow and radionuclide migration, which is a forum for cooperation in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock.

ANDRA, Nirex, POSIVA, ENRESA, JNC and SKB are cooperating under a special multilateral agreement regarding the TRUE Block Scale experiment.

A new Task Force on Engineered Barriers is planned. Several organisations are interested to participate. A meeting will be held in March 2000 (see chapter 4.8).

Table 6-1. Scope of international cooperation for 2000

Organisation	Scope of participation
Agence Nationale pour la Gestion des Dechets Radioactifs, **ANDRA**, France.	Detailed investigation methods and their application for modelling the repository sites Test of models describing the barrier function of the bedrock Demonstration of technology for and function of important parts of the repository system
Bundesministerium für Wirtschaft und Technologie, **BMWi**, Germany	Two-phase flow investigations including numerical modelling and model calibration Participation in the Task Force on modelling of groundwater flow and transport of solutes by using "German" computer codes Participation in the geochemical modelling efforts in the Äspö HRL Work related to transport and retention of radionuclides and colloids in granitic rock In-situ geoelectrical measurements with respect to water saturation of rock masses in the near field of underground tunnels Work on design and performance of in-situe tests using methods and equipment similar to those used in the Grimsel investigations
Empresa Nacional de Residuos Radiactivos, **ENRESA**, Spain	Test of models describing the barrier function of the bedrock (TRUE Block Scale) Demonstration of technology for and function of important parts of the repository system, (Backfill and Plug Test)
Japan Nuclear Cycle Development Institute, **JNC**, Japan. The Central Research Institute of the Electronic Power Industry**, CRIEPI,** Japan	The Tracer retention understanding experiments (TRUE) The detailed scale redox (REX) experiment Radionuclide retention experiments Task Force on modelling of groundwater flow and transport of solutes. Prototype repository project. Long-term test of buffer materials Groundwater updating

Organisation	**Scope of participation**
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, **NAGRA**, Switzerland	Test of models describing the barrier function of the bedrock Demonstration of technology for and function of important parts of the repository system
United Kingdom Nirex Limited, **NIREX**, Great Britain	TRUE Block Scale
POSIVA, Finland.	Detailed investigation methods and their application for modelling the repository sites Test of models describing the barrier function of the bedrock Demonstration of technology for and function of important parts of the repository system
USDOE/**Sandia National Laboratories**, USA	Test of models describing the barrier function of the bedrock

6.2 Summary of work by participating organisations

6.2.1 ANDRA

Background

L' Agence Nationale pour la Gestions des Dechets Radioactifs (ANDRA) provides experimental and modeling support to the HRL with emphasis on site characterisation to complete research activities in France.

The contributions of ANDRA and its contractors to the *TRUE Block Scale experiment* focused in the past on:

- design, performance and interpretation of single-hole and cross-hole hydraulic tests
- development and installation of multi-packer systems
- in-situ evaluation of non-sorbing tracers (^{3}He and different dyes) at the TRUE-1 site
- participation in the design of the tracer test stage
- modelling for the optimal orientation of an additional borehole

- modelling studies on the correlation of flow and transport data as a means for predictions

The contributions of ANDRA and CEA to the *REX experiment* focused on laboratory work on the removed part of the experimental fracture.

In 1999, ANDRA started with three modelling teams on *Task 5 of the Äspö Task Force* (Hydrological-hydrochemical modelling of the perturbations of the initial conditions due to construction of the HRL).

Objectives

The main objectives are to increase the understanding of flow and transport in fractured rock, and to evaluate experimental and modelling approaches in view of the site characterisation of granites in France.

Scope for 2000

ANDRA's contribution to the TRUE Block Scale experiment will focus on:

- Design, performance and interpretation of tracer tests with ^{3}He. This technique has not yet been used at the HRL and has the potential to easily identify diffusion processes due to the high diffusion coefficients of ^{3}He in comparison to other conservative tracers such as uranine.
- Continuation of the modelling studies concerning predicting arrival times of tracer breakthrough based on hydraulic data

ANDRA will continue with the modelling work within the Task 5 of the Äspö Task Force.

6.2.2 BMWi

Background and objectives

In addition to the research carried out in Germany for final disposal in a salt formation, the purpose of the cooperation in the Äspö HRL programme is to complete the knowledge on other potential host rock formations for radioactive waste repositories. The work addresses groundwater flow and radionuclide transport, two-phase flow and transport processes, and development and testing of instrumentation and methods for detailed underground rock characterisation. Five research institutes are performing the work on behalf of BMWi: BGR, FZK/INE, GRS, TU-BS, and TU-C.

Scope for 2000

Since 1996, a programme is carried out addressing two-phase flow and transport processes in saturated fractured rock. For these investigations an experimental site was established in niche 2/715. A series of gas injection tests was and is being performed in which the hydraulic and transport properties of the dominant hydraulic flow path were determined. Based on the experimental results, two-phase flow and transport models were calibrated and developed further. In 2000, two-phase flow dipole experiments with tracers in the water phase and in the gas phase will be conducted and modelled numerically. The current investigation phase will be concluded and the final report will be written. In order to eliminate the influence of the EDZ on the flow regime in the rock, tests are planned within a natural hydraulic flow field. For this purpose, boreholes about 50 m deep are to be drilled into the largely undisturbed, only slightly fractured rock in which experiments with tracered gas and water will be performed. By comparing the results of the current and the envisaged programme the influence of the EDZ can be determined.

In co-operation with KTH a project is planned to further improve the numerical tools for calculating gas-water flow in fractured porous media. The aims are to further develop the methods to describe two-phase flow processes in single fractures and to develop upscaling methods for transferring the constitutive relations from microscale to macroscale. Furthermore, data from the HRL shall be used to generate geostatistical models. In order to facilitate simulations of two-phase flow in fractured and porous media in a field scale with sufficient accuracy and acceptable computation time, the existing module MUFTE_UG will be improved by implementing advanced numerical methods. In 2000, data will be collected and an existing module will be further developed for simulating flow in single fractures and geostatistical methods will be integrated in the modelling process.

In the Prototype Repository Project electrical resistivity measurements will be conducted in boreholes and backfilled tunnel sections in order to investigate time-dependent changes of water saturation in the backfill and in the EDZ. In these investigations advantage is taken of the dependence of the electrical resistivity in rocks on fluid content, porosity, and fluid resistivity. In common hard rocks, porosity and fluid resistivity can be regarded as constant in time. In the bentonite backfill, however, the fluid resistivity may change due to chemical reactions. In order to correlate the fluid resistivity in the buffer with the fluid content, the field measurements will be accompanied by laboratory tests. In the year 2000, model calculations will be conducted in order to develop the optimal geoelectrical array configuration and, in accordance with the overall progress of the project, the arrays will be installed. Field monitoring will start as far as possible and reasonable. The laboratory programme will be launched.

An additional contribution to the Prototype Repository Project will consist of THM modelling aimed to determine transport parameters within the repository. For this purpose, available finite-element computer programmes will be used and developed further and expanded by integrating other available programmes in the system.

Model calculations continue in the Task Force on modelling of groundwater flow and transport of solutes. A large-scale numerical model of a fracture system with more than ten intersecting fractures will be developed. This model will be used to simulate the transport of substances dissolved in water and the mixing of these substances in the flow field. The chemical reactions that occur during the transport of the dissolved substances will be taken into consideration. The aim is to determine the influence of the tunnel excavation on the flow regime. A three-dimensional computer programme will be used to calculate the two-phase flow in the unsaturated zone.

Geochemical investigations were conducted aiming to improve the knowledge of the behaviour of repository-related chemical elements in the granitic rock matrices. In laboratory experiments on samples from the HRL, the potential uptake of REE, U, and Th by allanite from migrating waters containing these elements was studied. These investigations are being concluded, the final report will be issued in year 2000. In a follow-up programme, retention of typical elements in altered rock around fractures will be studied.

In another attempt, Uranium and Thorium located within the rock matrix are used as natural analogues to assess the potential transport and retention of actinides in the rock. This study utilizes isotopic disequilibria which are observed in a number of secondary carbonates located within the granite. In the final step, measurements will be carried out on the U- and Th-distribution in nine samples. The work will be concluded in March 2000 with a doctoral thesis.

Within the Radionuclide Retention (Actinides) Project the migration of long lived actinide nuclides (Np-237, Pu-244 and Am-243) will be studied in an overcored open granitic fracture using the CHEMLAB II probe. Special cells for encapsulating the bore cores containing a fracture parallel to the axis have been developed and tested. The hydraulic properties of the bore cores were studied by tracer experiments. Sorption properties of granite and of fracture filling material for the selected actinide ions have been determined from results of batch and column experiments. The required technical developments of the system and necessary laboratory experiments have been finished and field experiments are scheduled for spring 2000. In parallel, the corresponding laboratory experiments will be performed. Based on the hydraulic properties and sorption data, the migration of actinides will be modelled and compared to the experimental results.

6.2.3 JNC/CRIEPI

Background

JNC and CRIEPI join the Äspö Hard Rock Laboratory Project since 1999 and has been conducting the modelling development for groundwater flow and solute transport, the application of fault activity dating method, groundwater dating method and groundwater flow velocity/direction meter redox experiment in detailed scale and so on. Furthermore, CRIEPI was conducted groundwater sampling at the Äspö site for demonstration of groundwater dating methods.

JNC's participation will focus on the modeling development for groundwater flow and radionuclide migration, and T-H-M coupling process analysis.

CRIEPI's participation will focus on modeling and analysis of tracer tests for Task Force on Groundwater Flow and Transport of Solutes and development of the T-H-M model.

Scope for 2000

Task Force on Groundwater Flow and Transport of Solutes

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

During 2000, JNC's participation will include Task 4, flow and transport modelling for the TRUE-1 rock block, and Task 5, Hydrological-Hydrochemical Modelling at the Äspö island scale.

CRIEPI will analyze all tracer tests conducted in the type of Feature A under fixing the unit set of value for hydraulic and various transport parameters in the Task 4. In Task 5, CRIEPI will have applied the original code FEGM/FERM to the site scale groundwater flow and solute transport under the disturbed groundwater condition in tunnel excavation.

Redox Experiment in Detailed Scale

JNC will contribute to organize a seminar to spread the result from the REX project.

Prototype Repository Project

JNC and CRIEPI will participate in the Prototype Repository Project.

JNC will participate WP4f3, WP4f4, and collaborate on WP3.

During 2000, JNC will carry out coupled T-H-M analysis in WP4f3, and investigation and analysis of coupled T-H-M and chemical processes in WP4f4.

For WP3 during 2000, JNC will present comments on durability of sensors used in Prototype Repository Project and comments on some buffer properties and emplacement method. The laboratory tests will be carried out by using sensors for measurements of water content in buffer, e.g. TDR, and the data will be presented.

CRIEPI will develop the T-H-M model to simulate the multi-interacted phenomena in the engineering barrier system and will fabricate the code to simulate it.

Task Force on Engineered Barriers

JNC will participate in Task A, selection of conceptual and mathematical models and identification of the parameters these need for calculations.

Voluntary Project on Groundwater Dating

CRIEPI will collect the data to estimate groundwater residence times by measuring the dissolved He content, ^{14}C and ^{36}Cl concentration in 16 groundwater samples collected at the Äspö site in 1999.

Reporting

1) Prototype repository Project by JNC

2) Modeling and analyses performed by CRIEPI in Task 5

General

1) Participating in the information exchange meeting

2) Dispatching JNC's and CRIEPI's technical specialists
/ Mr. J. Goto (April, 2000~March, 2001)
/ short period visiting specialists (as occasion arises)

Table 6-2. Scope of international cooperation

Organisation	**Scope of participation**
Japan Nuclear Cycle Development Institute (**JNC**), Japan	Test models for groundwater flow and radionuclide migration. Contribute to organise the International REX seminar. Analyse coupled T-H-M process. Laboratory tests of water content sensors used in the Prototype Repository Project.
The Central Research Institute of Electric Power Industry, **CRIEPI**, Japan	Application of: I. Modelling and analyses for groundwater flow and radionuclides migration II. Geochemical modelling and analyses under changing groundwater flow conditions. III. Modelling and analyses of coupling phenomena in the repository system. IV. Groundwater dating methods.

6.2.4 United Kingdom Nirex Limited

Background

United Kingdom Nirex Limited (Nirex) has been supported by AEA Technology plc to provide modelling for the TRUE Block Scale Project.

Objectives

The TRUE Block Scale Project is an international project designed to:

- increase understanding and the ability to predict tracer transport in a fracture network;
- assess the importance of tracer retention mechanisms in a fracture network;
- assess the link between flow and transport data as a means for predicting transport phenomena;

Experimental Concept

The TRUE Block Scale Project is in its final phase. The project is entering the so-called ‘Predictive Stage of Tracer Testing’. This phase consists of a progressive campaign of hydraulic interference testing, point dilution measurements and finally tracer testing of progressively more reactive tracers, culminating in a series of sorbing radioactive tracers. The three phases of this stage are have been defined as Phase A, Phase B and finally Phase C. The activities this year supported by Nirex have been principally focussed on the predictive modelling of the Phase A testing. Phase A consists of five tests. The first three tests consist principally of dilution tests with different sink (abstraction) configurations. The final two consist of tracer testing.

There have been various modelling concepts used by the partners in the project. Nirex (supported by AEA Technology) are using the discrete fracture network (DFN) approach to predict the outcome of the various phases of the project.

Nirex’s modelling support has been used to develop a:

- site-model, that includes the influence of the HRL, tunnel system and Äspö island to capture the overall water balance, establish the distribution of salinity and to provide appropriate boundary conditions for sub-models;
- local scale model of the TRUE Block on a 100-500m scale to capture the features of the March’ 99 structural model (this model encompasses the current knowledge of the structures in the TRUE Block); and
- detailed subscale model to describe variability of the components (structures) of the structural model.

Site-scale model

A site-scale model has been established that includes both the discrete features of the site (fracture zones) and the distribution of salinity. The purpose of this model is to study the influence of the larger scale flows on the local scale model of the TRUE Block and provide self-consistent boundary conditions for the local scale models.

Local-scale model

A basic local model of the TRUE Block site has been constructed based on the so-called March’99 model. This includes a parameterised structural model (primarily based on transmissivity measurements arising from the pretesting of the key structures) of the basic geometrical model. This has been implemented using the DFN software NAPSAC. Figure 6-1 shows the March ’99 model with transmissivity correlation length on a 10-100m scale.

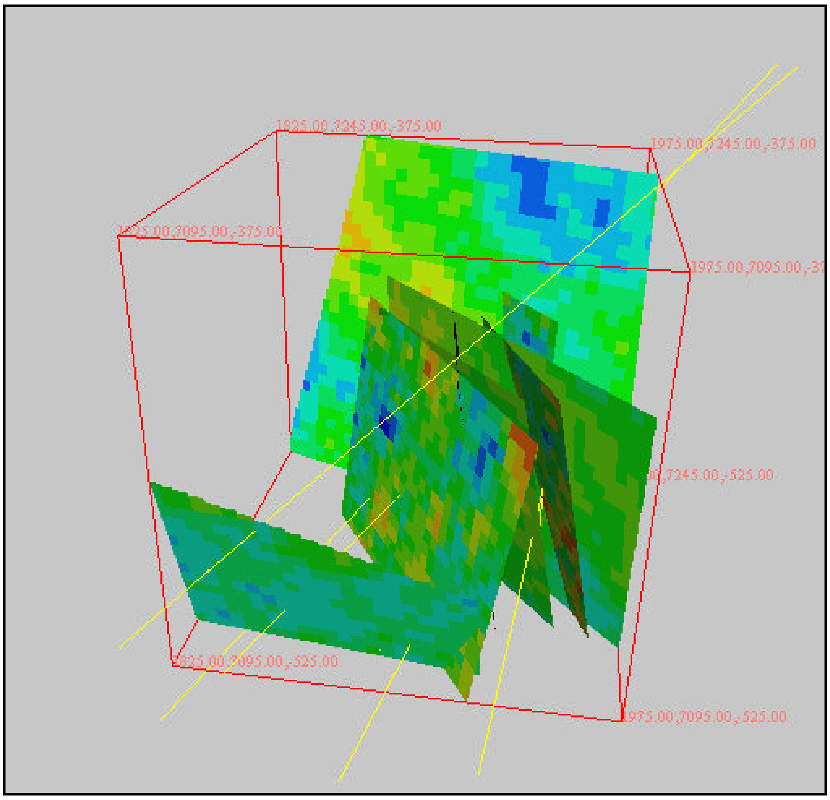


Figure 6-1 *Basic March ’99 structure model with heterogeneity in transmissivity, T on a 20m scale. The colour shading indicate the scale of variability in T.*

Detail subscale model

The discrete fracture network software NAPSAC has been used to include variability on a sub-scale to enable small-scale variability, potentially down to a scale commensurate with the dimensions of a borehole diameter, to be included. Figure 6-2 shows the results of a NAPSAC groundwater flow calculation (showing pressure contours). The underlying model has variability on the 1m length-scale with borehole KI0025F03:P5 used as a sink. Figure 6-3 shows a release of tracer travelling towards the sink, the flow channels have been removed to more easily show the dispersion of the flow paths. This has demonstrated that it is possible to perform detailed scale calculations. Work is progressing on calibration approaches and the integration of data on various length-scales.

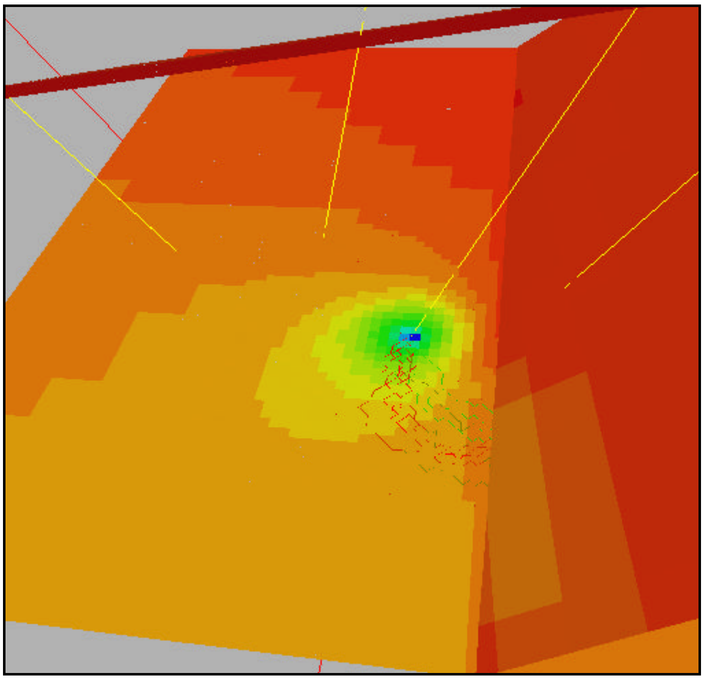


Figure 6-2 *Pressure contours showing drawdown as a result of .pumping borehole section KI0025F03:P5 with pathlines visible from a release in a neighbouring borehole. This is a result of the simulation of tracer test A-5.*

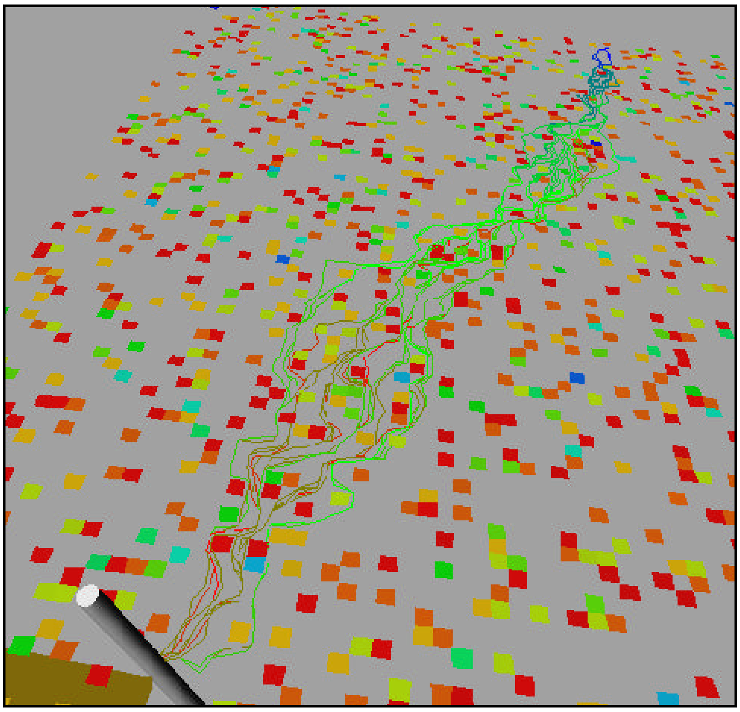


Figure 6-3 *This figure shows pathlines of particles (coloured according to time) released from a point in the feature and being received by the abstraction borehole. The flow channels (higher* $T>1.0$ ´10^{-8}*) have been removed (in the visualisation) to more easily visualise the flow in the channels. The small-scale variability is on a 10cm scale.*

Scope for 2000

Future modelling work in 2000 will concentrate on the understanding and prediction of tracer experiments performed in the TRUE Block. In particular, this will cover:

- the prediction and subsequent calibration as part of a structured testing programme;
- Phase B predictions;
- Phase C predictions.

The modelling activities will be undertaken on behalf of the TRUE Block Scale Project.

6.2.5 POSIVA

Introduction

The Project Agreement between SKB and POSIVA covers the co-operation in the Äspö HRL. The work within the Joint Project comprises three main areas:

- Detailed investigation methods and their application for modelling the repository sites
- Test of models describing the barrier function of the bedrock
- Demonstration of technology for and function of important parts of the repository system

An agreement regarding the LOT–project was attached to the Project Agreement between SKB and Posiva in August 1999. Posiva will participate in the LOT-project during the period 1999-2001.

According to a specific agreement Posiva is participating in TRUE Block Scale (TBS) experiment together with Nirex, ANDRA, SKB, ENRESA and PNC.

The following text comprises the work to be done in 2000 according to the Joint Project and the TBS agreement:

Detailed investigation methods and their application for modelling the repository sites

Applicability of different investigation methods for assessment of repository sites

Posiva conducts an investigation programme in the Laxemar KLX02 borehole by the technology used in the site characterisation programme in Finland. Details of this study are presented in the description of the Hydrochemical Stability project.

Test of models describing the barrier functions of the bedrock

Task Force on Modelling of groundwater flow and transport of solutes Tracer Retention Understanding Experiment (TRUE), Task 4

Background

Between 1995 and 1999 nearly 20 different tracer tests have been performed. Task Force modelling groups modelled eight of the tracer tests as blind modelling predictions before the experimental results were made public. Posiva provides Task Force with a modelling team from VTT.

Objectives

From Posiva's point of view this project is useful to learn more about water flow and tracer transport in a heterogeneous single fracture as a basis for flow and transport conceptualisation for performance assessment. Especially a carefully conducted set of tracer tests in a hydraulically well characterised fracture with accurately measured source terms and varied pumping conditions was expected to reveal essential features of flow and transport processes.

Experimental Concept

Tracer tests are performed in a single fracture using simple flow geometry and both conservative and sorbing tracers. Posiva's modelling team has accomplished the analysis of the STT1 (Sorbing Tracer Test) and STT1b tests and predictions of the breakthrough times in the STT2 test for the Task 4.

Scope for 2000

According to the original plan no more tracer tests will be performed in Task 4. During year 2000 modelling work of the latest (sorbing) tracer tests will be reported.

Impact of the tunnel construction on the groundwater system at Äspö – a hydrological-hydrochemical model assessment excercise, Task 5

Background

Task 5 is also part of the Hydrochemical Stability project. The detailed scope for modelling during 2000 is described below.

Scope for 2000

The groundwater flow modelling based on the M3 results formed the first part of Task 5 as regards to the contribution of VTT Energy to the modelling work. The current work concerns the integration of the hydrological model with the chemical modelling. In the present approach the geochemical end-members differ from the M3 approach, so the approximations of the geochemical boundaries have to be re-estimated.

The residual pressure and chloride fields are simulated first. In the mixing calculations the transport equations of the different groundwater types are solved using these fields.

Detailed performance measures are used for the presentation of the results. The mixing ratios calculated at the control points and at certain cut planes are compared with those from the chemical modelling.

The work is scheduled for the first months of year 2000.

Tracer Retention Understanding Experiments (TRUE) - Block Scale

Background

TRUE Block Scale experiment will be performed in network of fractures with expected transport length of 10-50 m. Posiva participates in TRUE Block Scale experiment according to specific agreement on co-operation between ANDRA, Nirex, ENRESA, PNC and SKB.

Objectives

From Posiva’s point of view this project is useful to learn more about water flow and tracer transport in a network of fractures. This provides a basis for flow and transport conceptualisation for performance assessment.

Experimental concept

The experiment is designed to study transport of tracers in a network fractures. The intended target volume is a cube with size about 50 m. The experimental volume has been investigated by six boreholes. Based on the structural model suitable fractures in the experimental volume have been isolated by packers. Tracer experiments will be performed between the intersected fractures so that a couple of different fractures can be expected to be active in the tracer test.

Scope for 2000

During year 2000 the TRUE Block Scale Experiment reaches the tracer test phase. It is estimated that the main retardation process taking place in the natural flow conditions of the deep underground repository is matrix diffusion. In this case the interaction between the migrating species and surrounding rock is controlled, not only by the retardation and diffusion properties of the rock matrix, but is also governed by the flow rate over unit width of the flow channel (and, of course, on the length of the flow path). Matrix diffusion-like behaviour is possible in relation to the stagnant areas of the flow field or fault gauge. Posiva’s approach is to predict the breakthrough of the tracer using flow rate information from tracer tests and dilution tests.

Hydrochemical stability project

Background

Posiva and SKB initiated in 1997 a common project with the aim to investigate the hydrochemical stability of deep groundwater in crystalline bedrock. At present this project is carried out within the Äspö agreement between SKB and Posiva. It also covers the technical parts of the participation in the EC EQUIP (Evidences from Quaternary Infillings for Palaeohydrology) project and the modelling Task 5 within the framework of the Äspö Task Force for modelling of groundwater flow and transport of solutes.

Objectives

The project aims at clarifying the general hydrochemical stability of importance for the site performance. Important questions concern the understanding of the critical groundwater parameters, such as redox parameters and salinity, and processes influencing and controlling them. The processes affecting them presently form the basis for evaluation of future evolution and stability. The aim is to form a "conceptual model" for hydrochemical evolution at Äspö over the next 100 000 years, which will form a basis for a methodology to describe the hydrochemical evolution at any candidate site in Sweden and Finland, e.g. Olkiluoto.

Subprojects conducted within the frame of the project are:

- Modelling groundwater evolution
- Re-sampling and analysis of groundwater from KLX02
- Chemical characterisation of groundwater in very low conductivity rock

Experimental concept

The modelling strategy is based on the process identification for Swedish and Finnish sites, geochemical mixing modelling for Äspö and Olkiluoto, site intercomparison with PCA analysis, including also M3 and NETPATH modelling for Olkiluoto. Hydrologic modelling for Äspö and Olkiluoto is included with inclusion of the results from Task 5. Task 5 is an integrated effort to describe the transient groundwater flow and chemistry situation during the tunnel construction.

The aim of the joint SKB/POSIVA measurements of the deep borehole KLX02 at Laxemar is to demonstrate Posiva´s new flow measurements and sampling techniques and to compare the results with earlier measurements from this borehole. The overall goal is to increase the information from deep saline groundwater in Sweden and Finland. The equipment used is the Difference flowmeter for hydrogeological determination of the flow situation including also the EC-electrode (to be used for the estimation of TDS), and the PAVE equipment for groundwater sampling.

Groundwater sampled from Äspö and sites in Finland has been collected from water conducting fracture zones with hydraulic conductivity greater than $K = 10^{-9}$ ms^{-1}. As rock of low hydraulic conductivity ($K< 10^{-10}$ ms^{-1}) constitutes the major volume of bedrock mass in any granite body, matrix fluids are suspected to contribute significantly to the salinity of deep formation groundwater. The main objectives of the matrix fluid project is to determine the origin and age of the matrix fluids, to establish whether present or past diffusion processes have influenced the composition of the fluids, to derive a range of groundwater compositions for the near-field, and to establish the influence of fissures and small-scale fractures on fluid chemistry in the bedrock. The experiment has been designed to sample matrix fluids from predetermined, isolated borehole sections in the borehole KF0051A located in the F-tunnel at depth of 450 m at the Äspö HRL. Detailed studies of the drillcore material (fluid inclusions, interstitial and intragranular fluids) form an essential part of the project.

Scope for 2000

The Modelling Tasks are carried out in accordance with the modelling plan and focus on the final report March 2000. The reporting includes evaluation of sites, similarities and differences, consideration of climatic changes and their effects on hydrodynamics and hydrogeochemistry and approaches to model these changes. The expected outcome is evaluation and implications for repository performance and assessing of the hydrochemical stability in candidate sites. VTT is actively involved in the reporting.

A progress report on the matrix experiment is scheduled for February 2000. Kivitieto from Finland will participate in the intercomparative study on characterisation of fluid inclusions. These studies will be reported by the end of 2000. The present plan is to continue the investigations up to the end of 2000.

According to the present timetable the Task 5 project will be reported in the middle of 2001. VTT from Finland will finalise their inverse mass-balance modelling of the hydrogeochemical data set from the Äspö tunnel. A report is scheduled for March 2000. The combined approach, a hydrological model based on the inverse geochemical model is also scheduled for March 2000.

EQUIP is an EC project with the aim of tracing palaeohydrological evidence from fracture infillings from different sites in Europe. The project is to be reported by the end of February 2000.

KLX02 PAVE samplings were successfully conducted from four depths in 1999. Posiva was responsible for the field measurements and PAVE samplings. The reporting of the field measurements, gas and microbe analyses is scheduled for the spring 2000. The difference flow measurements were partly run in 1999. In the year 2000 two campaigns has been planned, including also measurements in detailed mode in order to test possibility of studying individual fractures and detailed flow logging and EC-measurements in the entire borehole.

Demonstration of technology for and function of important parts of the repository system

Prototype Repository

Background

Posiva is a member in SKB’s group proposing a project called “Prototype Repository” for EU’s 5th framework programme. The Prototype Repository is an experiment to test and demonstrate SKB’s final disposal concept, which has several common features with Posiva’s concept.

Scope for 2000

Assuming that the project will be launched Posiva will participate in several Work Packages. Work done for the Work Package 1 and 2 will be mainly review work. Work Package 4 includes participation in the planning and follow-up of water analyses. Geochemical modelling of the near-field bedrock, close to the buffer and backfill tunnel interface is planned. Also hydraulic tests will be performed.

Long Term Test of Buffer Material (LOT)

Background

Posiva’s task is to study groundwater and bentonite porewater chemistry within the LOT-project. The task will be carried out by VTT Chemical Technology.

Objectives

The aim of the work to be carried out by VTT Chemical Technology is to obtain data of the chemical conditions to be developed in bentonite considering the effect of the temperature, additives and rock fractures. The study gives information about the chemical processes occuring in bentonite, but also supports the other planned studies in respect of the chemical conditions.

Scope for 2000

The development work of the measurement and analysing methods for bentonite and bentonite porewater has been underway in the year 1999. The work will be completed and the results reported during the first quarter of the year 2000.

Excavation of the parcel A0 is scheduled for the beginning of the year 2001. Detailed planning and preparative work will be carried out during 2000.

Characterisation of excavation disturbance around full-scale experimental deposition holes

Background

In the deep repository, bedrock in the excavation-damaged zone adjacent to the walls of deposition holes for waste canisters may provide a potential pathway for the transport of groundwater and radionuclides. Rock characteristics in the excavation-damaged zone may play a role in saturation of the bentonite buffer and in gas release.

Experimental concept

The excavation disturbance caused by boring of the experimental full-scale deposition holes was characterised in the Research Tunnel at Olkiluoto. Characterisation was carried out by using two novel methods: the ^{14}C-PMMA and He-gas methods. Both of the measurement methods have been in continuous use in 1999 and the work has included development of both the measuring and interpretation techniques in order to study disturbance caused by boring with mini discs, a technique used in the Äspö Hard Rock Laboratory.

Scope for 2000

The final reporting of the work is going on and shall be finished in 2000.

In situ failure test

Background

The stability of the deep repository is of great importance from the point of view of both safety and constructability. For the rock to be failed, fracturing must occur and result in an unstable situation. A significant component of progressive failure is the fracture propagation. The development of computers and associated modelling programs has made it possible to model the process of fracture propagation.

Objectives

The general objective of the in situ failure test is to assess the applicability of numerical modelling codes and methods to the study of rock failure and associated crack propagation in larger than laboratory scale.

Experimental concept

In the in situ failure experiment, a hole cored in one of the full-scale deposition holes will be broken by using an artificial stress field large enough to cause failure. After the failure test the observed patterns of failure and the results obtained from the computer model will be compared and evaluated.

Scope for 2000

The study is in progress and a preliminary field test followed by the final in situ failure test and the characterisation of the failure shall be carried out in 2000.

Study of blast damaged samples from ZEDEX tunnel

Background

When excavating using drill and blast technique a zone of damaged bedrock will appear adjacent to the surfaces of the deposition tunnels. The zone of damaged bedrock is a possible pathway for water flow and the consequent migration of radionuclides from the deposition holes. Both the structure and the properties of this zone are of interest.

Experimental concept

Samples have been taken from the ZEDEX tunnel and studied by using the ^{14}C–PMMA technique.

Scope for 2000

The work will be reported in 2000.

6.2.6 Sandia

A framework for cooperative work between the United States and Sweden is provided by the "Agreement Between the U.S. Department of Energy and the Swedish Nuclear Fuel and Waste Management Company Concerning a Cooperative Program in the Field of Radioactive Waste Management". In 1998, specific collaborative activities were initiated with respect to experimental and modeling work being done at Äspö. This specific collaboration was initiated by the signing of a bilateral agreement between the U.S. Department of Energy Carlsbad Area Office [DDOE/CAO] and SKB.

An implementing agreement between Sandia National Laboratories [SNL] and SKB was signed in September, 1998. Much of the work accomplished in 1999 was done under the three tasks outlined in this agreement. The work accomplished in 1999 included: 1) numerical modeling of the TRUE tracer tests along with participation in the Äspö Task Force on Groundwater Flow and Transport Modeling, 2) experimentation with techniques for examining diffusion in low porosity rocks, and 3) initiation of a transport code comparison to understand differences in upscaling transport parameters to the PA scale.

The three tasks defined in the technical planning memorandum are discussed in detail below. Participation in the 3rd Äspö International Seminar including presentation of two WIPP papers.

Task 1: Modeling of TRUE-1 results with multirate model

Background

A recent development in the modelling of solute transport in fractured rocks has been the consideration of multiple rates of mass transfer in the predictions of solute movement. This "multirate" model has been applied successfully in modelling the results of several non-sorbing tracer tests conducted at the WIPP site (New Mexico, USA). In this application, a classical single-rate model could not reproduce the observed mass-recovery curves.

Objectives

The multirate model has not previously been applied to the results of a sorbing tracer test in fractured rock. Work begun in late 1998 and continued through 1999 applied the multirate model to the results of the TRUE-1 tracer tests. These tracer tests included both non-sorbing and sorbing tracers. Parameter estimation applied to the observed results of the STT-1 and STT-1b tracer tests proved that the multirate model is fully capable of describing solute transport in Feature A of the Äspö site. A conceptual model defining matrix blocks of variable size, mylonite, altered diorite, and fault gauge is a plausible conceptualization of the geologic environment in Feature A. The variable geometry and mix of materials gives rise to a distribution of mass-transfer rates (diffusion and sorption).

Experimental Concept

In the multirate model, the various mechanisms that transfer solute mass between the matrix and the fracture systems can be conceptualized as a continuous distribution of rates each with a corresponding capacity in the matrix. Multiple rates of mass transfer may occur at Äspö due to the presence or absence of fault gauge, variations in the weathering of the host rock, variations in the mineralogy along the fracture walls, etc.

Results

Results of this work in 1999 indicate that the multirate model is fully capable of describing the mass transfer processes occurring within Feature A. A match of the multirate model to several tracers from the STT-1 tracer test is shown in Figure 6-4. A report on the application of the multirate model to the STT-1 tracer tests has been published as a SKB International Cooperation Report (ICR) (McKenna, 1999). Blind predictions of the STT-2 tracer test results have also been completed. Draft reports of the STT-1 tracer test estimation and the STT-2 blind prediction have been submitted to SKB for review.

Task 2: Visualization of Diffusion Processes in Low Porosity Material

Background

The Flow Visualization Laboratory at Sandia National Laboratories has developed state of the art X-ray transmission techniques for visualizing and quantifying the movement of solutes in rock samples. These techniques have been used successfully to visualize the migration of solutes in rock fractures and the surrounding matrix for the Yucca Mountain (Nevada, USA) and WIPP (New Mexico, USA) nuclear waste repositories. This method is also being tested on lower porosity Kurihashi granodiorite, (Kamaishi Mine, Japan). However, it is anticipated that a different experimental technique will be needed to visualize the migration of solute in very low-porosity rocks.

Objectives

The objectives of this task are to develop a technique for visualizing mass transfer in low-porosity rocks such as the Äspö granodiorite. Once a technique has been developed, the goal will be to design and run appropriate visualization experiments for the Äspö rocks.

Experimental Concept

Quantitative visualisation of the movement of solutes in rocks samples is a valuable tool for understanding potential retardation processes in the transport of radionuclides. Extension of these techniques to very low-porosity environments could prove to be very useful to nuclear waste management programs.

Results

In 1999, it was decided to run the experiments using synchrotron source microtomography at Argonne National Laboratories. The synchrotron at the Advanced Photon Source (APS) at Argonne is 1.1 km in circumference and has an energy of 7 GeV. This is the highest energy synchrotron in the United States and one of only three in the world. A high- energy, monochromatic x-ray beam is needed to penetrate the cores on which we will run our experiments.

To date, we have run two scoping-phase experiments at Argonne (Table 6-3). Both experiments used 9 mm diameter cores. In the first experiment, dry cores were imaged and in the second, the cores were saturated with CsCl prior to imaging. During the first scoping experiment it was determined that the pore space could be observed in the Äspö diorite samples. We were also able to visualize the difference between mafic and felsic minerals (Figure 6-5). During the second scoping experiment we determined that the CsCl could enhance the visualization of pore space. For these experiments the cores were imaged at two different energies (35.8 and 36.2 keV). The two different energy levels bound the absorption edge of Cs, since Cs will absorb the x-rays at the higher energy, but not at the lower energy level. By differencing the two images taken at different energy levels, one can subtract out the solid material and visualize the pore space (Figure 6-6). For the first and second round of experiments the voxel size was 18.5 µm and 21.6 µm on a side, respectively.

We are presently designing experiments to be imaged at the synchrotron to help visualize the connectivity of pores, the relation of different mineralogy to porosity, and visualize diffusion in the cores.

Table 6-3. Summary of scooping experiments that have been run.

Date	*Core Information*	*Preliminary Questions*	*Answers*
June, 1999	9 mm dry core	Can the x-ray beam penetrate the sample?	YES, at a beam energy of 40 keV we were able to image the cores.
		Can the pore space be visualized?	YES, pore space was visualized in certain cores (see Figure 1).
September 1999	9 mm core saturated with CsCl	Can CsCl enhance the visualization of the pore space?	YES, pore space was visualized in rocks samples where pore space was not seen in the dry cores (see Figure 2).
		Is CsCl a suitable tracer?	YES
		What is the detection limit of Cs?	Appears to be somewhere between 10 g/L and 100 g/L. More work needs to be done to investigate the detection limit further.

Task 3: Scaling of Transport Parameters

Background

Both SKB and SNL are faced with the task of scaling transport parameters measured in laboratory experiments and in field tracer tests up to the time and length scales of performance assessment.

Objectives

Objectives for this task are to examine defensible means for upscaling transport parameters to the performance assessment scale. Work began in 1999 on comparison of the SKB performance assessment transport code, FARF-31, to the SNL multirate transport code, STAMMT-L.

Experimental Concept

Initial work will involve numerical simulations to determine the sensitivity of solute transport at PA time and length scales to different transport parameters. Initial results will focus scaling efforts to parameters and critical regions of joint parameter space that matter to PA results.

Results

An initial comparison of the FARF-31 and STAMMT-L codes was completed in late 1999. This comparison was completed for a 1000 meter travel distance with 2 different radionuclides. This comparison has raised some additional questions regarding the differences in implementation of effective transport parameters at the performance assessment scale in the two different codes. Additional work to answer these questions is underway.

Work funded under the WIPP project in 1999 is also being used in this study to focus scaling efforts to parameters and critical regions of joint parameter space that matter to PA results. Results of this work indicate that under typical time and length scales, characterisation of the mass-transfer capacity of the aquifer is more critical than characterising the variability in mass-transfer rates.

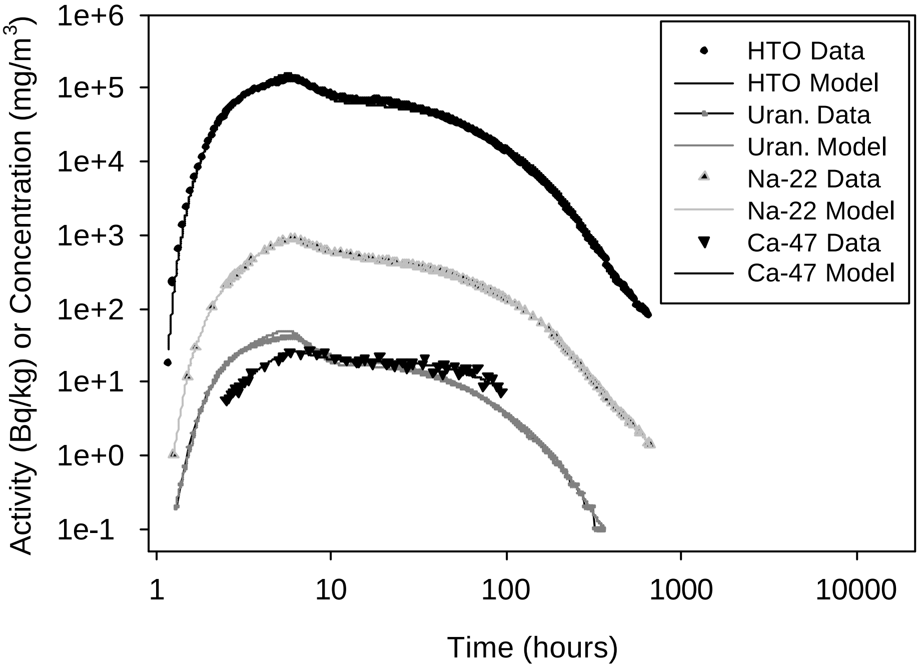


Figure 6-4 *Multirate model matches to data collected on four different .tracers in the STT-1 tracer test.*

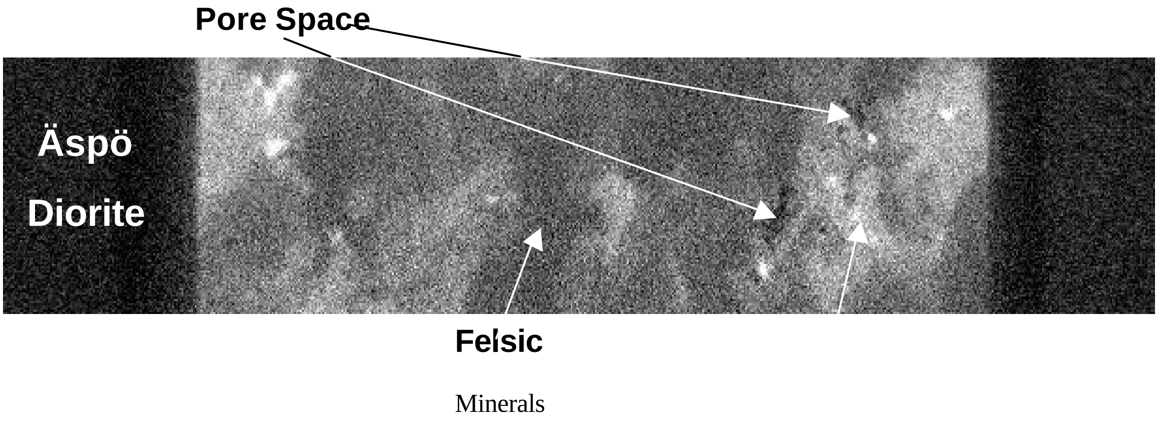
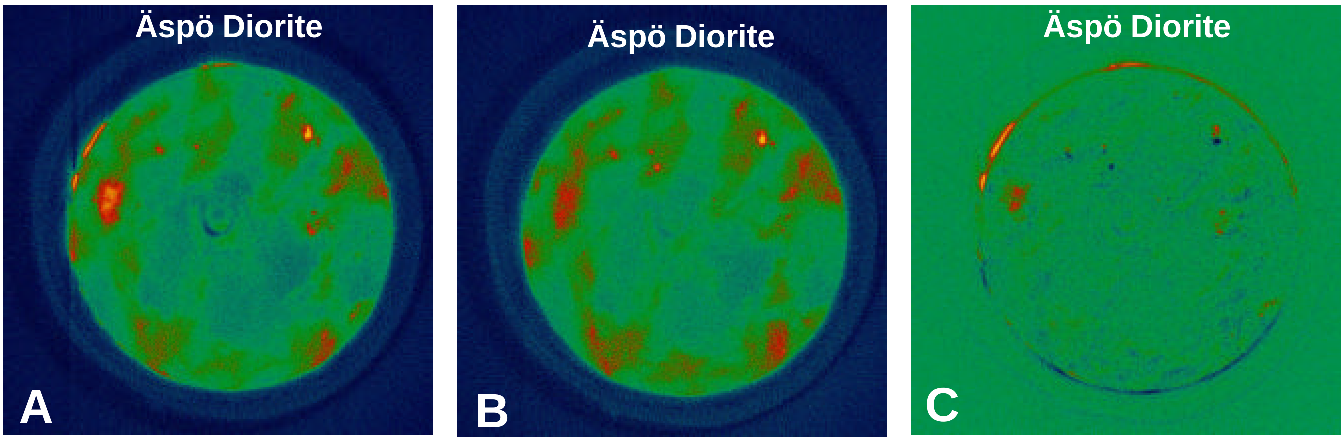


Figure 6-5 *Two-dimensional slice from tomographic reconstruction of a 9 mm core .from first scoping experiment. Voxel size of images is approximately 19 mm on a side, however resolution has been lost in converting file to a jpeg file. Both pore space and differentiation between felsic and mafic minerals are possible to visualize in this image.*



36.2 keV **35.8 keV** **36.2 keV – 35.8 keV**

Figure 6-6 *Two-dimensional slice from tomographic reconstruction of a 9 mm core from second scoping experiment. Images A-B were taken on the Äspö diorite at the two different energy levels noted. Image C is the image calculated from subtracting the 35.8 keV image from the 36.2 keV image. Pore space (red) is clearly visualized for the Äspö diorite.*

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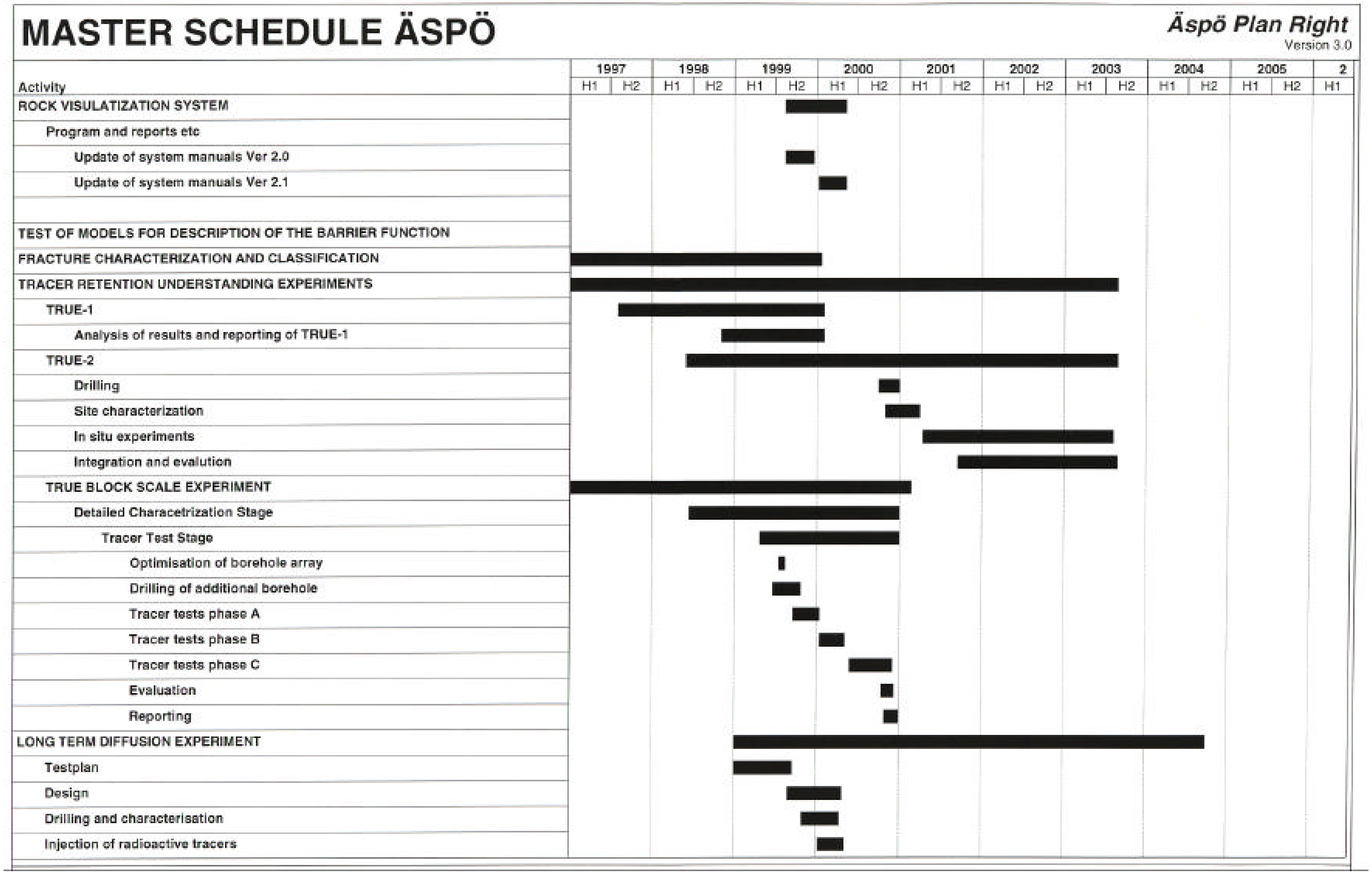
Appendix A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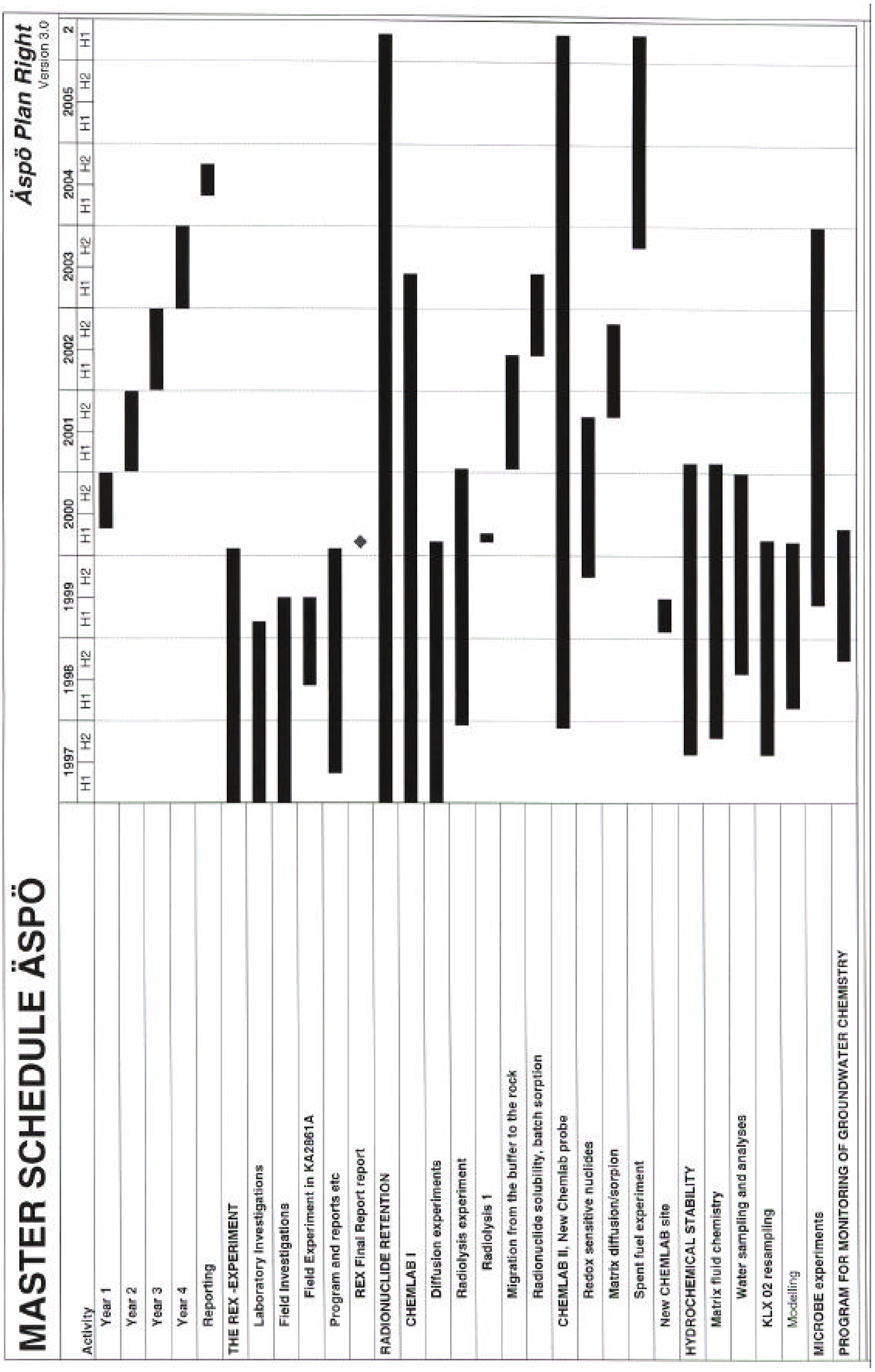
2
H1
H2
ROCK VISULATIZATION SYSTEM
Program and reports etc
Update of system manuals Ver 2.0
Update of system manuals Ver 2.1
TEST OF MODELS FOR DESCRIPTION OF THE BARRIER FUNCTION
FRACTURE CHARACTERIZATION AND CLASSIFICATION
TRACER RETENTION UNDERSTANDING EXPERIMENTS
TRUE-1
Analysis of results and reporting of TRUE-1
TRUE-2
Drilling
Site characterization
In situ experiments
Integration and evalution
TRUE BLOCK SCALE EXPERIMENT
Detailed Characetrization Stage
Tracer Test Stage
Optimisation of borehole array
Drilling of additional borehole
Tracer tests phase A
Tracer tests phase B
Tracer tests phase C
Evaluation
Reporting
LONG TERM DIFFUSION EXPERIMENT
Testplan
Design
Drilling and characterisation
Injection of radioactive tracers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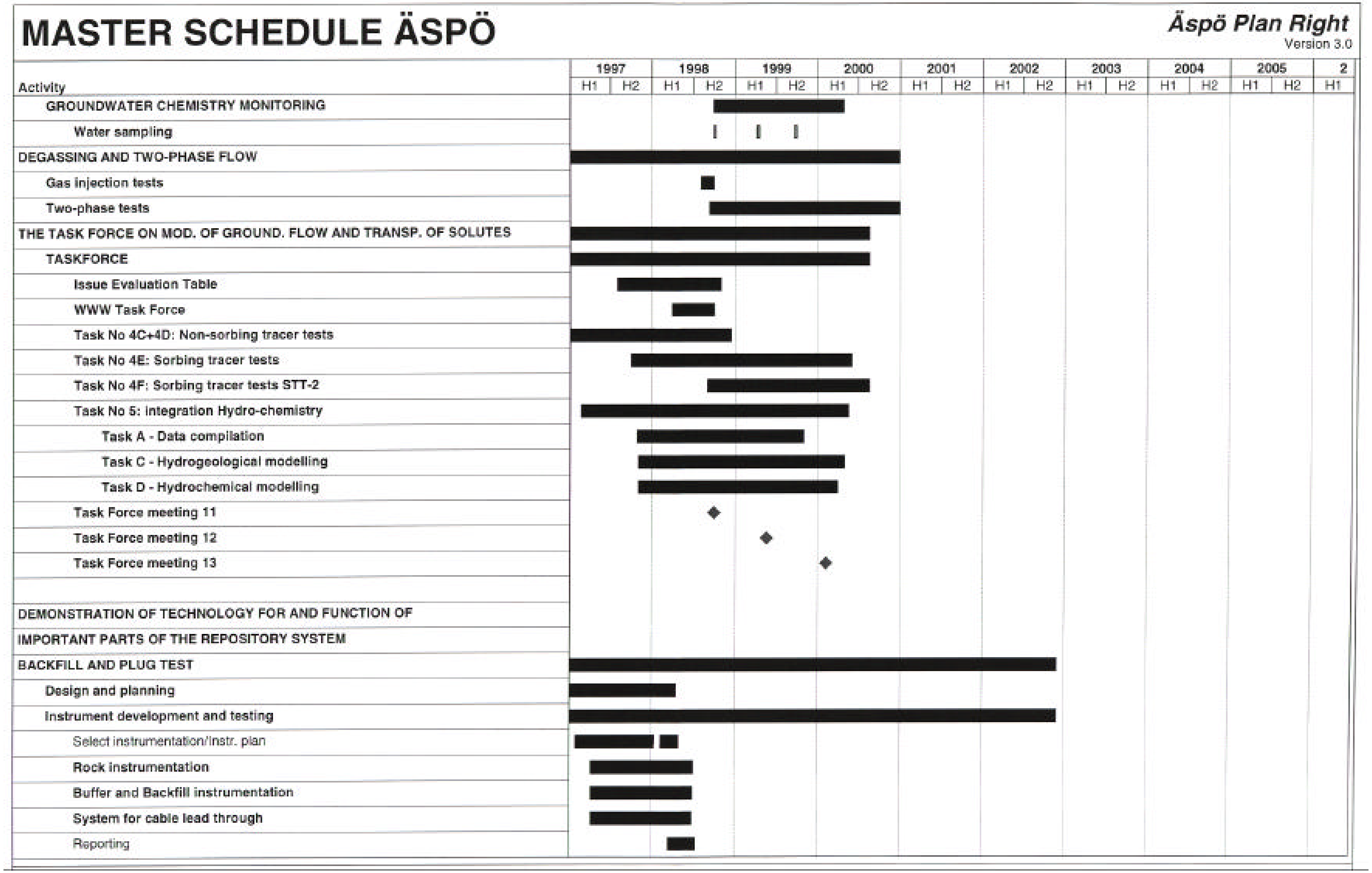
Year 3
Year 4
Reporting
THE REX -EXPERIMENT
Laboratory investigations
Field investigations
Field Experiment in KA2861A
Program and reports etc
REX Final Report report
RADIONUCLIDE RETENTION
CHEMLAB I
Diffusion experiments
Radiolysis experiment
Radiolysis 1
Migration from the buffer to the rock
Radionuclide solubility, batch sorption
CHEMLAB II, New Chemlab probe
Redox sensitive nuclides
Matrix diffusion/sorpion
Spent fuel experiment
New CHEMLAB site
HYDROCHEMICAL STABILITY
Matrix fluid chemistry
Water sampling and analyses
KLX 02 resampling
Modelling
MICROBE experiments
PROGRAM FOR MONITORING OF GROUNDWATER CHEMISTRY


MASTER SCHEDULE ÄSPÖ
Äspö Plan Right
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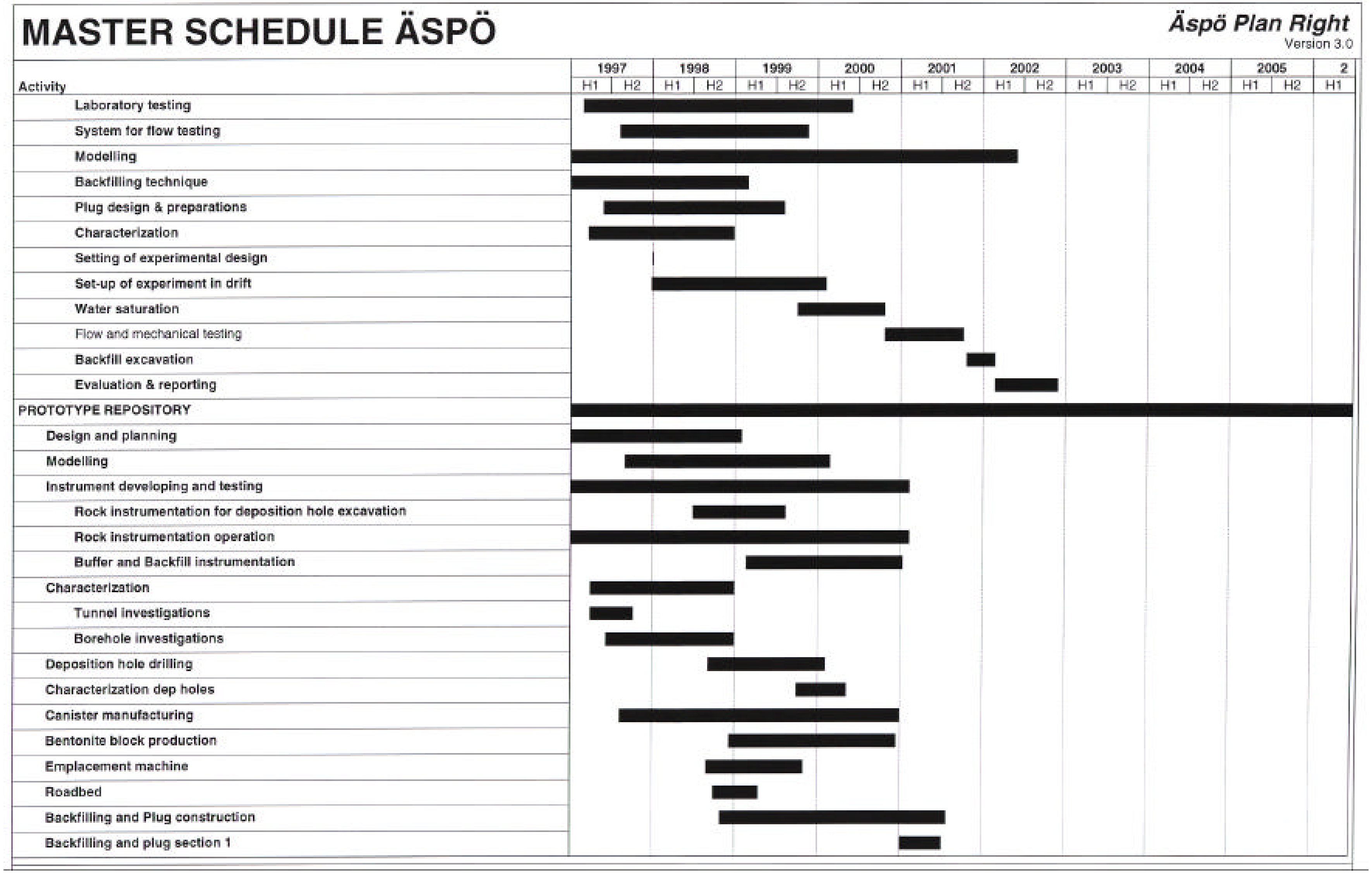
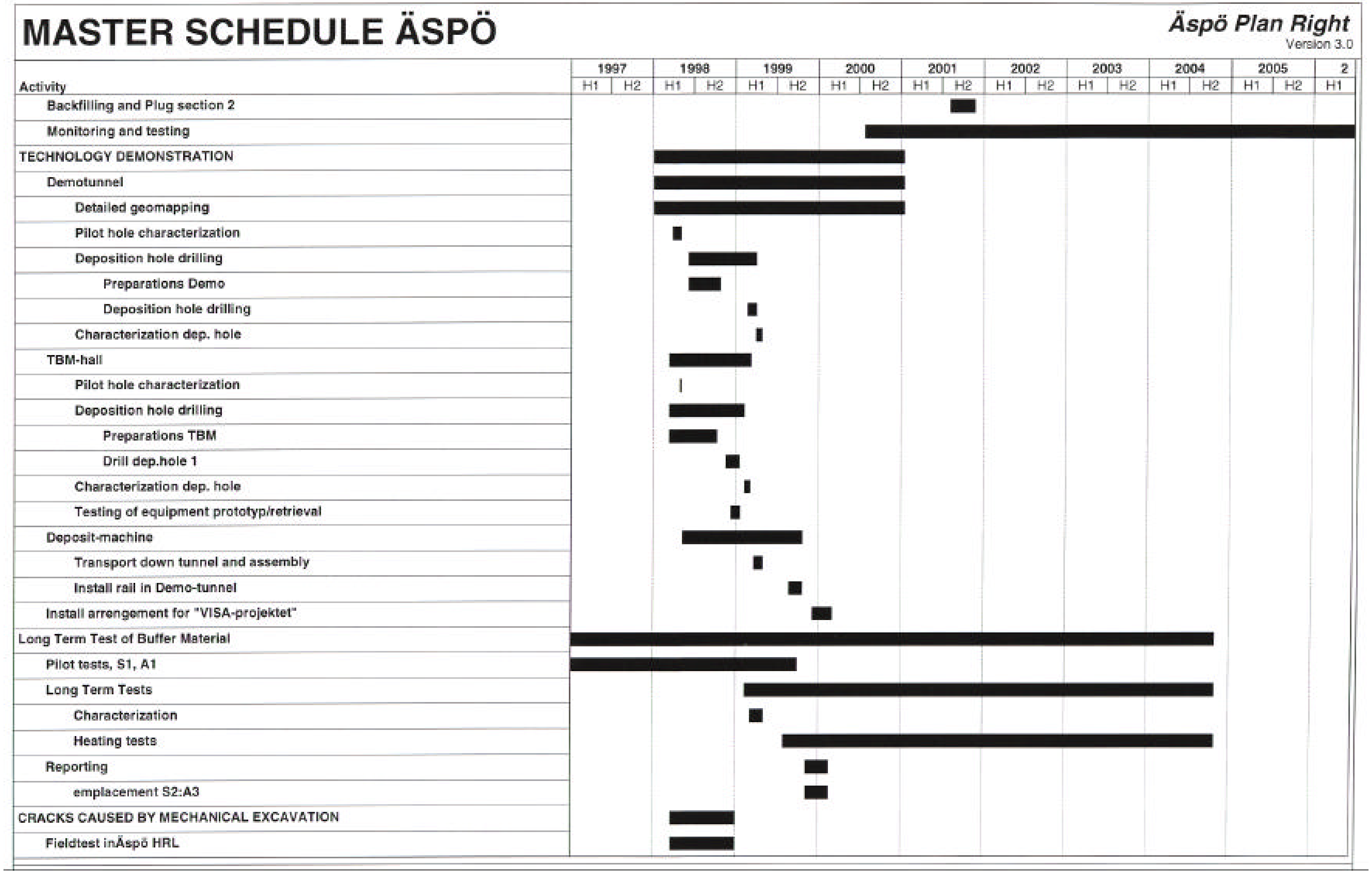
GROUNDWATER CHEMISTRY MONITORING
Water sampling
DEGASSING AND TWO-PHASE FLOW
Gas injection tests
Two-phase tests
THE TASK FORCE ON MOD. OF GROUND. FLOW AND TRANSP. OF SOLUTES
TASKFORCE
Issue Evaluation Table
WWW Task Force
Task No 4C+4D: Non-sorbing tracer tests
Task No 4E: Sorbing tracer tests
Task No 4F: Sorbing tracer tests STT-2
Task No 5: Integration Hydro-chemistry
Task A - Data compilation
Task C - Hydrogeological modelling
Task D - Hydrochemical modelling
Task Force meeting 11
Task Force meeting 12
Task Force meeting 13
DEMONSTRATION OF TECHNOLOGY FOR AND FUNCTION OF
IMPORTANT PARTS OF THE REPOSITORY SYSTEM
BACKFILL AND PLUG TEST
Design and planning
Instrument development and testing
Select instrumentation/instr. plan
Rock instrumentation
Buffer and Backfill instrumentation
System for cable lead through
Reporting


MASTER SCHEDULE ÄSPÖ
Äspö Plan Right
Version 3.0
Activity
1997
1998
1999
2000
2001
2002
2003
2004
2005
2
H1
H2
Laboratory testing
System for flow testing
Modelling
Backfilling technique
Plug design & preparations
Characterization
Setting of experimental design
Set-up of experiment in drift
Water saturation
Flow and mechanical testing
Backfill excavation
Evaluation & reporting
PROTOTYPE REPOSITORY
Design and planning
Modelling
Instrument developing and testing
Rock instrumentation for deposition hole excavation
Rock instrumentation operation
Buffer and Backfill instrumentation
Characterization
Tunnel investigations
Borehole investigations
Deposition hole drilling
Characterization dep holes
Canister manufacturing
Bentonite block production
Emplacement machine
Roadbed
Backfilling and Plug construction
Backfilling and plug section 1


MASTER SCHEDULE ÄSPÖ
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Version 3.0
Activity
1997
1998
1999
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2001
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2003
2004
2005
2
H1
H2
Backfilling and Plug section 2
Monitoring and testing
TECHNOLOGY DEMONSTRATION
Demotunnel
Detailed geomapping
Pilot hole characterization
Deposition hole drilling
Preparations Demo
Deposition hole drilling
Characterization dep. hole
TBM-hall
Pilot hole characterization
Deposition hole drilling
Preparations TBM
Drill dep.hole 1
Characterization dep. hole
Testing of equipment prototyp/retrieval
Deposit-machine
Transport down tunnel and assembly
Install rail in Demo-tunnel
Install arrengement for "VISA-projektet"
Long Term Test of Buffer Material
Pilot tests, S1, A1
Long Term Tests
Characterization
Heating tests
Reporting
emplacement S2:A3
CRACKS CAUSED BY MECHANICAL EXCAVATION
Fieldtest inÄspö HRL

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