International
Progress Report

IPR-99-04

Äspö Hard Rock Laboratory

Planning Report for 1999

January 1999

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19

Äspö Hard Rock
Laboratory

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THE ÄSPÖ HARD ROCK LABORATORY,
Planning Report for 1999

This report provides a detailed description of the planned work for 1999 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.

A reorganisation has been made of SKB in order to provide a better 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. 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 1999 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 1999. Some main activities for 1999 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. During 1999 an updating of the geoscientific models of Äspö HRL will be initiated. The updated model will cover the last tunnel spiral from the level of 340 m down to 460 m.

The basic development of an advanced interactive visualisation system for interpretation of data and design of a repository (Rock Visualisation System) was completed when Version 1.0 was delivered and put into use in November 1997. Development of the RVS system will continue based on experiences from the use of the system within several SKB Projects.

Different methods for characterisation from underground excavations and boreholes will be tested and evaluated.

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.

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 1999 the goals are to complete the first detailed scale experiment (TRUE-1), complete the characterisation for the block scale experiment (TRUE-Block Scale) and initiate the matrix 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 1999 diffusion experiments will be completed and experiments including effects of radiolyses will start. A second CHEMLAB unit will be used for experiments with redox sensitive nuclides and transuranics also starting during 1999.

The detailed scale redox experiment (REX) focusses on the issue of what will happen to the oxygen that is trapped in the tunnels when the repository is closed. This experiment will be completed and reported during 1999.

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 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.

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 will be finished, the tunnel backfilled, and the plug to seal the drift constructed. Then water saturation will start.

During 1999 the characterisation work of the rock mass in the area of the Prototype Repository will be completed. Boring and characterisation of the six deposition holes in the Prototype Repository will be made during the year.

Four full-scale deposition holes will be drilled for the demonstration project. The deposition machine will be delivered during the year. Testing and demonstration of the deposition of full size canisters will begin.

Two full-scale deposition holes will be drilled for the purpose of testing technology for retrieval of canisters after the buffer has become saturated. These holes will also be used for comprehensive studies of the drilling process and the rock mechanical consequences of drilling the holes.

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 will 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.

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).

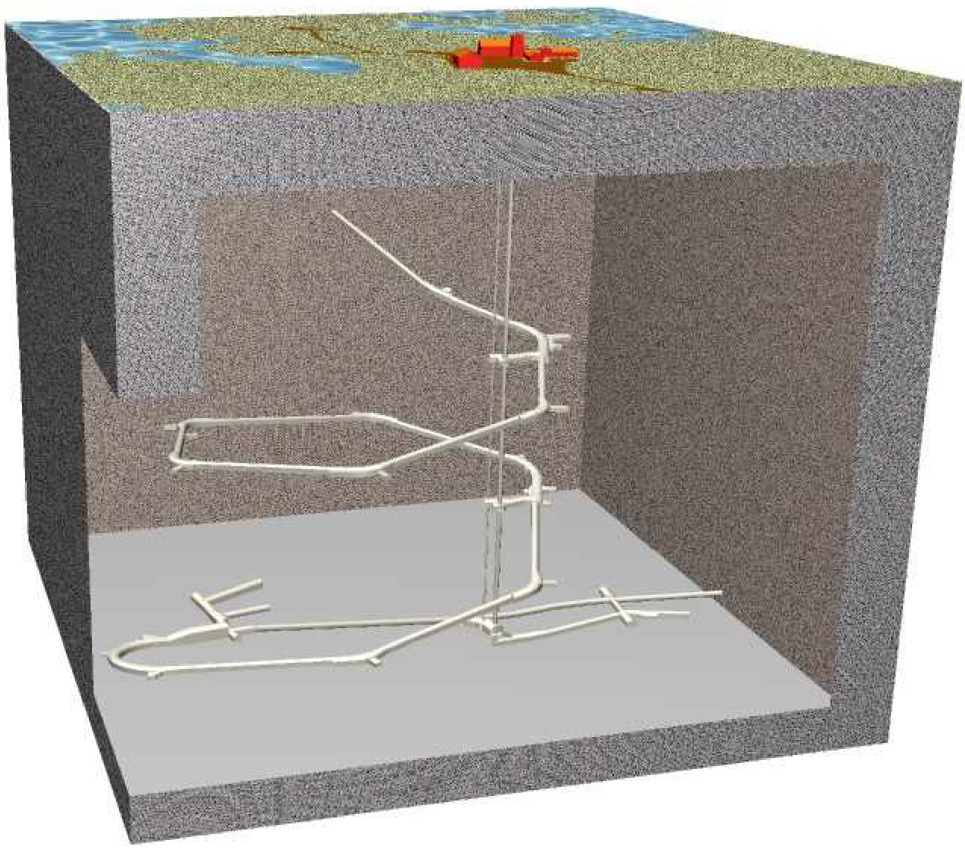

Figure 1-1 *Overview of the Äspö Hard Rock Laboratory Facilities.*

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 1998. 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.

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.

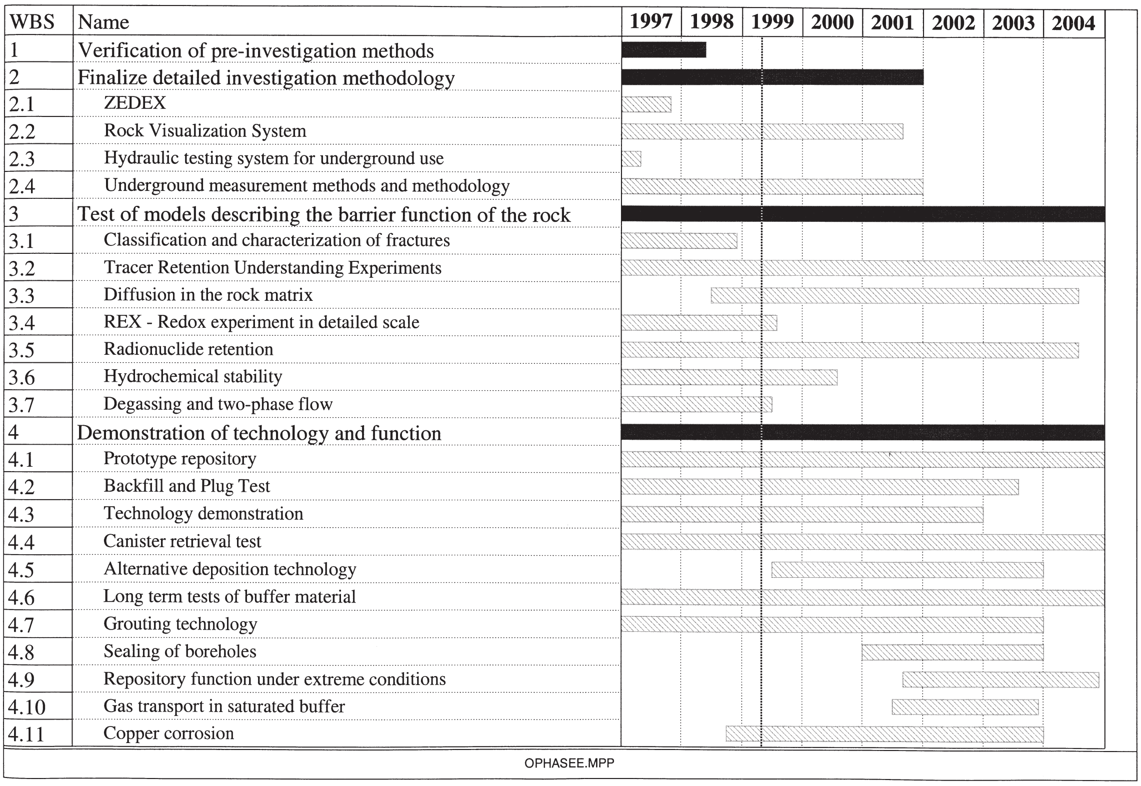

Figure 1-3 *Overview schedule for the Operating Phase of the Äspö Hard Rock Laboratory.*

1.3 Organisation

1.3.1 SKB's organisation

A reorganisation has been made of SKB that became effective on July 1st 1998. The reorganisation has been made in order to provide a better 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

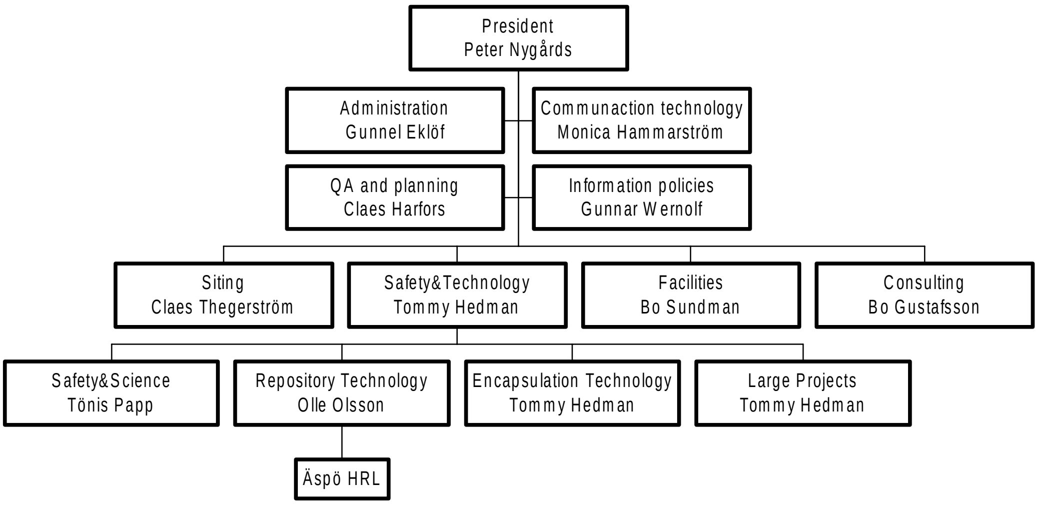

Figure 1-4 *Organisation of SKB valid from July 1st 1998.*

SKB has been organised into four divisions corresponding to SKB's main tasks. These are Siting, Safety and Technology, Facility Operations, and Consulting services. There are four support units for Communications Technology, Information policies, Quality systems and planning, and Administration (Figure 1-4).

All research, technical development, and safety assessment work has been organised into one department, Safety and Technology, in order to improve co-ordination between the different activities. The Safety and Technology department has been 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 constructions 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. They are also responsible for the further development and administration of SKB's geoscientific database, SICADA.

– 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.

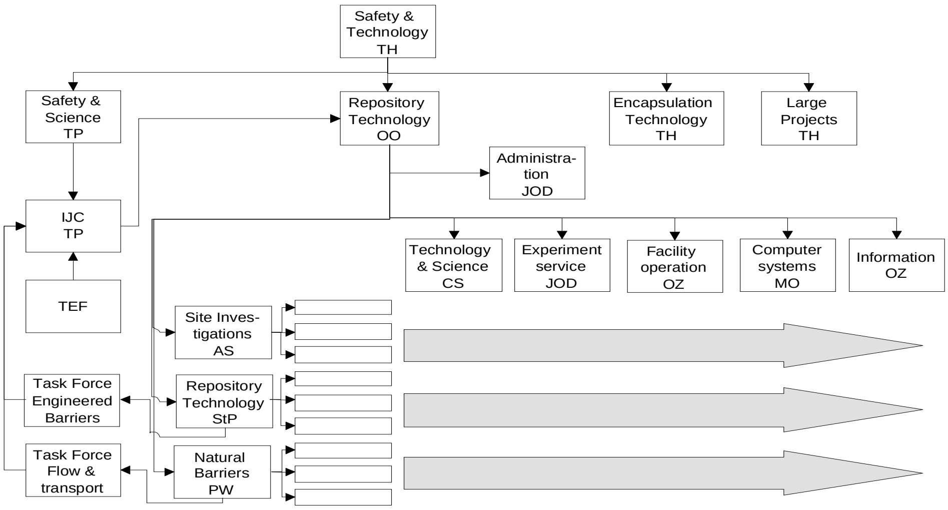

Figure 1-5 *Organisation of Repository Technology.*

1.3.3 International participation in Äspö HRL

The Äspö Hard Rock Laboratory has so far attracted considerable international interest. As of February 1999 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 1998).

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 Force on modelling of groundwater flow and transport of solutes

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.

1.4 Formulation of experimantal 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.

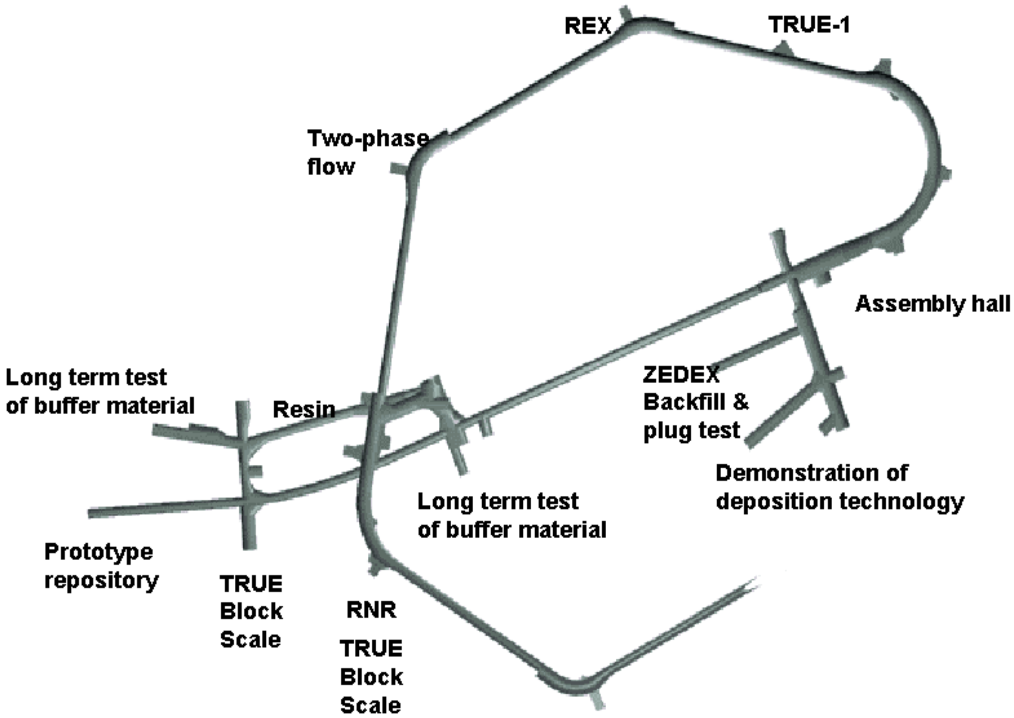

Figure 1-6 Underground excavations at the 300-450 m levels and current allocation of experimental sites.

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 Repository Technology
Äspö International Cooperation Report	Contributing organisation	Director Repository Technology
Status Reports (Short summary of work covering each 3 month period)		Director Repository Technology
International Progress Reports	Project Manager	Director Repository Technology
Technical Documents	Author	Project Manager

1.7 Quality assurance

1.7.1 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, procurement, 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).

1.7.2 Objectives/Scope 1999

SKB is investigating the prequisites to become certified according to the ISO 9001 and ISO 14001 standards.

In addition to the SKB-HLK, for each major project will have a separate QA-manual by the end of 1999. The QA-manuals will contain basic information on preconditions, routines etc with the aim of applying the quality system of the Äspö HRL according to prescribed instructions.

Instructions for Quality plans, which are guiding the activities such as field investigation, data evaluation, error reporting, etc. have been revised.

More emphasis will be put on environmental and safety aspects as well as performing risk assessment on the execution of activities. The quality control of the results/data is receiving increased importance.

A routine for the application of general conditions has been developed which is integrated in the acquisations and purchases during 1999.

Administrative prescriptions for the execution of work performed by contractors has been developed.

The intention is to make the Äspö Handbook available on SKB:s Intranet during 1999. (The Handbook covers issues of descision-making, procedural instructions, manuals etc to guide the works pertaining to quality assurance and environmental issues at the Äspö HRL.)

The software application for time and resource management in MS Project called Äspö Plan Right was customized for project management at the Äspö HRL, will be upgraded to Project 98 and more functions will be installed.

1.8 Information and public relations

1.8.1 General

Communicating information about the Äspö Hard Rock Laboratory is an important and integral part of Äspö HRL work. This information must be formulated in accordance with SKB's overall communication policy, which means that the information about the Äspö HRL shall be accurate, comprehensible, candid and up-to-date.

Numerous target groups can be defined, e.g. the general public, the municipality, the county administration, OKG, the nuclear regulatory authorities, participating organisations from other countries etc. An important task is also to communicate information within SKB and to everyone involved in the work, whether on the site or elsewhere.

The general public normally receives information via the mass media in connection with major events at Äspö HRL. Visitors to the Äspö research village are offered an opportunity to visit the tunnel down to a depth of 460 m below ground.

Local authorities are regularly contacted and informed on the progress of the investigations.

A "Newsletter" is published once every third month or so to furnish up-to-date information to persons closely associated with the project (consultants, contractors, communications officers, SKB's internal staff).

The landowner, OKG, has appointed a special liaison officer (Mats Lundgren).

1.8.2 Organisation

Within the Oskarshamn municipality, SKB has three facilities in operation (Äspö Hard Rock Laboratory, CLAB and the Encapsulation Laboratory) and a feasibility study is in progress for evaluating the suitability of siting the deep repository in Oskarshamn. In order to co-ordinate information and communication activities in Oskarshamn, the information group at the Äspö HRL has got new responsibilities.

Since most of the visitors SKB receives want to see facilities in Oskarshamn the administration of visitors to all SKB facilities will be carried out from Oskarshamn by the information group. During 1999 the information group will continue with guided tours of CLAB. In co-operation with the SKB information division the group will also take part in the preparation of information material about the facilities and SKB's activities in Oskarshamn.

1.8.3 Scope of work

- A general video about Äspö HRL will be produced and published during 1999 as well as a video about safety underground.
- In order to file photos about Äspö HRL and different activities a new library will be developed.
- A new system for making reservations for groups visiting SKB's facilities will be developed.
- A new homepage on Internet which contains more information about the feasibility study will be installed.
- Most of the exhibitions will be updated due to the new graphic profile and new activities.

1.8.4 Special events

Every spring an ”Äspö day” is arranged and in 1999 it will take place in May. Staff from the site office will serve as guides on Äspö and in the tunnel. The public is invited via advertisements in the local newspapers and several hundred people normally show up. The arrangement is very popular and has become something of a local tradition.

Another arrangement for the general public is the summer tours. Theese are arranged in co-operation with OKG and Figeholm Taxi. During two months, mid June to mid August, tourists and others interested in our work have the possibility to see the facility and get information about SKB's activities. Last year (1998) during the summer almost 900 visitors toured the underground facility.

1.8.5 The VISA project

The main aim of the VISA project is to get acceptance for SKB's R & D program in order to find a site for the deep repository. It is important that politicians, the general public in communities where SKB performs feasibility studies, students etc. have the possibility to see demonstrations of repository technology in a realistic environment. The VISA-project is an important information project in which SKB will show the different steps in spent fuel management and at the same time communicate relevant information about SKB's activities.

The information tour is planned to start at Simpevarp and after a short introduction the visitors will be transported by bus down to the underground part of Äspö HRL. After a guided tour underground the visitors will take the elevator up to Äspö village.

An entrance building will be built during 1999 as part of the VISA project. It will serve as a meeting place where an introduction will be given to the information tour. The VISA tours will start during the second period of 1999.

2 METHODOLOGY FOR DETAILED CHARACTERIZATION 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. During 1999 an updating of the geoscientific models of Äspö HRL will be performed.

2.2 Underground measurement methods and methodology

2.2.1 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.

2.2.2 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.

2.2.3 Scope for 1999

A report on underground investigation methods used during the construction phase of the Äspö HRL will be published early 1999. 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). The technique may also be tested for mapping the deposition holes to be drilled as part of the Prototype repository project.

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 1999 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.

2.3 Updating of the geoscientific models of Äspö HRL

2.3.1 Background

Some basic research that is not project-related is conducted at the Äspö HRL. This work is aimed at providing support for the research, development and demonstration projects by conducting and comparing measurements of common interest for all projects. According to SKB's planning, the suitability of geological formations for deep disposal of spent nuclear fuel will be evaluated with the aid of geoscientific models of the site in question, including:

- geological model,
- geohydrological model,
- groundwater chemical model,
- geomechanical model,
- heat transport model,
- radionuclide transport model.

These models are compiled in conjunction with a site investigation and present an aggregate of existing knowledge on a site.

On Äspö, geoscientific information has been systematically collected during the pre-investigation and construction phases. Data continues to be collected from the various tests and projects that are being conducted. The information that has been gathered up to now and including completion of the main tunnel down to a level of 450 metres has been used to devise site-specific models of the conditions on Äspö. The models contain dimensionality, material properties, method for specification of properties in the whole model, boundary conditions, numerical or mathematical tools, and what parameters the model depicts (Olsson et al., 1994). Structure and content are described in greater detail in Rhén et al. (1997). The purpose of constructing these models has primarily been to verify our ability to foresee the properties of a rock mass on the basis of information from completed site investigations.

The existing geological, geohydrological and groundwater chemical models of Äspö will gradually be revised, particularly in the light of the new information that is constantly obtained from the projects described later. A test plan for this modelling exercise, which is given the name GeoMode, will be presented early 1999. The rock mass to be modelled cover the last tunnel spiral from the level of 340 m down to 460 m.

A geomechanical model, heat transport model and a radionuclide transport model will also be developed but outside the GeoMode project.

2.3.2 Objectives

The aim of the GeoMode project is to develop tools for constructing geological, geohydrological and groundwater chemical models as a basis for the different experiments to be conducted at Äspö HRL. The goal is to construct an integrated model until Late 2000. The second aim is to define bounding conditions for the experiments. A third aim is to develop tools for the model construction and to increase competence in the different subjects, geology, geohydrology and groundwater chemistry.

2.3.3 Scope for 1999

The project GeoMode will start with planning and preparation of a test plan. A definition of the boundary conditions for the different subjects will be performed in early 1999. A screening of data for the different subjects will then be performed. Input of data will follow and the first visualisation will be performed in spring 1999. A first interpretation of the different subjects will follow. A visualisation of the different subjects will be presented and a progress report on the different subjects will be presented in late 1999. The report will be reviewed by experts in the different subjects and a seminar will be held.

2.4 Rock Visualisation System

2.4.1 Background

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

The experiences obtained from the investigations at Äspö HRL have shown that it is very 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.

To fulfil the above strategy and requirements SKB has developed the Rock Visualisation System. The Principal Investigators in the Äspö project and other geoscientific experts in SKB's organisation have greatly been involved in defining the functions needed in the system. The first version of RVS was delivered in November 1997

2.4.2 Objectives

The main objectives for the project is to develop an advanced visualisation system based on a commercially available CAD system that should be well integrated with the investigation database SICADA. Furthermore, the system should have the following features and properties.

- Borehole planning
- Visualisation of borehole data
- Geological modelling
- Tunnel design
- Animation
- Drawing
- Data import/export
- Interaction with MicroStation User's in the organisation (import/export of DGN-files)
- Data traceability (data versions)
- Model traceability (model versions)
- Construction traceability (tunnel layout versions)

2.4.3 System concept

The Rock Visualisation System is based on the CAD-system MicroStation 95 including MicroStation Modeler and MicroStation QuickVision. MicroStation is a modern and powerful 3D-modeling system developed by Bently Systems Inc in U.S.A, and is running on computers with the most common operating systems as DOS, Windows, Windows 95, 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 database engine (MS/Access) 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 if another database engine 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 visualisations of background data)

– Model project (Containing modelled 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 assigned 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. An example of that is shown in Figure 2-1. By using the *object selector*, an unique feature in the system, objects can be turned on (visible) or off (not visible).

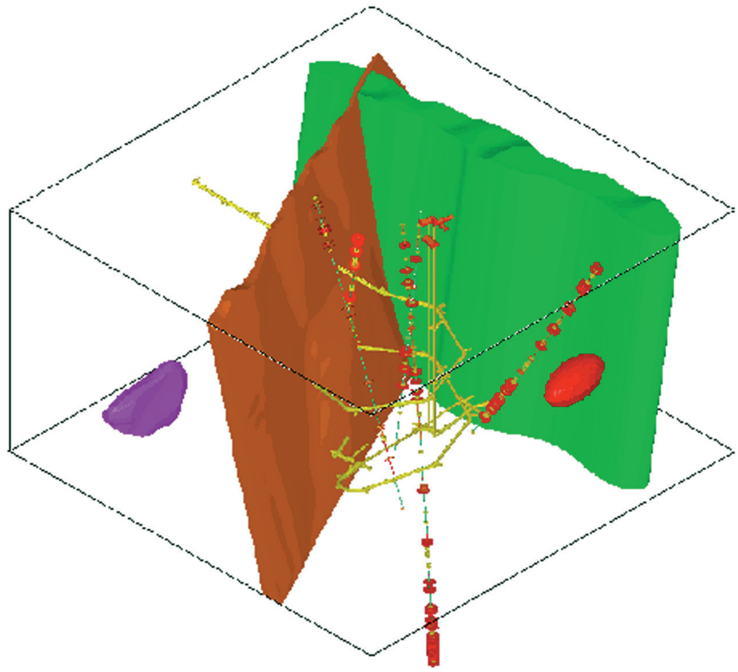

Figure 2-1 *Objects can be turned on (visible) or off (not visible), by using the object selector. The rock mass visualised in this case includes visible objects of several types including borehole data, modelled objects (a fracture zone in brown, a lens in red and two arbitrary rock bodies in purple and green) and construction objects (tunnels in yellow).*

From the users point of view the system can be divided in five program modules, namely:

– Borehole Visualisation

– Modelling

– Tunnel design

– Animation

– Drawings

An overview description of these parts were described in the Planning Report for 1998. Hence, the reader is advised to read the previous report if more information about these program modules is wanted.

2.4.4 Scope for 1999

The development plan is mainly driven by the experiences reported by the users during 1998. One of the most highlighted needs of change concerns the surface modelling tool in the system. The problem is that a modelled surface, plane as well as undulating, is forced by the system to be terminated against the model boundary, but the users want this to be a user defined capability. The system allows a surface to be terminated against any arbitrary solid object, but first the surface itself and the termination surface must be converted to solids. This work flow is not accepted by the users.

The problem described is a consequence of a limitation in the current version of MicroStation 95. Boolean operations in MicroStation 95 requires that each object involved is described by the rules of the ACIS (acronym based on the names of the original programmers) standard. ACIS is a solid modelling engine composed of a library of C++ functions developed by SPATIAL TECHNOLOGY INC. The ACIS library is linked to MicroStation 95.

We are happy this time to present an easy solution of the problem, because the latest version of MicroStation (called MicroStation/J) is not dependent on ACIS anymore. ACIS has been exchanged by the Parasolid surface and solid modelling engine. Hence, the conversion of RVS from MicroStation 95 to MicroStation/J has the highest priority during 1999. There is no meaning to do any refinements of the system before this work has been completed. The plan is to be ready with this phase in April 1999. The new version of RVS based on MicroStation/J will have the version number 2.0.

Version 2.1 is planned to be tested and released before July 1999 and will include:

– A new surface modelling tool based on *Parasolid*

– A set of minor and major refinements of existing functionality

During 1999 we also plan to:

– realise an already specified method specialised on visualisation of pressure transients in arbitrary number of existing borehole sections while drilling a new borehole. By using this tool it should be easier to interpret how observed discontinuities along boreholes are interconnected to each other.

– introduce a new technique for visualisation and interpretation of anomalies obtained by seismic profiling from surface and radar measurements along boreholes.

– start programming interfaces to different numerical software packages (e.g. groundwater flow)

– improve the capability of the local RVS database (used locally on each RVS workstation)

– reorganise the *On-line Help* by using the latest concept of Webb interfaces

– realise a long list of very useful functions defined by the users and the RVS project group during 1998.

Meanwhile RVS have been used by the consulting companies engaged by SKB, most of them have asked if it is possible to use the system when working for other client than SKB (Some users are really impressed of the capabilities available in RVS). Until now the answer is no, but during 1999 SKB will decide in what way external organisations will have the possibility to use the system in co-operation with other clients. In general it would be an advantage to distribute the system to as many users as possible, but first we need to build up an organisation to manage this new kind of situation. We also need to ensure long term assistance from the external companies that have been involved in the development of the system. To be realistic we can not distribute RVS before the On-line Help is good enough and we also need to wait for the function and improvements included in version 2.1. Hence, external use of RVS is not possible before August 1999.

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. These are 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 at Äspö.

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 1999 focus is on the sporadic high permeable features (HPF:s) which normally are not detected by remote sensing tools, e.g. borehole radar and other geophysical tools. The consequences to repository lay-out and implementation into numerical models will be assessed.

Hydrochemical stability and potential variablility 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. Of special importance are redox conditions and microbial activity, which will be reported within the REX project during 1999.

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 which 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 that occur in the nearfild and farfield. Some elements are strongly retarded while others are escaping with the flowing groundwater. The major emphasis in the safety assessment calculations has therefore been put 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 oxidized to neptonyl and pertechnetate by radiolyses 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 1999 the goals are to complete the first detailed scale experiment (TRUE-1), complete the characterisation for the block scale experiment (TRUE-Block Scale) and initiate the matrix 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 1999 diffusion experiments will be completed and experiments including effects of radiolyses will start. A second CHEMLAB unit will be used for experinets with redox sensitive nuclides and transuranics also starting during 1999.

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 1999 the outcome of this experiment will be modelled in cooperation with the GRS/BGR team.

Dilution is the third important 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 effect could be extracted from results of tracer tests. Such work is worthwhile to carry out, but has not been planned.

3.2 Numerical modelling

Laboratory model, concept

Tests of a new method to generate the hydraulic conductivity field in the finite volume code PHOENICS have been made. The starting point is a fracture network with assigned transmissivities. After the grid size is defined an algorithm calculates the hydraulic resistance in the cell walls in the finite volume model. Anisotropic conditions can rather easily be included in the model and the effective hydraulic conductivity is expected to be more or less independent of chosen cell size model.

Objectives

The method of how to generate the hydraulic conductivity field is considered as a step in the direction of a more realistic description of the hydraulic conductivity field.

Scope of work for 1999

A testplan for the numerical groundwater flow modelling during 1999-2000 will be written early 1999. The laboratory model will take the boundary conditions from the site model. The method of generating the hydraulic conductivity field reported above is used for the laboratory model. The results will be presented during spring 1999.

High Permeability features (HPF)

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 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 during drillings in the operation phase of the Äspö HRL.

During the 4th IJC/TEF meeting at Västervik in mid May 1997 it was identified as important to assess the possibility to predict fractures or features with high transmissvities at Äspö from data collected during the pre-investigation phase.

High Permeable Feature (HPF) is defined as 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.

Objectives

The objective with the current study is to:

– compile information that can be coupled to High Permeable Features at southern Äspö.

– analyse these data statistically and investigating possible correlation's between HPF and other observed features.

Scope of work for 1999

The results are planned to be presented in a report spring 1999. The analyses of HPFs will continue during 1999 in order to improve the statistics of the distances between features with a specified transmissivity range or above a defined transmissivity value.

Updating of site-scale and laboratory model

In TR 97-06 site scale and regional scale models were presented for the Äspö area. During 1999 the statistics of the HPFs (High Permeability Features) will be improved and the model of the larger conductive features in the site scale model will updated. Based on these results the site scale, laboratory model and possibly the regional model will be updated during 2000. The method used for creating the conductivity field in the laboratory model will be used in site scale and the regional models.

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 2 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 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 ongoing, is performed on a small scale, is of limited duration in time, and is primarily aimed at technology development. The 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 Experiment, has also been initiated. 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.

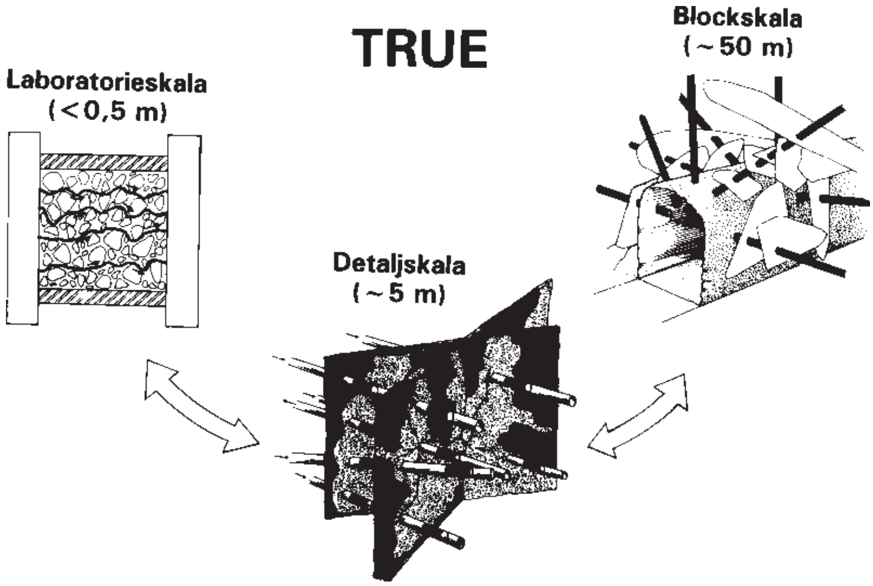

Figure 3-1 *Schematic representation of transport scales addressed in the TRUE programme*

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.

3.3.1 TRUE-1

Background

The first tracer test cycle (TRUE-1) constitutes a training exercise for tracer test technology on a detailed scale using conservative and weakly sorbing tracers in a simple test geometry, c.f. Figure 3-2. In addition, supporting technology development is performed of techniques to better understanding tracer transport through detailed characterisation of pore space distribution, as obtained from resin injection. The TRUE-1 cycle is expected to contribute data and experience, which will constitute the necessary platform for subsequent more elaborate experiments within TRUE.

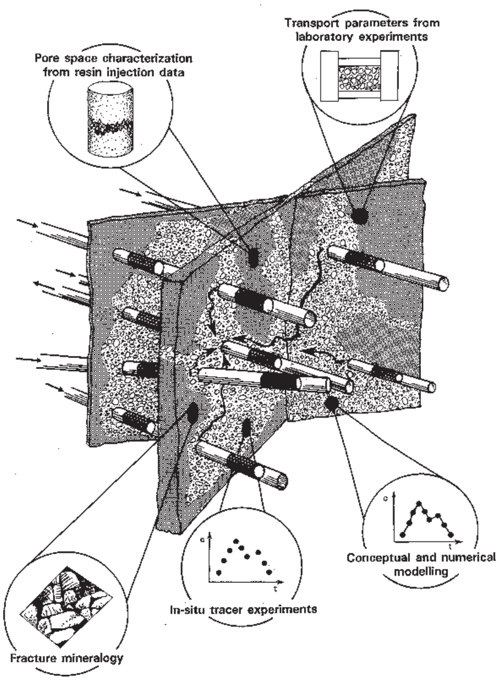

Figure 3-2 *TRUE-1: Schematic view of target fracture used for tracer experiments on a detailed scale and main experimental components.*

Objectives

The objectives of the first tracer test cycle (TRUE-1) are;

- To conceptualise and parametrise an experimental site on a detailed scale (L=5m) using conservative tracers in a simple test geometry.
- To improve tracer test methodologies for conservative tracer tests on a detailed scale.
- To develop and test a technology for injection of epoxy resin on a detailed scale and to develop and test techniques for excavation (drilling) of injected volumes, and
- To test sampling and analysis technologies to be employed in the analysis of matrix diffusion.

Experimental concept

Improved understanding of transport and retention processes in a singular feature through interactive use of site characterisation (including in-situ tracer experiments in variable flow geometry and flow paths), conceptual and analytical/numerical modelling, and supporting laboratory measurements.

Results

The performed laboratory experiments to determine distribution coefficients and diffusivities for sorbing radioactive tracers planned to be used in-situ have been reported during the year. The results are based both on generic Äspö material, Äspö diorite and Fine-grained granite, and site-specific material from Feature A, at the TRUE-1 site, see below. The basic result is that the batch experiments show that the sorption of the tracers increase in the order $Na^+ < Ca^{2+} \approx Sr^{2+} < Rb^+ \approx Ba^{2+} < Cs^+$ with a sorption coefficient of Na^+ in the order of (4-30)•10^{-6} m^3/kg and for Cs^+ in the range (1-400) •10^{-6} m^3/kg. Variations in sorption characteristics is attributed to variations/differences in geological composition, contact time and particle size. Sorption is generally found to be stronger for Äspö diorite than for Fine-grained granite, this fact attributed to the higher biotite content in the Äspö diorite. In altered material, biotite has been transformed to chlorite, with a lower sorptivity as a result. The diffusion results shows that the tracers have been retarded in the same order as indicated above for the sorption experiments. It was furthermore found that the larger size fraction from the sorption experiments, showed the best correspondence with sorption coefficient evaluated from the diffusion experiments. Effective diffusivites and transport porosities were found to decrease with increasing sample length, 1, 2 and 4 cm drill cores were used in the experiments. In addition it was found that the evaluated formation factor for sorbing and non-sorbing tracers in the same sample is approximately the same. Finally, the diffusivity and porosity for the site-specific material from Feature A was found to be lower than the generic material.

During 1995 site characterisation at the TRUE-1 site was carried out. This included drilling of five boreholes and subsequent characterisation. A reactivated mylonite, Feature A, was selected for further study. The characterisation and building of descriptive models is detailed by Winberg et al., (1996). Late 1996, SKB took the decision also to include reactive tracer tests, which originally was not included in the TRUE-1 programme.

During 1996 through 1997 a series of tracer experiments with conservative tracers were performed focused on Feature A have been performed in the instrumented array (Andersson 1996), (Andersson et al, 1997), (Andersson and Jönsson, 1997). These tests have tested different flow regimes, different source and sink combinations, serving as a preliminary exercise for the subsequent tests with radioactive sorbing tracers. It has been identified that the flow paths defined by KXTT3, KXTT4 and KXTT1 were the most suitable. These flow paths were subsequently subject to preliminary design tests (Andersson and Wass, 1998). Detailed plans for the planned experiments with radioactive traces were presented by Andersson et al. 1997.

With the PDTs as a base the first test with sorbing tracers (STT-1) was commenced in mid July, 1997 in the flow path between KXTT4 and KXTT3, pumping in KXTT3 at Q=400 ml/min. Towards the end of 1997, it was projected that a full Cs-137 breakthrough could not be expected until after about 10000 hours (420 days). Figure 3-3 shows the tracer breakthrough after about 100 hours of pumping. It was also projected that only about 30 % of the injected Cs-137 mass would be recovered. It was recommended by the project group to follow this breakthrough, and to also perform a complementary injection in KXTT1 in the same radially converging flow field. The extension of the experiment, denoted STT-1b, was commenced in early December 1997. Figure 3-4 shows the tracer breakthrough in the pumped section after 100 hours.

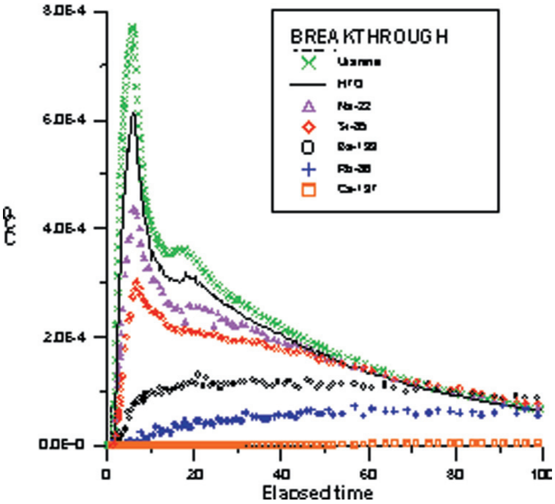

Figure 3-3 STT-1 - *Tracer breakthrough after 100 hrs in the pumping section KXTT3:R2. Injection in KXTT4:R3. Tracer concentrations are normalised to injection concentration at t=4 hours.*

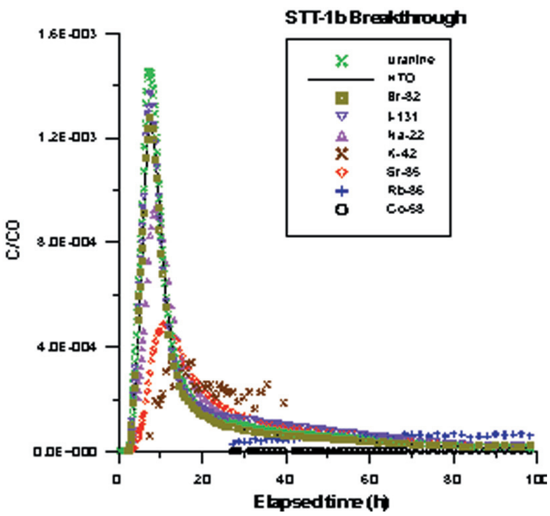

Figure 3-4 STT-1b - *Tracer breakthrough after 100 hrs in the pumping section KXTT3:R2. Injection i KXTT1:R2. Tracer concentrations are normalised to injection concentration at t=4 hours.*

In July 1994 the most recent tracer test was commenced, denoted STT-2. In this case the flow path between KXTT1 and KXTT3 was revisited, this time still using a radially converging flow field, but at a flow rate reduced from 400 ml/min to 200 ml/min. The basic set of radioactive sorbing tracers used in STT-1 and STT-1b was also employed here. This experiment is presently the subject of predictions using numerical models within the Äspö Task Force.

During the last two years an evaluation framework has been developed within the project which in a Lagrangian framework solves reactive transport in rock fractures. By solving the system of coupled equations for a single trajectory a new parameter β was derived. The latter parameter is a random quantity which integrates aperture along a flow path with the residence time ϑ as a integration variable. The parameter β controls surface sorption and diffusion/sorption into the rock matrix and allows direct account of flow heterogeneity on mass transfer. The processes accounted for in the framework are; variable advection, sorption on fracture surfaces, diffusion into the rock matrix, diffusion into stagnant water zones, and sorption into gouge material (including irreversible sorption). Results from evaluation of STT-1 and STT-1b show that diffusion is observable, that the variability in β is important, that "enhanced sorption " is observed (possibly due to gouge), irreversible sorption effects observed for Cs-137 (not conclusive), the dominant mass transfer process is sorption on surfaces/in gouge material (distinction not unique). The established approximate relationship between β and ϑ allows estimation of β for Feature A which is in the order of 0.6 m^{-1}.

During 1998, the pore space data obtained from the Pilot Resin Experiment has been analysed using two techniques, a photo microscope approach and an image analysis approach. The resulting aperture statistics based on data from the two methods show similar results. The mean aperture for the two samples are 281 and 295 µm, respectively. The coefficient of variation for the two analysed samples are 37 and 39%, respectively. Variograms based on the aperture data show practical ranges in the order of 3.5 and 5 mm, respectively.

Scope for 1999

The field work related to the First TRUE Stage has been concluded during 1998. Activities foreseen during 1999 are :

– Finalisation of evaluation and reporting of the First TRUE Stage.

3.3.2 TRUE-2

Background

In the Program for TRUE (Bäckblom and Olsson, 1994) a series of tracer experiments have been identified in the Detailed Scale. TRUE-1, cf. Section 3.3.1, has been focused on technology adaptation, investigation of experimental outcome of various flow geometries and combinations of sinks and sources. These results have consisted the basis for performing the subsequent series of tracer tests with sorbing tracers. In addition a technique has been developed and tested to assess pore space using epoxy resin.

In TRUE-2, which will constitute a second test in a detailed scale, at a new experimental site, the focus will be more on retention processes in a single fracture, their identification and discrimination. Modelling work in associated with the experiment will involve full application of the evaluation framework successfully applied during the First TRUE Stage, cf. Section 3.3.1. In addition, the time frames of the planned experiments will be such that diffusion becomes a measurable process. A tantamount feat will be to locate and characterise yet another single fracture, equitable to feature A at the TRUE-1 site.

Preceding TRUE-2, a single hole experiment aimed at demonstrating and quantifying diffusion into the rock matrix is planned to be performed in a low-permeable part of the Äspö HRL, cf. Section 3.4.

During 1998 USDOE/Carlsbad office/SANDIA/WIPP has showed an interest in participating in work within the TRUE Project. To this effect the framework for such a collaboration has been defined during the past year. The focus of this work is comparison and evaluation of multi-rate diffusion and sorption processes in different geological environments and their application to performance assessment. The work also includes an address of ways to develop visualisation of diffusion in low-porosity geological environments.

During the fourth quarter of 1998 a desktop study has been carried out with the objective of identifying suitable sites for drilling pilot boreholes within a second site selection programme, SEECT-2, the latter to be launched early 1999.

Objectives (tentative)

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

- conceptualise and parametrise an experimental site on a detailed scale (L=5m) using conservative and sorbing tracers in a simple test geometry,
- conduct tests with sorbing tracers over time scales such that diffusion becomes a measurable process,
- apply developed evaluation framework for identifying (discriminating) retention processes in the evaluation of the performed tests,
- apply the concept of multi-rate transport analysis in evaluation of the performed test
- 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 experiments on site-specific material, and specifically 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 Lagrangian and multi-rate frame frameworks. The experimental work will be completed with resin injection and evaluation of pore space.

Scope for 1999

The schedule for the start up of TRUE-2 has been postponed about a year compared to what was outlined in the Planning Report for 1998.

The first half of 1999 will be ia. devoted to a Review Meeting where the findings of TRUE-1 will form the platform for detailing the objectives and work scope of TRUE-2. This review meeting will be held jointly for TRUE-2 and LTDE, thus allowing for strengthened synergy and reducing inadvertent overlaps. Based on the review meeting, a Test Plan will be finalised.

The SELECT-2 programme will comprise 3-4 boreholes drilled at four sites defined by a preliminary study conducted during the fourth quarter 1998. The boreholes will be drilled during spring 1999.

On the basis of the outcome of the SELECT-2 programme, a site will be selected for continued study. The detailed site characterisation will be performed during the second half of 1999. Tests with conservative tests are planned to start the second quarter 2000.

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 1998 three 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, flow and pressure build-up tests. Cross-hole tests include collection and analyses of pressure responses due to drilling, cross-hole seismic surveys and cross-hole hydraulic interference tests. The latter tests included simultaneous tracer dilution tests, which enabled assessment of change in flow rate in selected packer intervals, apart from drawdown due to the pumping. One of the tests was driven long enough to obtain a positive initial assessment of the possibility to observe tracer breakthrough in a block scale network of structures.

During the course of the Preliminary Characterisation and Detailed Characterisation Stages the initial deterministic model of the major structures within the studied block has been updated three times, cf. Figure 3-5, and a fourth update is presently under way. One of the most recent achievements is definition of a structural classification scheme, which divides the identified structure intercepts in four different categories, cf. Figure 3-5. 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 northeasterly structures and three subhorizontal structures have been interpreted. The performed seismic and hydraulic cross-hole studies both show that these latter two sets are subordinate, most importantly from the hydraulic standpoint.

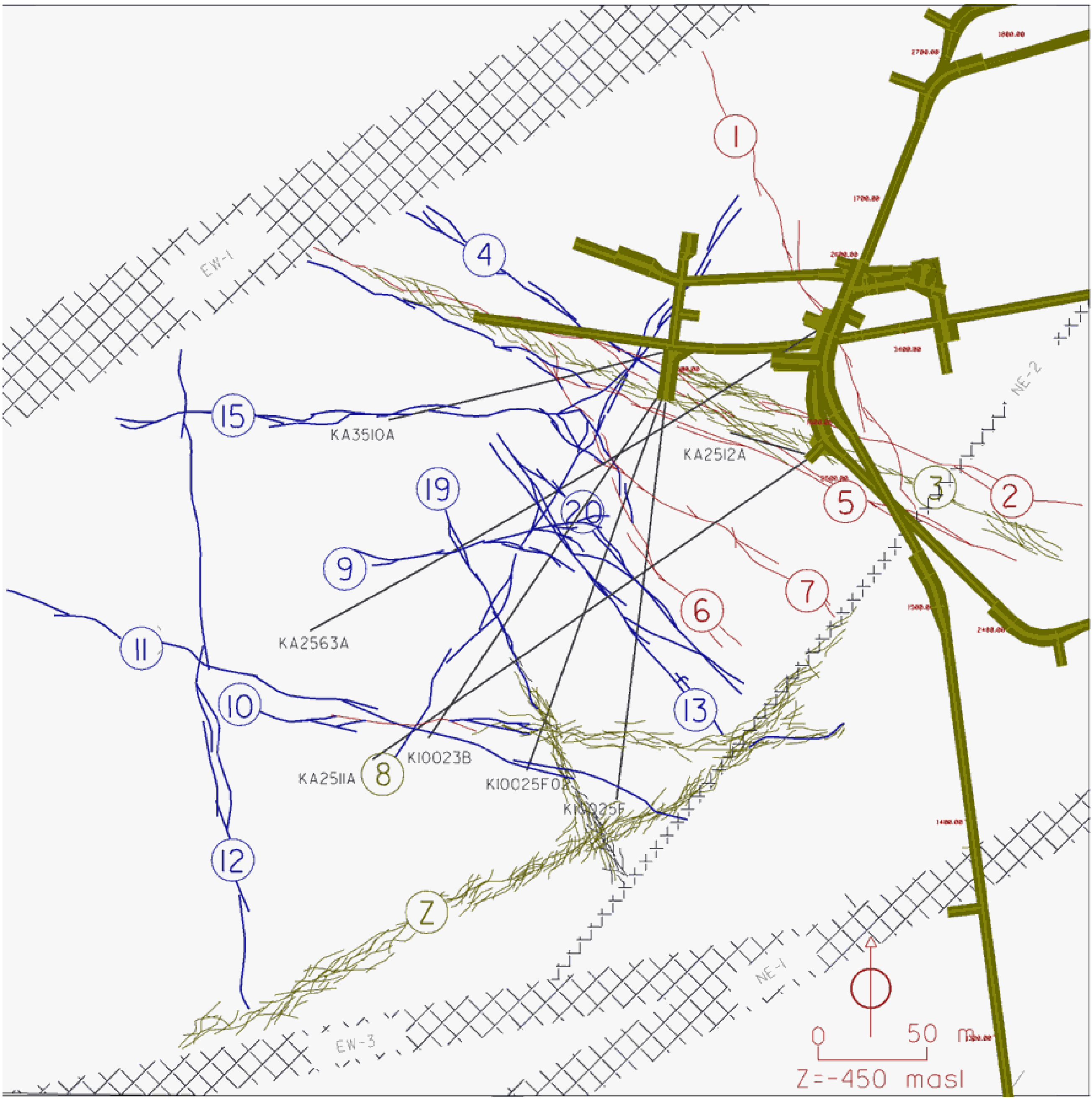

Figure 3-5 *Plan view of the Sep'98 structural-geological conceptual model of the TRUE Block Scale rock volume. The colour red represents a single fracture, blue a single fault and yellow a fracture zone. Swarms of fractures do exist but are of limited extension.*

During 1998 a hydraulic model has been built using pressure response data collected in the borehole array during drilling. I.e. no structural information has been utilised. The model has later been substantiated using existing interference test data. The developed hydraulic model is in parity with the developed structural model.

Numerical modelling has intensified during 1998 during which building of channel network and stochastic continuum models were added to the already existing discrete feature network model. The latter two models are presently being calibrated using existing cross-hole interference test and tracer dilution test data. The DFN model has also been utilised to simulate the performed tracer test.

Mineralogical and geochemical work focused the identified network for future tests is presently under way.

At a review meeting held in mid November 1998 the present understanding of the investigated block was presented. In addition the prospects for performing tracer tests in the block scale was review and discussed (Winberg (ed), in press). It was shown that;

1. an interconnected network of deterministic conductive structures has been identified that may be observed in a number of boreholes. The structures are relatively well known geometrically and structurally. Consistency in hydraulic connectivity is proven from observation of pressure responses during drilling and from hydraulic cross-hole interference tests,
2. relatively well-defined hydraulic structures have been identified which constitute the boundaries to the outlined block,
3. the transmissivity range of the structures making up the identified network is less than $7 \cdot 10^{-7}$ m^2/s,
4. a conceptual model has been developed for natural groundwater flow in the structures supported by geometrical, structural and hydraulic field data. Additional support is provided by performed numerical modelling and independent geochemical data,
5. a number of candidate sections for establishing source and sink sections for future tracer experiments are available in the existing borehole array,
6. tracer tests can be successfully performed in the identified network of structures at a length scale in excess of 16 m over reasonable time frames, as evidenced by the results from one flow path.

Scope for 1999

The following activities are planned for 1999:

- Finalisation of reporting Scoping and Preliminary Characterisation Stages
- Optimisation of instrumentation in boreholes KA2511A and KA2563A
- Complementary detailed flow logging
- Complementary tracer dilution tests
- Tracer design tests
- Definition of hypotheses to addressed by tracer tests
- Tracer tests with conservative and weakly sorbing tracers
- Continued development of numerical models

3.4 Long term test of diffusion in the rock matrix

3.4.1 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.

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 (reviewed by Ohlsson and Neretnieks 1995) and also *in situ* (Birgersson and Neretnieks, 1990). 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 is made using the multi-rate diffusion concept which accounts for pore-scale heterogeneity (Haggerty and Gorelick, 1998, Haggerty et al., in review)

A proposal for a matrix diffusion experiment (MDE) for Äspö HRL has previously been presented by Birgersson et al. (1994).

3.4.2 Objectives

The (tentative) objectives of the Long-Term Diffusion Experiment project are:

– To investigate diffusion into matrix rock *in situ* under natural rock stress conditions and hydraulic pressure and chemical conditions of the groundwater.

– To obtain data on sorption properties (and processes?) of some radionuclides on undisturbed matrix rock and on fresh granitic rock surfaces.

– To compare laboratory derived sorption coefficients of the investigated host rock with the sorption behavior observed *in situ* at natural conditions and to evaluate if laboratory scale sorption results are representative also for larger scales.

– To evaluate the impact of heterogeneous diffusion.

3.4.3 Experimental concept

A part of the Äspö Hard Rock Laboratory tunnel has been tentatively selected within which it is expected to a find large mass of low-conductive rock (i.e., rock with few fractures). A number of boreholes are planned to be drilled into this rock volume, using careful drilling techniques, including triple-tube techniques, in order to reduce damage to the host rock. It is preferable if the boreholes intersect a water conducting fracture before entering the low-conductive bedrock; this gives options to adopt the pressure and the chemical composition of that fracture water as the "natural conditions" which should be applied in the planned experiment. In the case no conductive fracture intersects the section one may be forced to use water from a neighbouring fracture with similar chemistry to fill up the section. Inflatable packers will ensure that natural groundwater pressure conditions are maintained in the packed-off section. In any case, great efforts will have to be made in order to maintain constant pressure in the borehole sections for the duration of the experiment. After borehole TV imaging and hydraulic tests in the boreholes, sections of the boreholes that are suitable for the tracer experiment will be selected, and packed off. The proposal below outlines a parallel development of an experiment involving three boreholes and the use of two different experimental approaches used in parallel. The two approaches are:

1. Injection of tracers over a four year period, observation of tracer in a nearby (0.2-0.3 m distance) observation hole followed by an over-coring of the injection hole,

2. Injection of sorbing tracers over limited time (0.5-1 year) followed by continuous flushing of the injection section with non-spiked water for an additional 3-4 years for the observation of back-diffusion of the tracers.

It is preferable if suitable sections can be identified in three different boreholes. Of these three, two should be located parallel to each other, with a distance of 0.2-0.3 m between the two sections. One of these sections, #1, should be used for the injection of tracers. The water in this section should be continuously circulated during 4 years and measurement of the tracer concentration should be conducted, either by on-line detection or by sampling. The other section, #2, should be used as an observation well; i.e., a continuous slow flushing should be performed of that section and the out-going water should be analysed in order to detect a "breakthrough" caused by the matrix diffusion process. After an experimental time of 4 years, over-coring of borehole section #1 should be performed and small diameter cores obtained parallel to the diffusion direction and cut in to small slices and analysed for their content of tracers.

The third borehole section, #3, should preferably be located some distance away from the other two. In this borehole section, injection of tracers, a closed circulation of the water and measurements will be conducted as described for borehole section #1 above. However, after a circulation time of 0.5-1 year, flushing the borehole section with non-spiked groundwater will start up and will continue for the rest of the experimental time in order to study the back-diffusion of the tracers. During the flushing procedure, analysis of the water with respect to the amounts of the natural tracers present in the matrix at the start of the experiment (e.g., He, H_2 and Ar) are also performed. Performed scooping calculations employing the multi-rate diffusion concept has shown that a natural tracer test more readily than an injected tracer experiment can serve to distinguish heterogeneous diffusion from that of homogeneous. It has also been identified that heterogeneity in diffusivity will be primarily observed in the late-time slope of such a tracer experiment with natural tracers.

In reality there will most likely be a need for making priorities between the two approaches described above, given experimental constraints (it is possible that three suitable borehole sections and/or that two parallel borehole sections cannot be found) and/or economical constraints. In such a case, a discussion has to be performed in order to determine which of the proposed experimental concepts that should given the highest priority and which one should be excluded. A review meeting planned for March 1999 will also provide an input to making such priorities. The intention is also to investigate the possibility to locate the experiment together with the ongoing Matrix Fluid Chemistry Experiment.

A detector system will continuously measure the concentration change in the water phase. By this arrangement it is possible to follow the adsorption of various radionuclides on the rock surface in the borehole section, and at the same time get a check of unexpected fast losses of any of the radionuclides. The radionuclides should be injected in small volumes in order not to cause any major influence on the natural pressure or groundwater chemical conditions. By using a loop of circulating water it is also possible to inject different radionuclides at different times. Elements which are expected to have a low apparent diffusivity due to a strong sorption should be injected first, and elements with a high apparent diffusivity should be injected later in order to keep the migrating radionuclides at a controlled distance from the injection section.

The borehole instrumentation should be as simple as possible and should be known to have a long term stability and durability. Continuous measurements of pressure and temperature should be performed in the borehole. Continuous measurements of the activity in the circulating loop should be automated similar to the on-line measurements performed in TRUE-1 experiments with sorbing radioactive tracers.

The experiment is expected to run in the field for about five years, including excavation work.

3.4.4 Scope for 1999

- Test Plan
- Continued test design
- Review meeting
- Construction of equipment
- Selection of experimental site
- Drilling
- Site characterisation
- Installation of equipment
- Check of installation
- Injection of tracers

3.5 The REX-experiment

3.5.1 Background

A block scale redox experiment was carried out in a fracture zone at 70 m depth in the entrance tunnel to Äspö. In spite of massive surface water input, the fracture zone remained persistently anoxic. The main conclusion from that study was that the increased inflow of relatively organic-rich shallow groundwater instead of adding dissolved oxygen, it added organic compounds that acted as reductants in the deeper parts of the fracture zone. These conclusions are specific to this particular fracture zone, experimental conditions and the time scale (3 years) of the experiment, but are probably also relevant for other conductive fracture zones.

The detailed scale redox experiment (REX) is focussed on the question of oxygen that is trapped in the tunnels when the repository is closed. Questions regarding the role of oxygen in this context are:

- Will oxygen penetrate into the rock matrix during construction and operation?
- If yes, how much of the rock will be oxidised and how long time will it take before oxygen is consumed?
- What happens to the oxygen in the backfill/buffer: how much is consumed by the rock, and how much by the buffer?

The REX project focuses on the first two of these questions, especially the second one. The third question is not included in the experiment.

3.5.2 Objectives

The objectives of the experiment are:

- How does oxygen trapped in the closed repository react with the rock minerals in the tunnel and deposition holes and in the water conducting fractures?
- What is the capacity of the rock matrix to consume oxygen?
- How long time will it take for the oxygen to be consumed and how far into the rock matrix and water conducting fractures will the oxygen penetrate?

3.5.3 Experimental concept

The emphasis of the project is on a field experiment involving motionless groundwater in contact with a fracture surface. To this aim a ≈200 mm borehole has been drilled in the tunnel at 2861 m. Additional field data (hydrochemical and bacteriological) are required to establish the boundary conditions for the experiments. The field study will be supported by laboratory experiments to determine oxygen reaction mechanisms and kinetics with Äspö samples (both for inorganic and microbially mediated processes). A replica experiment will be performed in France with the other half of the fracture surface obtained in the drilling procedure.

3.5.4 Scope of work for 1999

The aim of the field study is to isolate the innermost part of the borehole and to monitor the oxygen consumption as a function of time. The project is in its final phase. Oxygen injection and monitoring will be continued for the first months of 1999 followed by the interpretation of results and final reporting.

Data from experiments aimed at determining in situ oxygen consumption by microbes is being interpreted at the Göteborg University (Sweden).

The replica of the field experiment is being finalised at the CEA laboratories in Cadarache (France). The replica experiment is performed with the complementary half of the fracture surface left in the REX borehole in Äspö. This experiment also uses groundwater from the REX site.

Laboratory tests are performed to define the influence of several parameters on the capacity of minerals (with and without added bacteria) to consume oxygen. Minerals, rock samples, groundwaters and bacteria previously extracted from the Äspö site are used in these tests, which are performed at the University of Bradford and at the British Geological Survey (both in the UK). These tests will be finalised during the first half of 1999.

The results of the REX project will be used to refine the parameters needed in kinetic models of oxygen consumption in the performance assessment of a nuclear waste repository.

3.6 Radionuclide retention

3.6.1 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 reliezed from the waste form. The retention is mainly caused by the chemical character of the radionuclides themselves, 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 of 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, of organic matter, of bacteria etc. are present in the experiments. Laboratory investigations have difficulties to simulate these conditions and are therefore dubious as validation exercises. The CHEMLAB probe, see Figure 3-6, has been constructed and manufactured for validation experiments in situ at undisturbed natural conditions.

3.6.2 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 the relevant radionuclides

3.6.3 Experimental concept

CHEMLAB is a borehole laboratory built in a probe, in which migration experiments will be carried out under ambient conditions regarding pressure and temperature and with the use of the formation groundwater from the surrounding rock.

The full suite of planned experiments are:

– Diffusion of radionuclides in bentonite clay

– Migration of redox sensitive radionuclides and actinides

– Radionuclide solubility

– Desorption of radionuclides from the rock

– Migration from buffer to rock

– Radiolyses

– Batch sorption experiments

– Spent fuel leaching

3.6.4 Scope of work for 1999

A new site for the CHEMLAB experiments will be selected and installed.

In the present CHEMLAB probe the last diffusion experiment will be conducted and the entire suite of diffusion experiments will be reported. Later in 1999 similar experiments with radiolysis effects will be initiated.

A second CHEMLAB probe has been costructed and will be manufactured during the first part of 1999. The first experiments to be carried out in CHEMLAB-2 is the migration of redox sensitive nuclides and actinides.

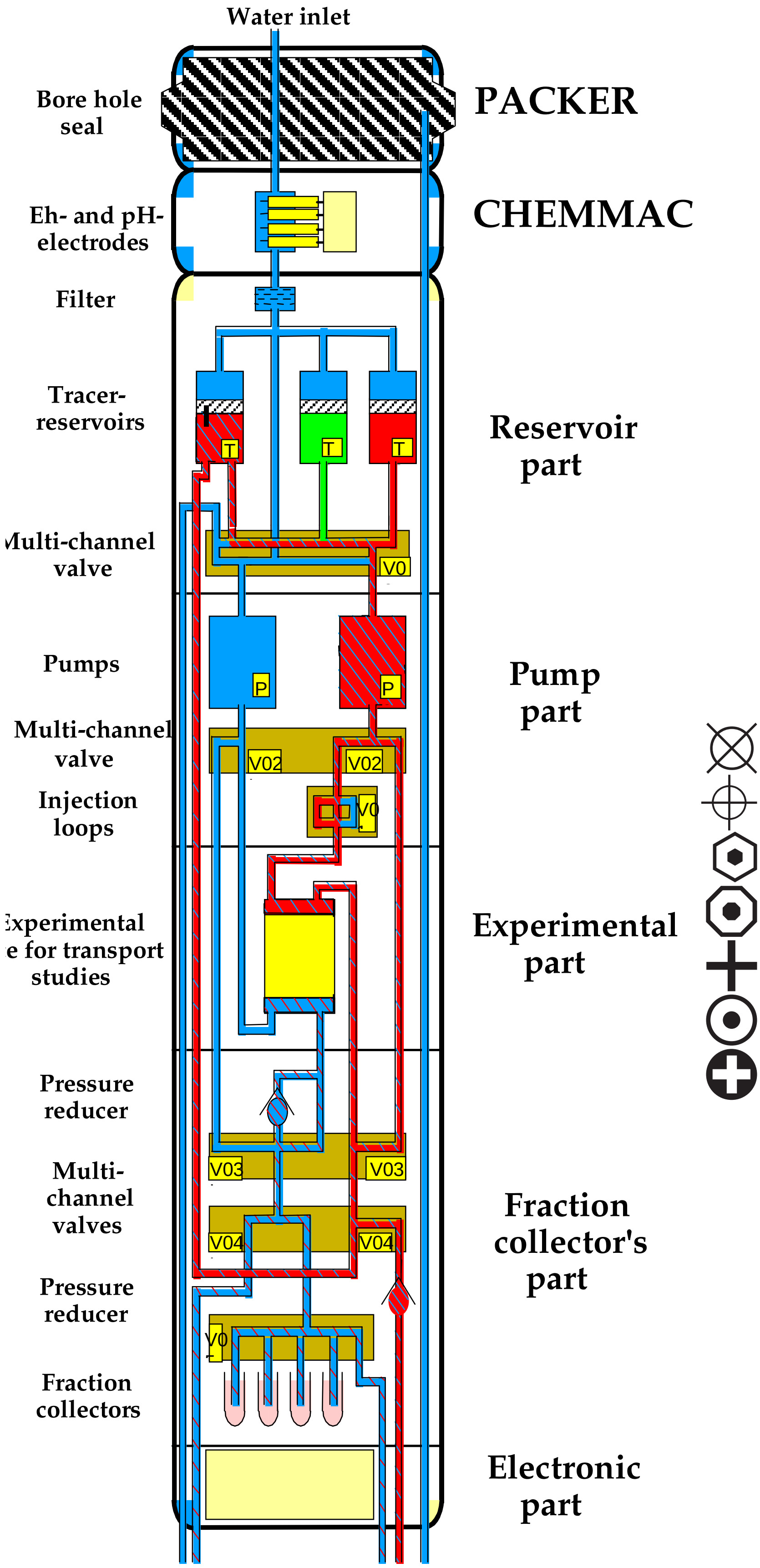

Figure 3-6 Schematic illustration of the CHEMLAB probe.

3.7 Degassing of groundwater and two-phase flow

3.7.1 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.

3.7.2 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.

3.7.3 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.

3.7.4 Scope for 1999

The degassing investigations will be finalised with a summarising degassing report in March, 1999. The report will synthesise results from both experimental and theoretical degassing studies. The parameters that were found to be influential on the degree of flow reduction due to degassing (see above) will be estimated as consistently as possible. Hereby, the obtained data set will provide a basis for extensive testing of hypotheses underlying different models and for testing the applicability of these models under a wide range of boundary conditions. Both degassing in single fractures and in fracture ensambles will be considered. The hypothesis and applicability testing will also be included in the summarising degassing report.

The two-phase flow investigations will continue considering boundary conditions that are relevant for gas generation and pressure build-up. Hereby, the applicability of various two-phase flow relations (including those originally developed for degassing conditions) will be investigated. Experimental two-phase flow field data will be obtained through the experiments that are conducted within the German-Swedish programme at the Äspö HRL (headed by BMWi). Through the modelling, the conditions prevailing during the field experiment should be reproduced. The test design work will be conducted in co-operation with the other participating organisations, with BGR being the main responsible organisation. The results will be reported in August.

3.8 Hydrochemical stability

3.8.1 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 groundwaters.

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.

3.8.2 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.

3.8.3 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 termodynamic 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 code M3 assumes a complete and complex mixing of the water in the investigated system. The principal assumptions behind this concept is that the varying hydraulic conditions of the past have caused the complex mixing pattern presently observed at Äspö. Mass balance calculations are then made to explain the difference between the ideal mixing and the observations.

The modelling strategy is based on:

- Process identification for Finnish and Swedish sites.
- Geochemical mixing for Äspö and Olkiluoto.
- Site intercomparison with PCA. Comparison between the M3 and NETPATH techniques for Olkiluoto.
- Hydrologic modelling for Äspö and Olkiluoto. Inclusion of the results from Task #5.

3.8.4 Scope of work for 1999

The integrated modelling effort within Task #5 will be completed by the different modelling teams. Three working group meetings are planned in order to support the modellers and discuss the results of the on-going work. A final report will be provided by each modelling team focussing on the hydraulic and hydrochemical conditions during the tunnel construction phase.

Modelling work for hydrochemical stability will benefit from the Task #5 modelling results. Inter-site comparisons using the M3 and NETPATH techniques will be finalised during 1999. Forward mixing calculations to estimate future hydrochemical changes and hydrological modelling will start during 1999. Hydrodynamic calcuations will be made to assess the stability of the deep seated high density saline groundwater.

3.9 Matrix Fluid Chemistry

3.9.1 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 groundwaters. It is considered expedient therefore to sample and quantify such fluids and to understand their chemistry and origin.

Such knowledge of matrix fluids and groundwaters from rocks of low hydraulic conductivity will complement the hydrogeochemical studies already conducted at Äspö, and 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.

3.9.2 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.

3.9.3 Experimental concept

The experiment has been designed to sample matrix fluids from predetermined, isolated borehole sections. The borehole was selected and drilled on the basis of: a) rock type, b) mineral and geochemical homogeneity, c) major rock foliation, d) depth, 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 uranine content, f) the collection of fluids (and gases) under pressure, and g) convenient sample holder to facilitate rapid transport to the laboratory for analysis.

The borehole was inclined upwards (~ 30-40^{o}).

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.

3.9.4 Scope of work for 1999

Borehole equipment was established in June 1998. The groundwater sampling and analyses will be done provided that there is sufficient amounts of water collected from the borehole sections. Groundwater sampling will also be obtained from the TRUE Block Scale and Prototype repository characterizations.

The mineralogical characterization will be initiated and the co-operation with the foreign laboratories will be initiated during the first part of 1999.

Drilling of boreholes to intersect small-scale water conducting fractures will be carried out in the vicinity of borehole KF0051A.

3.10 Calcite precipitation and dissolution

3.10.1 Background

It is of importance to understand the physical and chemical interactions between crystalline rock and the percolating groundwater, in order to predict increasing or decreasing groundwater flowrates due to the dissolution or precipitation of fracture filling minerals.

One of the most common minerals found in fractures of crystalline rocks is calcite, $CaCO_{3.}$ Swedish groundwaters are often supersaturated with respect to calcite and other carbonate minerals. However, precipitation seems to be inhibited and the explanation is probably found in the kinetics more than in the thermodynamics of the reaction.

Among the important factors that influence the rate of precipitation/dissolution reactions in an aqueous solution are temperature, size, shape, and electric charge of reaction solute species, ionic strength of the solution and pressure. The kinetics of calcite formation is very well documented due to its importance for understanding the carbonate geochemistry of the earth. Experimental studies have been performed over a wide range of saturation states, ionic strength, pH values and solution compositions including various metals and organic compounds.

3.10.2 Objectives

The objectives of the Calcite project are: 1) to study calcite precipitation/dissolution kinetics in an in-situ system, 2) investigate how various organic compounds can affect the calcite kinetics, and 3) ascertain coprecipitation of natural uranium with calcite in an in-situ natural system.

3.10.3 Experimental concept

The emphasis of the project is on a field experiment involving groundwater in contact with a fracture surface. It is planned that the experiment will be performed in the REX niche at 2165 m. The field study will be supported by laboratory experiments to determine reaction mechanisms and kinetics for calcite precipitation/dissolution

3.10.4 Scope of work for 1999

The project is now in its conceptual and planning stages. The design, construction and laboratory testing of the field equipment will start during 1999. Preliminary field experiments are planned to be conducted in 1999.

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

3.11.1 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 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

3.11.2 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.

3.11.3 Scope for 1999

The main objectives targeted to be accomplished during 1999 are summarised below:

- Official introduction of the Äspö Task Force WEB-site. http://www.skb.se
- Introduce more digital reporting in order to shorten lead time and rationalise distribution.
- Publish the evaluation of the predictive modelling work for the non-reactive tracer tests at the TRUE-1 site in a radially converging flow geometry as well as in a dipole configuration, Task No 4C&D
- Publish the Issue Evaluation Table report

- Finalise the publication of the Task No 4C&D modelling studies as Äspö ICR reports
- Perform predictive modelling of the irreversible sorption experiment STT2 in the TRUE-1 project. Denoted Task 4F.
- Develop initial and boundary conditions for Task 5.
- Perform predictive modelling of the tunnel conditions ahead of 2900 m in the framework of Task 5.
- Arrange the 12th Task Force meeting and publish its Proceedings.
- Identify a new modelling task, Task 6.

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

4.2.1 Background

Many aspects of the repository concept have been tested in a number of in-situ and laboratory tests. Models have been developed that are able to describe and predict the behaviour of both individual components of the repository, and the entire system. However, 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 which 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 idea of establishing a prototype repository at Äspö HRL have developed over a long time. More recent program planning, including the introduction of other large-scale experimental efforts at Äspö, have further clarified to role of such an experiment in the overall development of the deep repository program. As a result, the Prototype Repository Test is focused on testing and demonstrating repository system function. Certain activities aimed at contributing to development and testing of the practical, engineering measures required to rationally perform the steps of a deposition sequence are also included. Efforts in this direction are however limited, since these matters are addressed in other projects.

4.2.2 Objectives

The major objectives for the Prototype Repository are:

– To test and demonstrate the integrated function of the repository components under realistic conditions and to compare results with models and assumptions

– To develop, test, and demonstrate appropriate engineering standards and quality assurance methods.

– To simulate appropriate parts of the repository design and construction process.

The Prototype Repository should as much as possible simulate a real repository, regarding geometry, materials, and rock environment. The Prototype Repository is set up to simulate a KBS-3 type repository under what can be described as normal conditions or the reference scenario as described in SR-95. The Prototype Repository will differ from a real repository in that the canisters will contain electric heaters to simulate heat generation instead of spent nuclear fuel.

The evolution of the Prototype Repository should be followed for a long period of 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 operation operation stage (deposition of about 400 canisters) of the deep repository. The Prototype repository will in this context provide operating experience for 10-15 years longer than have been achieved with deposited canisters containing spent fuel.

4.2.3 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 will be made step-by-step followed by a detailing of the repository layout. The site of the Prototype Repository is given. However, methods for characterisation of the rock mass at the test site are expected to contribute to the assessment of methods for characterisation of the rock mass and the canister positions in a 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 4.2-1). 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 4-1). The tunnel will be backfilled with a mixture of bentonite and crushed rock (30/70).

A massive concrete plug designed to withstand full water- and swelling pressures will separate the test area from the open tunnel system. 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.

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 possibilities.

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

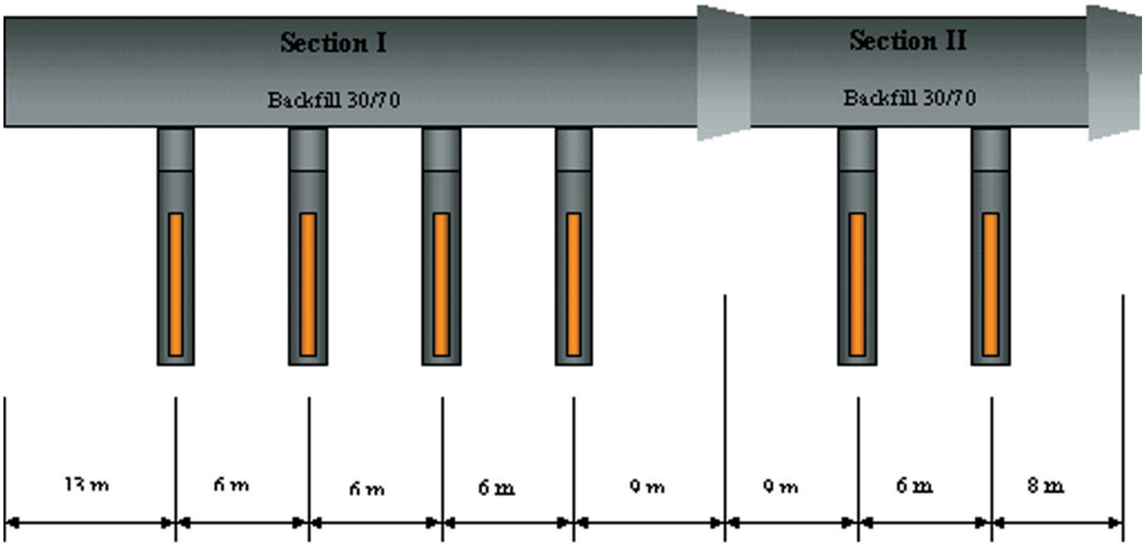

Figure 4-1 *Schematic view of the layout of the Prototype Repository (not to scale)*

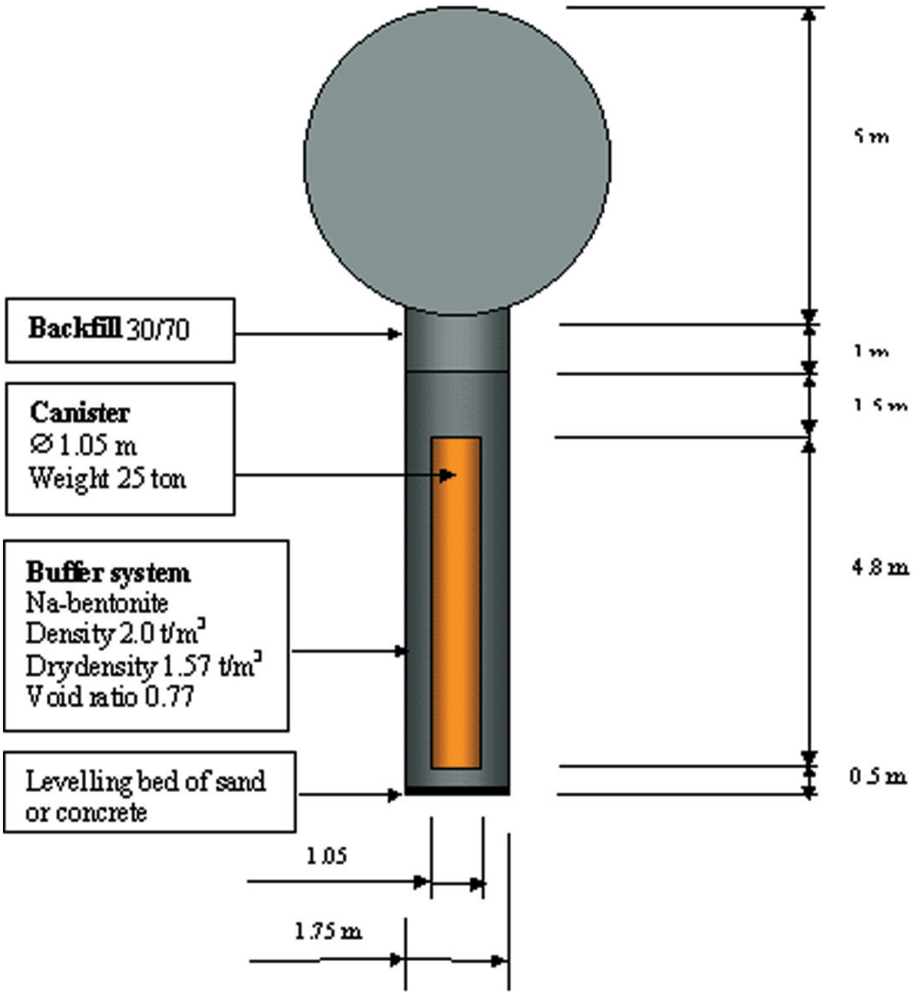

Figure 4-2 *Schematic layout of the deposition holes (not to scale)*

4.2.4 Scope for 1999

The characterisation work of the rock mass in the area of the Prototype Repository is continuing. The field activities are almost completed. Only some interference and flow tests remain. Such tests are also included in the program for rock mechanical and hydraulic response during excavation of the deposition holes.

Conceptual modelling of the site is continuously going on, and updated as more data from the characterisation is gained. The Rock Visualisation System (RVS) is used as modelling tool.

Laboratory testing to determine rock mechanical and thermal properties has started and the results are planned to be reported during the first half of 1999.

Prediction modelling will be performed, based on data achieved from the characterisation, regarding mechanical, hydrogeological and thermal conditions.

Boring of the six deposition holes in the Prototype Repository was originally planned to start in March, after boring of the holes for the Demonstration of Repository Technology and the Canister Retrieval Test. Technical problems with the boring machine, however, has delayed the boring and this affects the time schedule in the Prototype Repository. Now the boring are planned to start in June and finish in September 1999. Despite this delay the roadbed in the tunnel will be installed in March as planned.

The performance of the boring machine and the boring technique will be analysed. Special consideration to investigate the geometric result, surface roughness and the damaged zone (EDZ), i.e. the zone with induced fracturing. In order to examine the boring performance and its impact on the hole surface condition the machine will be equipped with a Measure While Drilling (MWD) system. During boring, the thrust, rotation speed and the penetration rate will be monitored.

Rock mechanical consequences due the deposition hole boring will be investigated. The main objectives of the investigation are to:

– Characterise the host rock and quantify the impact of stress redistribution and excavation induced damage around the deposition holes (micro cracking, fracture propagation and displacements)

– Investigate the magnitude of the stress related disturbed zone and to which extent it may influence the mechanical and hydraulic properties.

The investigation will be based on monitoring of acoustic emission, stress/strain, and displacements around the two deposition holes in the outer section. The instrumentation will be installed in holes drilled around the deposition holes. Hydraulic response during boring will be monitored in holes in both sections. The same instrumentation layout will be used during the operation phase with some supplement of instruments such as temperature and strain gauges installed from inside the deposition holes.

Planning of the instrumentation program for monitoring of processes in buffer, backfill and rock is continuously going on. Final selection and decision on number of each type of instruments and sampling equipment are schedule for the first half of 1999, followed by purchasing and preparation procedure.

Instruments and sampling equipment are planned to be connected to reading units installed in the G-tunnel. For this purpose, a number of holes will be drilled through the pillar between the

Prototype Repository and the G-tunnel, for lead-through of cables and tubes. It is of great importance that the holes are perfectly sealed off. For this purpose a test of sealing material is planned to be performed.

After boring of the deposition holes, characterisation will start. The investigation include:

- Borehole TV (BIPS)
- Laser scanning for geometric measurements including roughness and photo documentation (digitised picture) of the walls.
- Detailed geological mapping of wall and nearby drift floor.
- Inflow measurements
- Core sampling
- Laboratory testing of core samples

Results will be compared to earlier predictions.

Detail planning for the deposition sequence in the Prototype Repository will be made. The installation equipment for handling the canisters, bentonite blocks and buffer material and techniques for installation, including instrumentation will be developed and tested in-situ to achieve practical experience, before installation in the Prototype.

Equipment for emplacement of the buffer material and canisters is purchased. Manufacturing of canisters is proceeding. The result of the full-scale test performed at Kockum´s in Malmö, will be used in the continuing planning for heater design.

Final design of the plugs will be presented during the second half of 1999. The slots into the side rock will be excavate before installation of the two sections starts.

Installation of the inner test section starts in August 2000, and the plug is cast in December, so that monitoring may start early 2001. The installation in the outer section starts immediately thereafter and is finished before summer 2001.

4.3 Backfill and plug test

4.3.1 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*.

4.3.2 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

4.3.3 Experimental concept

Fig 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.
2. The *outer part* filled with backfill without bentonite.
3. The *plug*.

The backfill sections will be applied layer wise and compacted with a vibrating plate that has been 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.

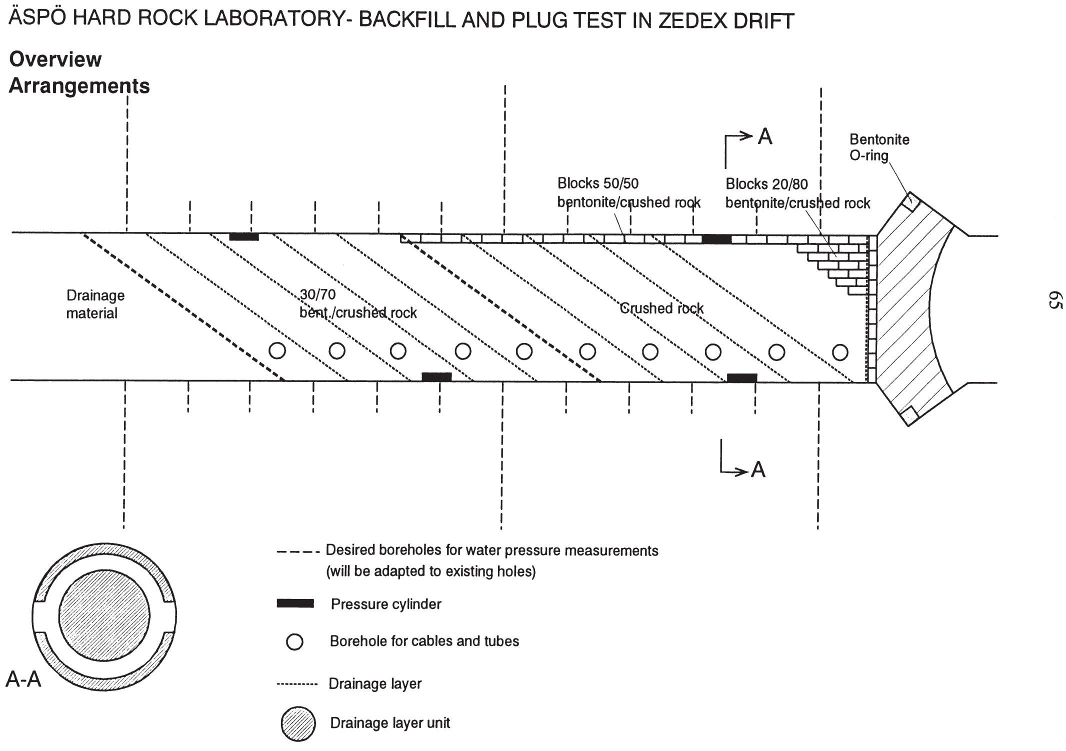

Figure 4-3 *An overview of the Backfill and Plug Test*

The inner test part will be 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 will be 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 will be 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 will be filled with bentonite pellets.

The two parts will be 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 will be installed in both backfill parts with the individual distance 2.2 m. Each mat section will be 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. Mats will also be installed on the inner surface of the plug.

The outer section will end 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 will instead be filled with blocks of bentonite/sand mixture with 20% bentonite content.

The backfill and rock will be 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 will be enclosed in Tecalan tubes in order to prevent leakage through the cables. The cables will be 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 will be 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 backfill should be completely saturated before flow testing but the plug may be tested in advance. 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.

4.3.4 Scope for 1999

The time schedule is shown in Figure 4-4. During 1998 the following main parts of the experimental setup were made:

– Drilling of holes and installation of steel tubes for the 12 through connections leading from the test drift to the Demo drift

– Hydraulic testing of the instrument holes in the rock

– Installation of rock instruments

– Plugging of old bore holes

– Excavation of the 1.5 m deep slot for the plug and building of the first part of the plug

– Preparation and mixing of the backfill material

During 1999 the rest of the experimental setup will be finished and the water saturation start. The following main field activities will take place:

– Compaction of blocks for the backfill and for the bentonite o-ring in the plug

– Setting up the data collection house and installation of the data collection system

– Backfilling of the test sections with inclined compaction and installation of filter mats etc.

– Installation of all instruments in the backfill with all cables and tubes led through the through connection holes to the data collection house

– Building of the rest of the plug with emplacement of the bentonite o-ring

– Start water saturation of the backfill

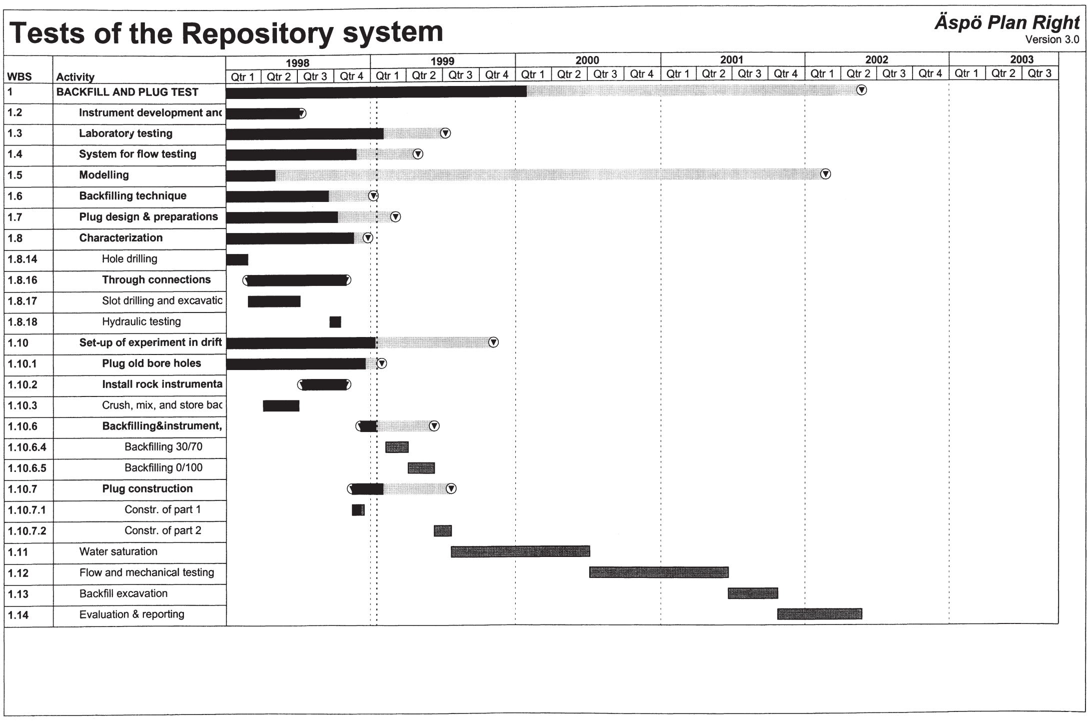

***Figure 4-4** Time schedule for Backfill and Plug Test*

4.4 Demonstration of repository technology

4.4.1 Background

The development and testing of methodology and equipment for encapsulation and deposition of spent nuclear fuel in the deep repository is an important part of SKB's programme. In addition to the technical aspects, it is also important to be able to show in a perceptible way the different steps in encapsulation, transport, deposition, and retrieval of spent nuclear fuel for specialists and the public. As part of the overall programme an Encapsulation Laboratory is under construction in Oskarshamn and it will be put into operation late 1988. Demonstration of deposition and retrieval of canisters will be made in the Äspö Hard Rock Laboratory. The demonstration project complements the Prototype Repository and the Backfill and Plug Test which focus on the integrated function of the engineered barriers in a realistic environment.

4.4.2 Objectives

The objectives of the technology demonstration are:

- to develop and test methodology and equipment for encapsulation and deposition of spent nuclear fuel,
- to show in a perceptible way for specialists and the public the different steps in transport and deposition of spent nuclear fuel, and
- to develop and test appropriate criteria and quality systems for the deposition process.

4.4.3 Experimental concept

The technology demonstration will be made in the new tunnel south of the ZEDEX drift excavated by drill and blast. This location provides good rock conditions, a realistic environment for a future repository, and allows transport of heavy vehicles to the test area. The demonstration will include handling and deposition of canisters and bentonite buffer in 4 full size holes. The procedures that are expected to be tested and demonstrated are:

- draining of canister holes
- buffer emplacement in the holes
- deposition of canister
- emplacement of buffer on top of the canister
- filling the slot between the buffer and the borehole wall
- filling the top of the deposition holes with backfill

The demonstration will also simulate the transfer of canisters from the transport casks to the radiation shield of the deposition machine. Arrangement for this is made in the assembly hall on 420 m level and a crane and other necessary equipment are installed above the first bored full size deposition hole. The radiation shield with canister is transported to the demonstration tunnel with a specially equipped truck.

4.4.4 Scope for 1999

The tunnel is ready for the boring of the four full-size deposition holes. Due to the delay in the boring program the holes may not be made until March-April 1999. The deposition machine will be delivered immediately thereafter and decommissioned at site in the tunnel. Tests with the machine are planned to start in 1999.

4.5 Canister retrieval test

4.5.1 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.

4.5.2 Objectives

The objectives of the retrieval test are

- to develop and test methodology and equipment for loosening 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.

4.5.3 Experimental concept

The retrieval test will be made in a new tunnel which is the extension of the tunnel on level 420 m leading to the tunnel for technology demonstration. The tunnel is situated adjacent to the tunnel where the deposition machine will be working, and this machine can easily be transferred to the tunnel for the retrieval test.

After geological characterisation of the tunnel two simulated full size deposition holes are bored and equipped with bentonite blocks, canisters with heaters and appropriate instruments. In addition the rock surrounding the simulated deposition holes is also instrumented for registration of the evolution of mainly the thermal and the geohydrological regimes.

The test is separated into three stages

Stage I: Boring of deposition holes and installation of bentonite blocks and of canisters with heaters. The holes are covered with a concrete lid and the tunnel is maintained unfilled.

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

Stage III: Test of loosening 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 loosening of the canister. The development up till today has listed both disintegration of the bentonite with salt solution and pumping of the slurry, and cooling of the bentonite as potential methods.

4.5.4 Scope for 1999

All preparations for the boring of the two deposition holes were made in 1998, but the technical problems with the boring machine has delayed the timeschedule for the Canister Retrieval Test to April/May according to the latest plan.

Just before the boring starts the seven 9 m deep cored holes around the periphery of the two large holes will be furnished with instruments for monitoring of acoustic emission from the rock around the holes during boring. Also four core drilled holes around each deposition hole will be furnished with sensors for rock stress/strain measurements. In both cases the same type of instruments are used as are installed in the Prototype Repository.

During boring rock-related, boremachine-related as well as boreprocess-related operations will be measured in accordance to special programs (also in accordance with measurements in the Prototype repository). After boring the two holes will be geologically and geometrically characterised. Rock samples will be cored from the wall and analysed in Finland with respect to porosity and conductivity as part of the cooperation with POSIVA. Samples are easier to take in the Canister Retrieval Test than in the Prototype Repository because the artificial watering will decrease the influence of the rock wall and thereby the need for as undisturbed near-field rock as possible. The main part of wall samples are therefore expected to come from the Canister Retrieval Test.

Two of the main engineering issues to be solved during 1999 are:

- How to supply water artificially during saturation of the buffer? The natural water flow in the rock around the two deposition holes is very low.
- How to provide the counter force of approximately 5 MPa from the swelling bentonite plus water pressure, which combined can amount to approximately 2500 tonnes? By bolting the lid to the floor or by constructing pillars taking support at the ceiling?

Late in 1999 foundations will be cast for the deposition machine, so that installation of buffer and canisters with electrical heaters can start in early 2000.

4.6 Long term test of buffer material

4.6.1 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 minimize 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.

4.6.2 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 summarized 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. illitization 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 realization of the full scale test series with respect to clay preparation, instrumentation, data handling and evaluation.

4.6.3 Experimental concept

The testing philosophy for all planned tests in the series (Table 4-1) is to emplace prefabricated units of clay blocks surrounding heated copper tubes in vertical boreholes. The test series will be 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 A1 parcel.

Table 4-1. Layout of the remaining parcels in the 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 will be equipped with heaters in order to simulate the decay power from spent nuclear fuel. The heater effect will be 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 will be placed in boreholes with a diameter of 300 mm and a depth of around 4 m

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

4.6.4 Scope for 1999

The planning and construction work for the remaining five test parcels have started. Investigation holes will be core-drilled and test concerning inflow and water-pressure will be made during the spring. The successive drilling of test holes are planned to be made by use of hammer drilling technique.

The emplacement of the remaining parcels is planned to start in May and will be finished during the summer.

Supporting laboratory work will be made parallel to the construction and running of the five new parcels during the rest of the year. The tests and analyses concern i.e. original clay characterization and gas opening pressure.

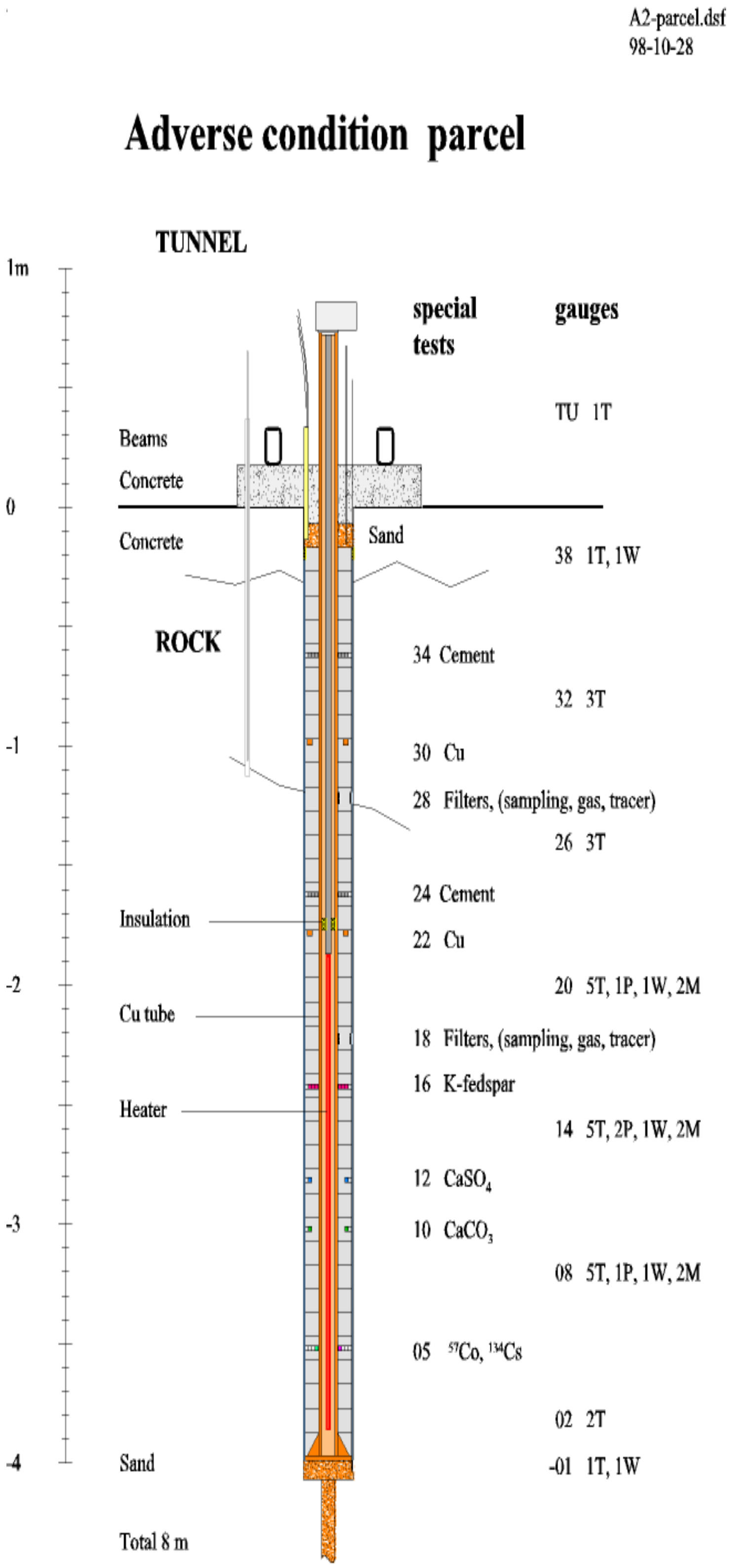

Figure 4-5 *Principle parcel layout. Numbers show bentonite block notation and the number of gauges at each level. T indicate thermocouples, W indicate water pressure gauges, P indicate total pressure gauges and M indicates moisture gauges.*

4.7 Development and test of grouting technology

4.7.1 Background

SKB is addressing general know-how about the grouting process and the main parameters that are of importance to control in order to successfully predict the grouting result. The research work is separated into different tasks and is scheduled to be carried out in three phases each lasting some 18 to 24 months. Currently the second phase is running, including laboratory tests and preparatory work for field tests, which are scheduled to be carried through during the years 2000-2003.

4.7.2 Objectives

The primary objectives are to test the coupled process of rock characterisation from a grouting perspective, to design a grout and finally to compare the achieved penetration of this grout to the predicted one. In addition SKB will define its demands on grouting. The field test is preferably carried out in two stages. In the first stage a single, well-defined, fracture will be used and in the second stage a set of fractures, i.e.a discontinuity.

4.7.3 Scope for 1999

In 1999 the preparatory work for the first field test continues with a selection of a suitable site. At this site, a single fracture, which is well-defined and relatively easy to characterise, will be chosen. Another demand on the site is that it has to be located in an area where it doesn't disturb other experiments or activities in the Äspö HRL.

The selection process includes a consensus among the participating researchers on which fracture to choose and what parameters to study in the field test. Initial preparation of the selected site will begin later.

5 ÄSPÖ FACILITY OPERATION

5.1 Plant operation

5.1.1 Background

The facility has now been in operation since the beginning of 1995 when the excavation was completed. The main goal for the operation of the facility is to provide a safe facility for all people working and visiting the laboratory. This includes preventive and remedy maintenance on all systems like drainage, ventilation, electricity and fire alarm. Secondly, some major works have been done to change and improve installations that due to the harsh environment don't fulfil the necessary requirements.

The work with improving the facility will always be an important part of the Operational Phase but the main activities should be completed within three years.

Today the organisation includes three employees. The organisation needs to be strengthened during 1999.

5.1.2 Scope for 1999

Last year two underground construction workers worked full time with scaling and rock support. The experience so far is good and this way of working will be continued during 1999.

Great effort will be put on safety issues. A new rescue tunnel is under construction and will bee completed in the beginning of 1999. This tunnel will also be used as a conference room and show room for visitors. As previous years all the staff will have annual education in handling fire equipment and first aid. Besides that all staff will participate in at least one evacuation exercise from the tunnel.

A computerised monitoringsystem will be taken into operation at the end of the year. This will considerably facilitate the possibilities to run the facility in an economic and safe way.

A redundant drainage system has been under investigation. The idea was to pump the water in a separate borehole, and in one step, up to the surface. A report however showed that this was a quite expensive solution and besides didn't fullfill our criteria on redundancy. Other solutions are under consideration and a redundant system should be ready for use late 1999.

5.2 Data management and data systems

5.2.1 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 *feasibility 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,
- accessability,
- 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 data needed in a typical safety assessment have been reported in Andersson et al, 1996. In this view the SKB's Site Characterisation Database and SKB's Rock Visualisation System plays important roles. These systems will be improved in conjunction with the ongoing and planned activities in SKB's siting work. This to fulfil the requirements expected from the regulatory authorities and the internal organisation as well.

5.2.2 Objectives

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 safety, quality and traceability.

A system like SICADA need to be held modern and also adapted and improved in parallel with the development of new and more extensive investigation programs.

5.2.3 System concept

Data model

The central data table in the system is the *activity_history* table. All data rows in this table have an 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 identifiers were introduced in order to make it possible to link an arbitrary number of investigation data tables to a certain activity. Hence, activity identifiers 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 a 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 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. Chemistry	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

Every set of investigation data in SICADA has been collected from boreholes, tunnels or other objects. Simple name conventions have been set up and used for objects (e.g. boreholes). The object names (sometimes called idcodes) and the hierarchical data structure are the key information when searching for data in the SICADA system.

All investigation data sets or parts of data sets are not possible to store in data tables in SICADA, but as least stored as *file references*. Some examples of this type of data sets are borehole radar images and geophysical profiles. The *file reference* is an optional *activity tag* available during data registration. Actually there is an on-line file archive managed by the SICADA system. This on-line archive is called *SICADA File Archive*. A registered *file reference* is actually an on-line pointer to the file in the SICADA File Archive.

The *activity tag* mentioned above is only one example of one of many useful tags in the SICADA system. There are currently about 60 different tags available in the system.

Applications

Five user applications/programs have been developed, namely:

SICADA/**Diary**	This application is used to *insert or update* data in the database.
SICADA/**Finder**	This application is used to *retrieve* data from the database.
SICADA/**Retriever**	This application is used to *retrieve* data from the database. (Look like the former GEOTAB-application)
SICADA/**Project**	This application is used to *check* the progress of the data entry work for a specified project/experiment.

An overview description of these applications were described in the Planning Report for 1998. Hence, the reader is advised to read the previous report if more information about these program modules is wanted.

5.2.4 Scope for 1999

All graphical SICADA applications are now based on the programming environment OpenRoad for UNIX. Currently, these applications are undergoing a conversion to fit the Windows NT operating system. This will give us an tremendous opportunity to offer the applications on every ones desktop. Even external computers can be connected if the users are recognised by the firewall.

SICADA for Windows NT is planned to be released in February 1999. Thereafter new improvements will be included successively. The current activities in the to-do list will nearly fill up the rest of the time schedule for 1999.

The previous plan for 1998 to realise a Webb interface for SICADA has been given a low priority. We have put the focus on SICADA for Windows NT instead. Actually, we are not planning do start up this activity during 1999 either.

We are heavily involved in SKB's plans to prepare for site investigation in the beginning of 2002. Work flows and data flows need to be set up and tested rigorously and the SICADA database, with the corresponding set of applications, will be adapted to support these processes.

5.3 Program for monitoring of groundwater head and flow

5.3.1 Background

The Äspö HRL operates a network for the monitoring of groundwater head, flow in the tunnel and electrical conductivity, as the core parameters. This system goes under the acronym of HMS (Hydro Monitoring System). Water levels and pressure head are collected from surface and tunnel boreholes. Additionally, the electrical conductivity of the water in some borehole sections and in the tunnel water is measured. The network includes boreholes on the islands of Äspö, Ävrö, Mjälen, Bockholmen and some boreholes on the mainland at Laxemar.

Data is transferred by means of radiolink, cable and manually to a dedicated computerised database. During 1997 the HMS computer system was uppgraded with new hardware and software. Pentium computers were installed and the DB/2 operating system was abandoned in favour of Windows NT where a new real time engine is accessing the HMS database. This engine provides integrated data acquisition, monitoring, data logging and report generation.

5.3.2 Objectives

The objectives for maintaining such a monitoring network has scientific and legal grounds:

- to provide means of monitoring responses in the surrounding rock when undertaking activities in the framework of the different projects, e g drilling, hydraulic testing, tracer tests.
- to have a baseline for the various model validation exercises
- for paleohydrological studies
- to comply with the water rights court condition that a monitoring program should be put in place and that the groundwater head conditions should continue to be monitored until the year 2004 at the above mentioned areas.

5.3.3 Scope for 1999

The HMS data will continue to support the various scientific projects undertaken, providing basic data which is distributed in space and time.

During 1999 the monitoring network will be extended with new boreholes drilled in the helical parts of the tunnel. These boreholes are associated with ongoing and planned experiments. Several ongoing research project will include some of their boreholes to the HMS. The exact number is uncertain but the maximum number can be estimated as follows

Project Name	Number of boreholes
SELECT-II	3
LTDE	1
TRUE-2	4
TRUE Block Scale	1
Prototype Repository	3
Äspö Tunnel	3

A project will be initiated for a detailed evaluation of the operations of the HMS. The intention is to assess methods, strategies and instruments used for the longterm monitoring of head and flow. This will also include the analysis of the data produced by the system. In this case the intention is to include the complete time period for which data has been collected with the purpose of putting it in its hydrogeological context.

5.4 Program for monitoring of groundwater chemistry

5.4.1 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.

5.4.2 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.

5.4.3 Planned work

Water sampling campaigns are scheduled to take place in April (v. 914-915) and September, 1999. Additional sampling occasions are planned for the TRUE Block Scale experiment (v. 902) and for the Prototype Repository experiment (v. 906). The sections to be sampled are listed in Table 5-2, The Hydrogeochemistry monitoring program.

The results from the Monitoring program undertaken between January 1995 and May 1998 will be presented in a report in the beginning of 1999. The results from the monitoring in October will be presented in a Technical Note in February 1999.

Table 5-2. Boreholes and sections sampled within the Program for Monitoring Groundwater Chemistry

Idcode	Secup/seclow	Class no	Comment
KAS03	533-626 m	4	
KAS03	107-252 m	4	Only in October
KAS09	116-150 m	4	
KA1131B		4	Only in October, replaces SA1229A
KA1755A	88-160 m	4	Replaces KAS04
KA2050A		4	Only in October
KA2162B		4	Only in October
KA2511A	139-170 m	4	Only in October
KA2563A	187-196 m	4	Only in October
KI0025F	158-168 m	4	Only in October
KI0025F	86-88 m	4	Only in October
KXTT3	12.42-14.42	4	
KR0012B		4	
KR0013B		4	
KR0015B		4	
SA0813B		4	
SA1009B		4	
SA1229A		4	Only in March
SA1420A		4	
SA1730A		4	
SA2074A		4	
SA2273A		4	
SA2600A		4	
SA2783A		4	
SA2880A		4	
SA3045A		4	

The hydrogeochemistry monitoring program is continuously updated. Adjustments in the monitoring program might be requested from the Task #5 modelling groups.

5.5 Technical systems

5.5.1 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.

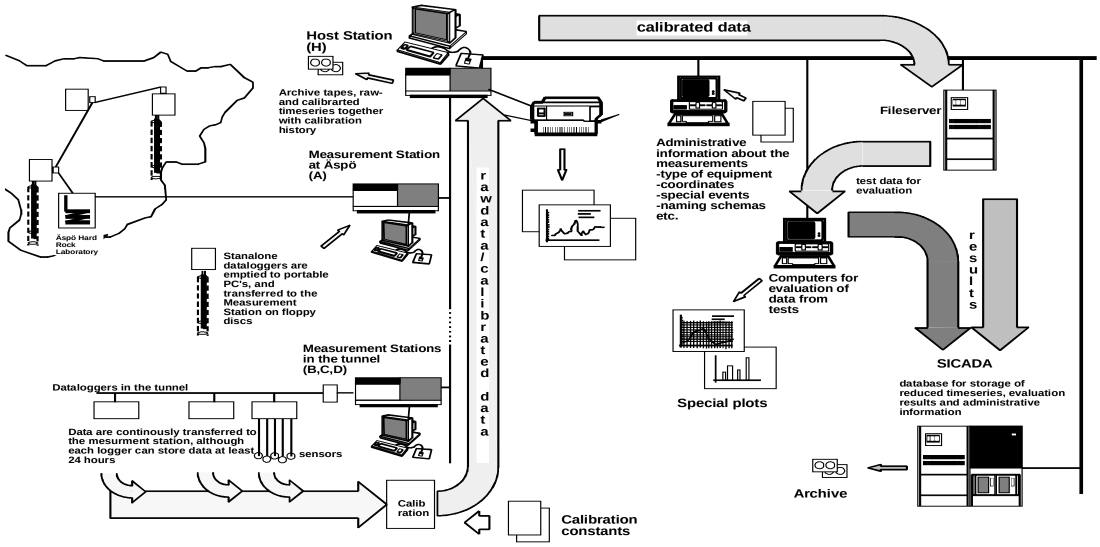

Figure 5-1 *Borehole system for groundwater monitoring*

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.

5.5.2 Scope for 1999

The experiment Backfill and Plug Test in the ZEDEX drift will be instrumented and connected to the HMS during 1999.

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

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

Evaluation of a presentation system for the HMS-system will be made during spring 1999 and be installed in the autumn.

6 INTERNATIONAL COOPERATION

6.1 Current international participation in the Äspö Hard Rock laboratory

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

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 organisations participation under the agreements.

Most of the organisations are interested in groundwater flow, radionuclide transport and rock characterization. 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.

A special multilateral agreement between ANDRA, Nirex, POSIVA and SKB regarding the TRUE Block Scale experiment has been signed. ENRESA and JNC have joined the project and as full partners with the beginning of the "Detailed Characterization Stage".

The agreement with AECL expired on January 21st, 1999.

Table 6-1 Scope of international cooperation

Organization	Scope of participation
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 - *Prototype repository*
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

Organization	Scope of participation
Japan Nuclear Cycle Development Institute (**JNC**), Japan.	Test models for groundwater flow and radionuclide migration: 1. Tracer retension understanding experiments (TRUE) 2. Disturbed zone effects 3. Degassing and two-phase flow conditions 4. Redox experiment in detailed scale 5. Radionuclide retension. Demonstrate construction and handling method. Test important parts of the repository system. Cooperation regarding the Kamaishi mine in-situ experiments concerning earthquakes.
The Central Research Institute of the Electric Power Industry, **CRIEPI**, Japan.	Application of: 1. Fault activity evaluation method. 2. Groundwater dating and flow. 3. Geochemical environmental evaluation methods (REX experiment). 4. Groundwater/radionuclide migration analysis methods (TRUE experiment).
United Kingdom Nirex Limited, **NIREX**, Great Britain	TRUE Block Scale
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, **NAGRA**, Switzerland	Groundwater flow and radionuclide migration. Disturbed zone effects (Degassing of groundwater and 2-phase flow, drift excavation effects). Construction/testing integration, TBM technique. Data flow management, documentation.
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.

Organization	Scope of participation
Empresa Nacional de Residuos Radiactivos **ENRESA**, Spain	Test of models for groundwater flow and radionuclide migration, (TRUE Block Scale) Demonstration of technology for and function of important parts of the repository system, (Backfill and Plug Test)
Sandia National Laboratories, USA	Tracer Retention Understanding Experiment (TRUE) TRUE 1 Experiments TRUE 2 Experiments Long-Term Diffusion Experiment Modelling Task Force

6.2 Summary of work by participating organisations

6.2.1 JNC/CRIEPI

Background

JNC and CRIEPI joined the Äspö Hard Rock Laboratory Project in October, 1991 and has been conducting the modeling 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.

During 1999 JNC and CRIEPI joined together the project. 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 the modeling development for groundwater flow with seawater and radionuclide migration, and the reporting for those modeling efforts and the results of voluntary field investigation at Äspö site applied by CRIEPI for the dating of fault activity and groundwater flow meter.

Scope for 1999

Task Force on Groundwater Flow and Transport of Solutes

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

Participation and assignment in the meetings and transfer of experience from modelling studies performed by CRIEPI for the Task Forces (Task4 and Task5).

JNC will continue to participate in the Äspö Task Force on Groundwater Flow and Transport of Solutes. During 1999, this 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.

Task 4 currently consists of active phases 4E and 4F, which both involve analysis, modelling, and prediction of sorbing tracer transport. During 1999, JNC's work will use newly-developed flow and transport features of the FracMan/LTG discrete fracture network code. The application will analyze and predict solute transport in fracture networks with consideration of the effects of advection, dispersion, diffusion, and sorption in mobile and immobile portions of the rock and fracture.

Task 5 currently requires development and calibration of a hydrogeological/geochemical model to explain the observed breakthroughs of various different groundwater types to the Äspö tunnel. This calibrated model will then be used to predict breakthrough times for these groundwaters in newer portions of the tunnel. During 1999, JNC will participate in Task 5 by applying the FracMan/PAWorks pathways analysis approach.

FracMan/PAWorks will be used to identify the pathways by which waters with different chemistries are transported to the tunnel. JNC's analysis will use reference boundary conditions and initial geochemical conditions provided by SKB as the basis for the analysis. JNC will participate in both calibration and prediction exercises within Task 5.

Redox Experiment in Detailed Scales

JNC will participate in the REX project as a JNC-BGS team, with the objective of developing the methodologies for laboratory and in-situ experiments to understand the role of fracture fillings as oxygen consumption in deep geological environment. JNC-BGS team has carried out the characterisation of fractures in the test site as well as sampling of rock and groundwater, analysis of fracture filling minerals and groundwater, and laboratory experiments.

JNC-BGS team is now carrying out CSTR (Continuously Stirred Tank Reactor) experiments.

Final report for three years experiments will be prepared in this year.

Prototype Repository Project

JNC and CRIEPI will participate in the prototype repository project.
JNC and CRIEPI will participate and assign in the meeting and transfer of experience from modeling studies.
JNC and CRIEPI will participate Task Force on engineered barrier systems.

Reporting

1) Redox experiment by JNC
2) Modeling development by CRIEPI
3) Application of the groundwater flow meter for velocity and direction of groundwater flow in the boring hole KA3510A

General

1) Participating in the information exchange meetings
2) Dispatching CRIEPI's technical specialists
/ Mr. T. Hasegawa (March 1, 1998 March 30 1999)
/ short period visiting specialists (as occasion arises)

6.3 UK Nirex

Background

United Kingdom Nirex Limited (Nirex) has provided support from AEA Technology plc to provide modelling support 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

Nirex's support has taken the form of establishing

– a reasonable site-model, that includes the influence of the HRL, tunnel system and Äspö island; and

– a local scale model of the TRUE Block on a 500m scale.

During 1998 a site-scale model has been established that includes both the discrete features of the site (fracture zones) and the effects 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. Figure 6-1 shows a site model showing the salinity distribution with a representation of background fracturing (to account for groundwater flow into and out of the rock mass between the large-scale features). The blue area shows the fresher water area associated with the presence of Äspö island. The red area indicates the deeper saline waters.

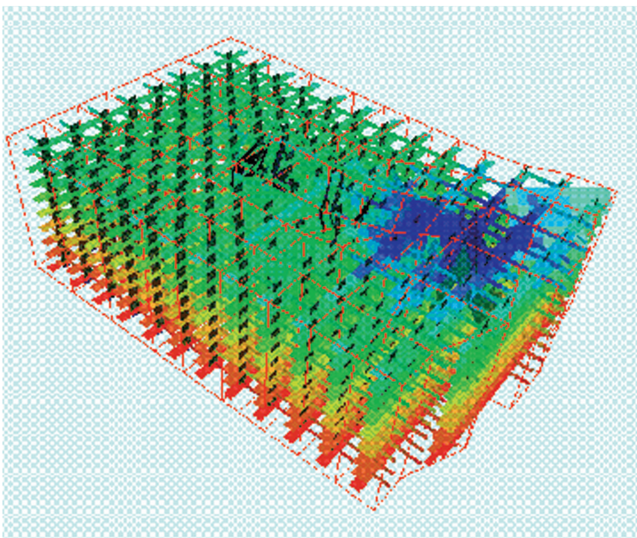

Figure 6-1 *A site-scale fracture network model showing the distribution of salinity.*

At the TRUE Block scale, fracture network models, based on the site structural model, have been used to understand the results of experiments performed in the TRUE Block. This has included the hydraulic responses observed in existing boreholes at the TRUE Block site due to drilling-induced drawdown of newly constructed boreholes (for example borehole KI0025F02). An interpretation of these responses has helped the process of identifying the connectivity between various parts of the block. This is useful as a first step in preparation for later hydraulic interference testing and tracer testing. An illustration of the spatial distribution of responses is given in Figure 6-2 This is a plan view of the TRUE Block site (the red lines indicate the trace of the fractures identified in the structural model). The spheres illustrate the position of the centres of packer intervals, the colours represent their relative drawdown, largest drawdown is red, the least drawdown blue. The path of the drilled borehole is illustrated by the largest diameter white cylinder.

The spatial distribution of drawdown show some interesting behaviour. Some packer intervals deeper into the block show larger drawdown than those intervals closest to the hydraulic disturbance caused by drilling. This type of observation provides information on overall connectivity of the block and helps design later stages of the project.

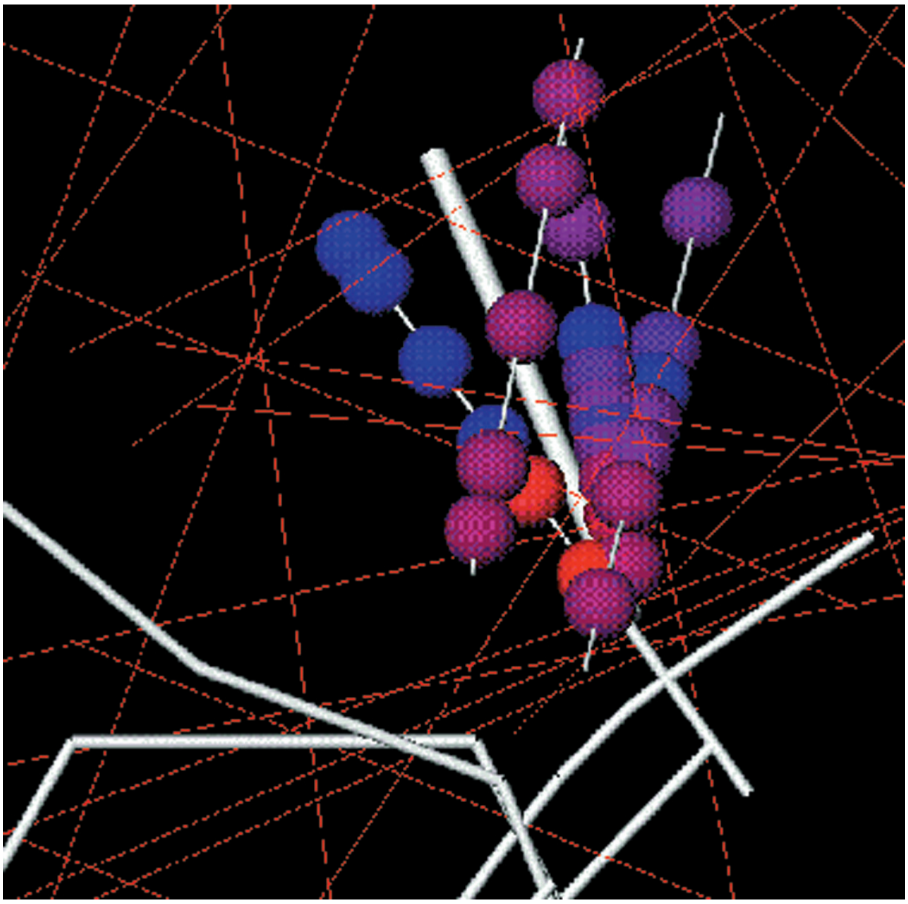

Figure 6-2 *An illustration of the spatial distribution of hydraulic responses due to the drilling of borehole KI0025F02.*

Future modelling work will concentrate on the design, understanding, and prediction of tracer experiments to be performed in the TRUE Block.

Scope for 1999

Future modelling work in 1999 will concentrate on the design, understanding and prediction of tracer experiments performed in the TRUE Block. In particular, this will cover:

- transfer of existing structural models to the NAPSAC software (scheduled to be completed in February-Task 3.3.9.2);
- Perform a review of the stochastic continuum work performed as part of the TRUE Block Scale Project (scheduled to be complete in April-Task 3.3.10.2);
- Using the updated NAPSAC structural model to devise test designs (scheduled to be complete in April-Task 3.3.11.1);
- Perform interpretation of cross-hole and dilution tests (complete May- Task 3.3.12.1);
- Perform additional predictive modelling as part of the tracer test stage planned to take place in the Autumn of 1999.

It is anticipated that additional modelling activities will be undertaken on behalf of the TRUE Block Scale Project but at the time of writing this has not been finalised.

Further Collaboration

Nirex is interested in the possibility of links between the Äspö HRL programme and European Commission supported projects and will support the development of projects which address important, safety-relevant issues or aspects of repository design which are relevant to the disposal of long-lived intermediate-level wastes (TRU).

6.4 BMWi

Background and objectives

Aditionally 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 investigations, and the development and testing of instrumentation and methods for detailed underground rock characterization. Four research institutes are performing the work on behalf of BMWi: BGR, FZK/INE, GRS, TUC.

(According to a decision made by the German Government recently, the responsibility for R&D related to disposal of radioactive waste was changed from BMBF to BMWi (Bundesministerium für Wirtschaft und Technologie).

Scope for 1999

A major part of the work carried out in the HRL is a programme to investigate two-phase flow processes in saturated fractured rock. For these investigations a field experiment is being conducted in niche 2/715. In 1999, a series of gas injection tests will be performed aimed at the determination of the hydraulic and transport properties of the dominant hydraulic flow path.

The transport of gas components through fractured rock will be calculated using calibrated 2D and 3D one-phase-flow models. For calculating 3D more-phase flow conditions in fractured rock the existing codes will be developed further.

Gas sampling from boreholes will be continued to determine the composition of gases in the granite, the formation water, and in the ventilation air. Electrical resistivity measurements will be conducted in a backfilled tunnel section in order to investigate time-dependent changes of water saturation in the tunnel, the EDZ, and the undisturbed rock.

Model calculations continue in the Task Force on modelling of groundwater flow and transport of solutes in Task #4 and Task #5. In TRUE-STT2 the transport of sorbing tracers in the fractured rock will be analysed using the numerical programme DURST/Rockflow. For Task # 5 supplementary calculations of groundwater flow and transport in additional main fracture zones will be carried out.

Geochemical investigations are conducted aiming to improve the knowledge of the behaviour of repository-related chemical elements in the granitic rock matrices. Laboratory scale tracer diffusion experiments on drill cores were stopped because of the extremely low diffusion rates. Instead of continuing these experiments, the distribution and total abundances of the minerals epidote and allanite are investigated. Allanite contains a large proportion of the bulk rock REE, as well as Th and U. It is formed from its precursor mineral epidote by uptake of REE, U, and Th from hydrothermal solutions. The amount of epidote in the granitic rock today is a measure for the potential uptake of REE, U, and Th by allanite from migrating hydrothermal waters containing these elements. The amount and the concentration of trace elements in epidote and allanite will be analyzed by microanalytical means (microprobe and Laser-Ablation ICP-MS)

In another attempt, Uranium and Thorium located within the rock matrix are used as natural analogues to assess the potential transport of actinides in the rock. This study utilizes isotopic disequilibria which are observed in a number of secondary carbonates located within the granite. Further investigations on the state of secular equilibrium of the 238U-234U-230Th decay series will include a larger number of samples in order to reveal the spatial distribution of equilibrium/disequilibrium conditions. This will give insight into the migration of natural U and Th within the past 10,000 to 500,000 years. A geochemical mass balance will allow to quantify the total amount of U and Th migration over that period of time.

The migration/retention of actinides (Pu, Am, Np) in granitic fractures is studied within the CHEMLAB project. Field experiments are in preparation and scheduled for 1999. For this purpose, a specially designed experimental cell is developed and tested and laboratory studies (batch and column sorption experiments) are performed. Prior to the in-situ experiments in CHEMLAB the migration behaviour of the actinides will be predicted by geochemical and transport modelling.

To measure colloids in Äspö groundwater under natural conditions a mobile Laser-induced Breakdown Detection (LIBD) system with a flow-through pressure cell for online measurements is developed and tested by online measurement of groundwaters at Wellenberg (CH) under atmospheric pressure. Online measurements at Äspö HRL are scheduled for 1999.

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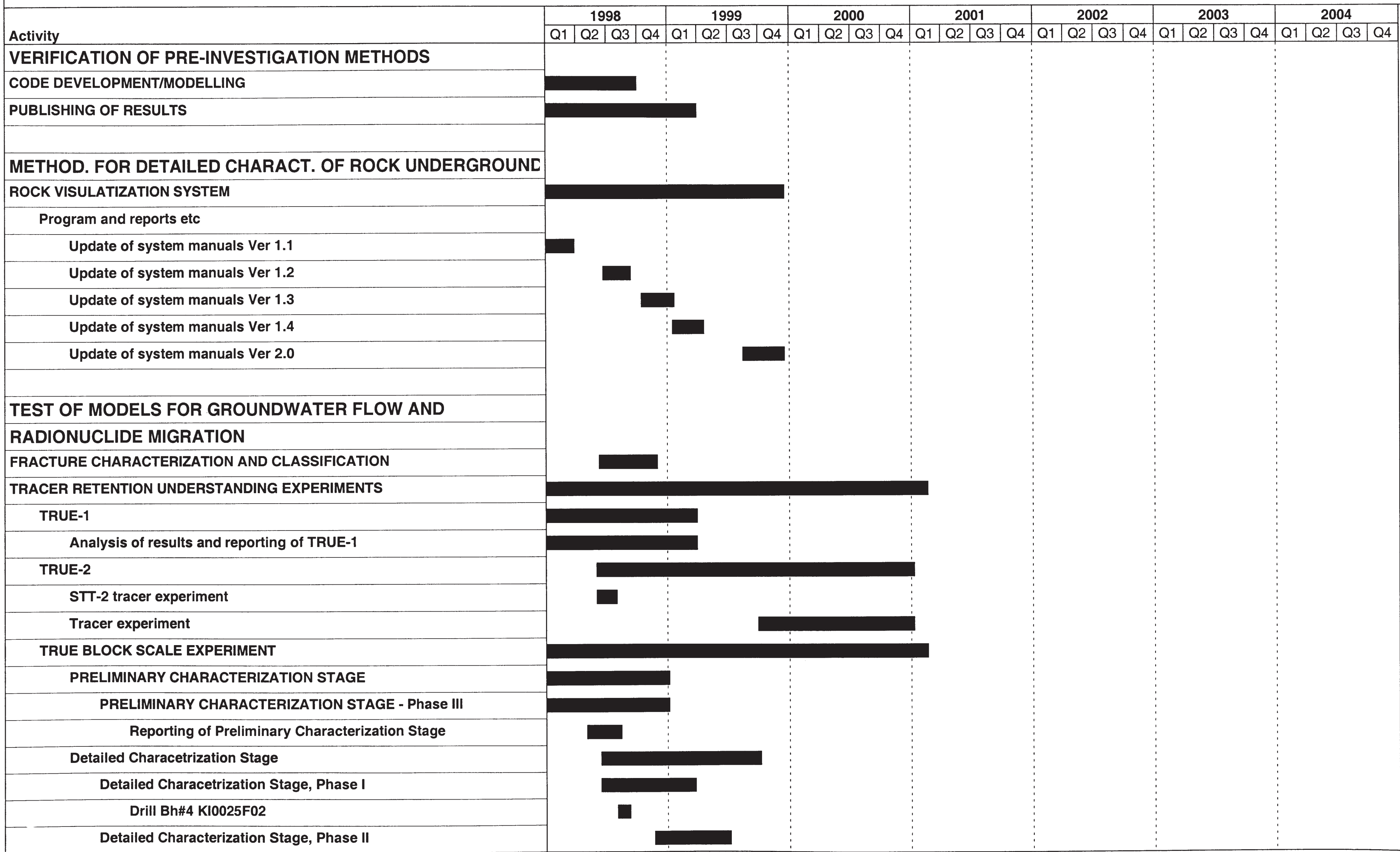

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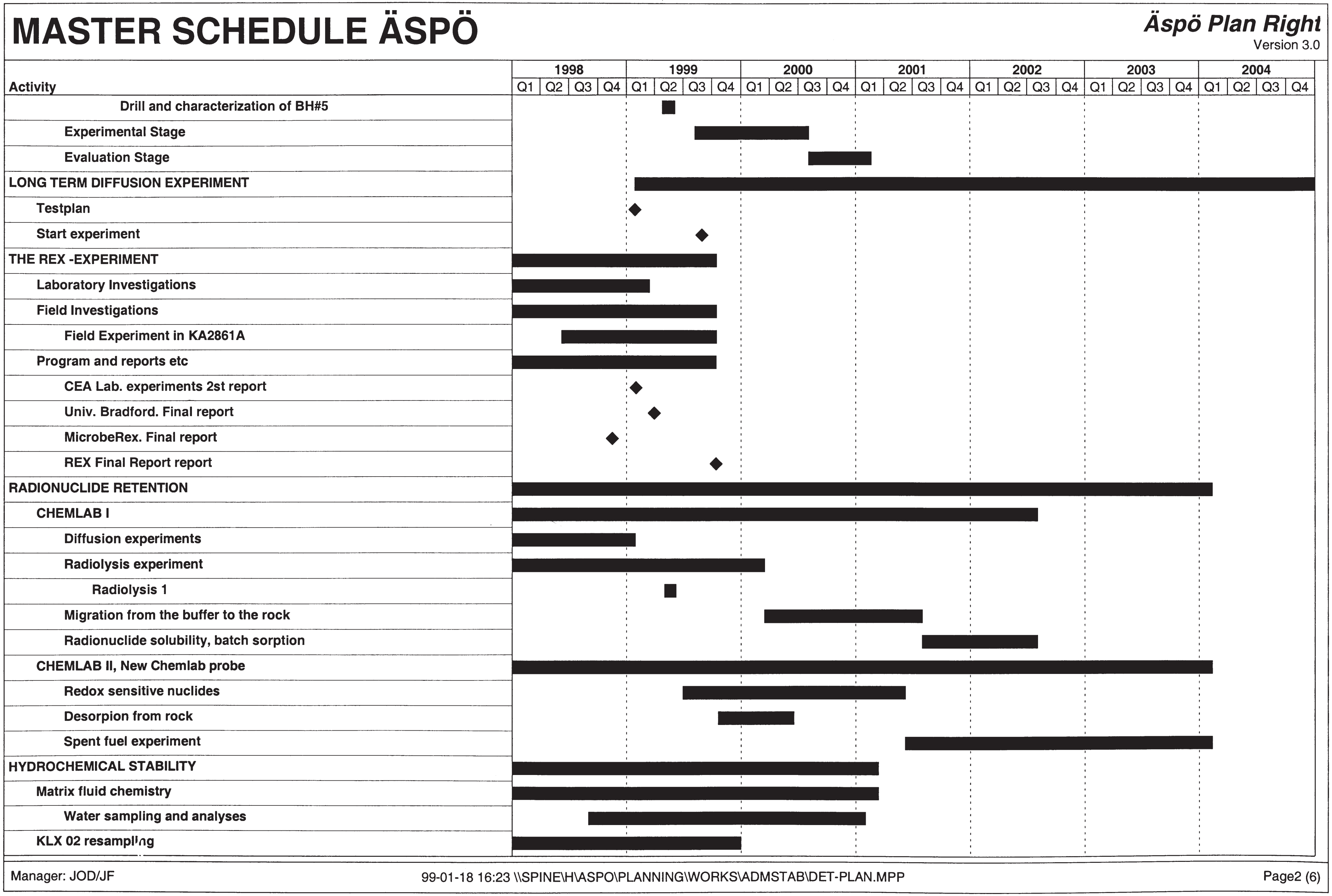
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Version 3.0
Activity
1998
1999
2000
2001
2002
2003
2004
Q1 Q2 Q3 Q4
Drill and characterization of BH#5
Experimental Stage
Evaluation Stage
LONG TERM DIFFUSION EXPERIMENT
Testplan
Start experiment
THE REX -EXPERIMENT
Laboratory Investigations
Field Investigations
Field Experiment in KA2861A
Program and reports etc
CEA Lab. experiments 2st report
Univ. Bradford. Final report
MicrobeRex. Final report
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
Desorpion from rock
Spent fuel experiment
HYDROCHEMICAL STABILITY
Matrix fluid chemistry
Water sampling and analyses
KLX 02 resampling
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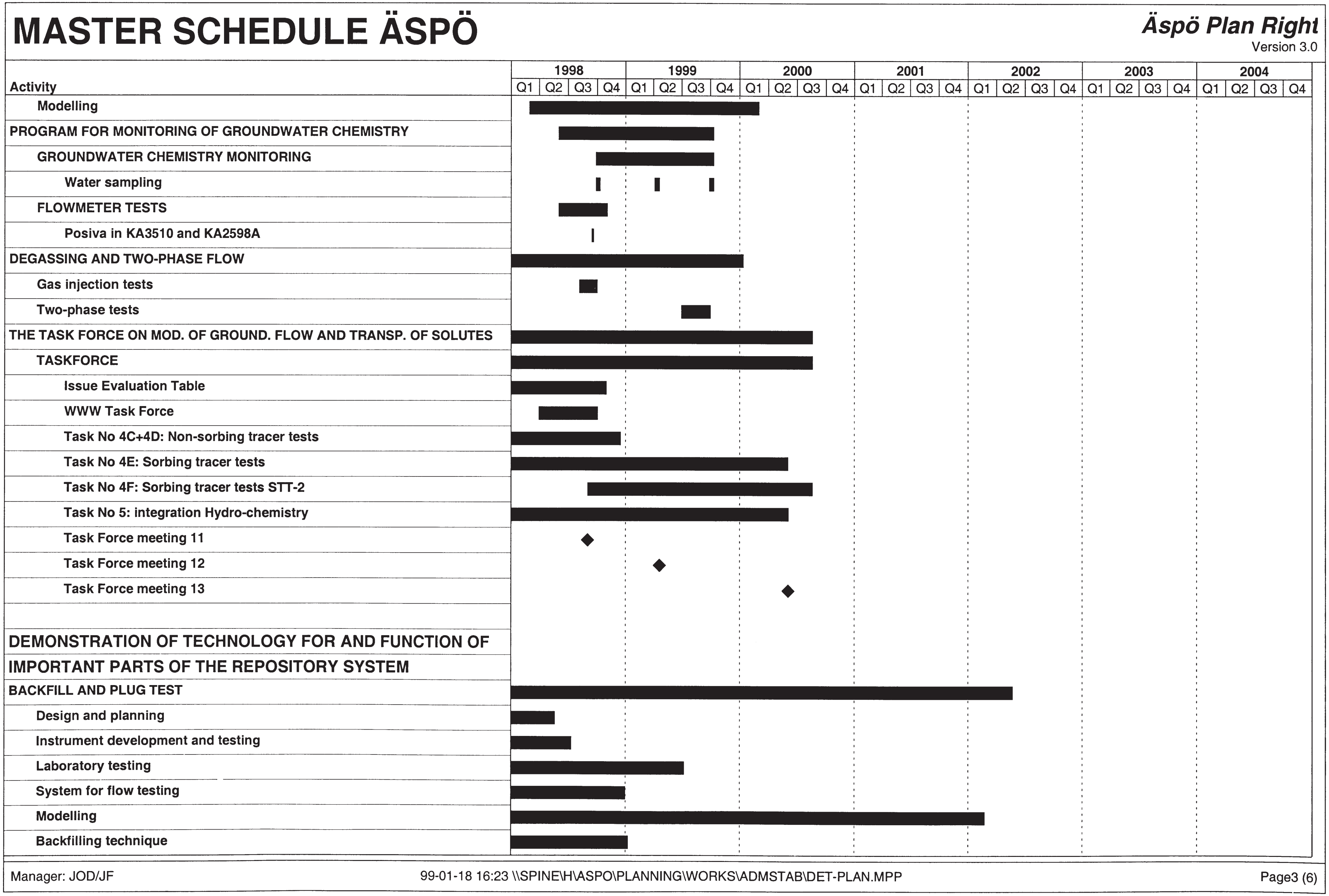
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Äspö Plan Right
Version 3.0
Activity
1998
1999
2000
2001
2002
2003
2004
Q1
Q2
Q3
Q4
Modelling
PROGRAM FOR MONITORING OF GROUNDWATER CHEMISTRY
GROUNDWATER CHEMISTRY MONITORING
Water sampling
FLOWMETER TESTS
Posiva in KA3510 and KA2598A
DEGASSING AND 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 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
Laboratory testing
System for flow testing
Modelling
Backfilling technique
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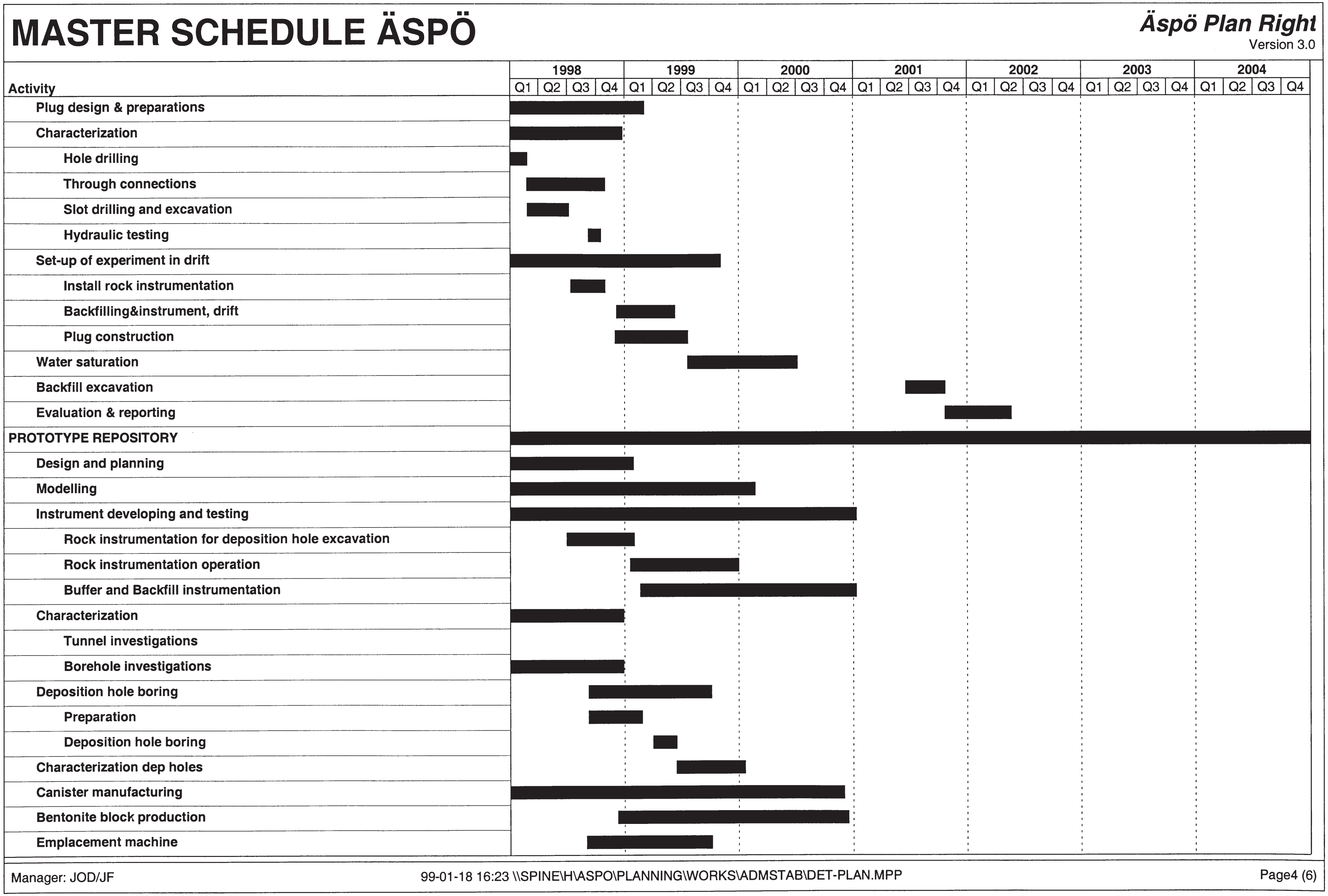

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Äspö Plan Right
Version 3.0
Activity
1998
1999
2000
2001
2002
2003
2004
Q1
Q2
Q3
Q4
Plug design & preparations
Characterization
Hole drilling
Through connections
Slot drilling and excavation
Hydraulic testing
Set-up of experiment in drift
Install rock instrumentation
Backfilling&instrument, drift
Plug construction
Water saturation
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 boring
Preparation
Deposition hole boring
Characterization dep holes
Canister manufacturing
Bentonite block production
Emplacement machine
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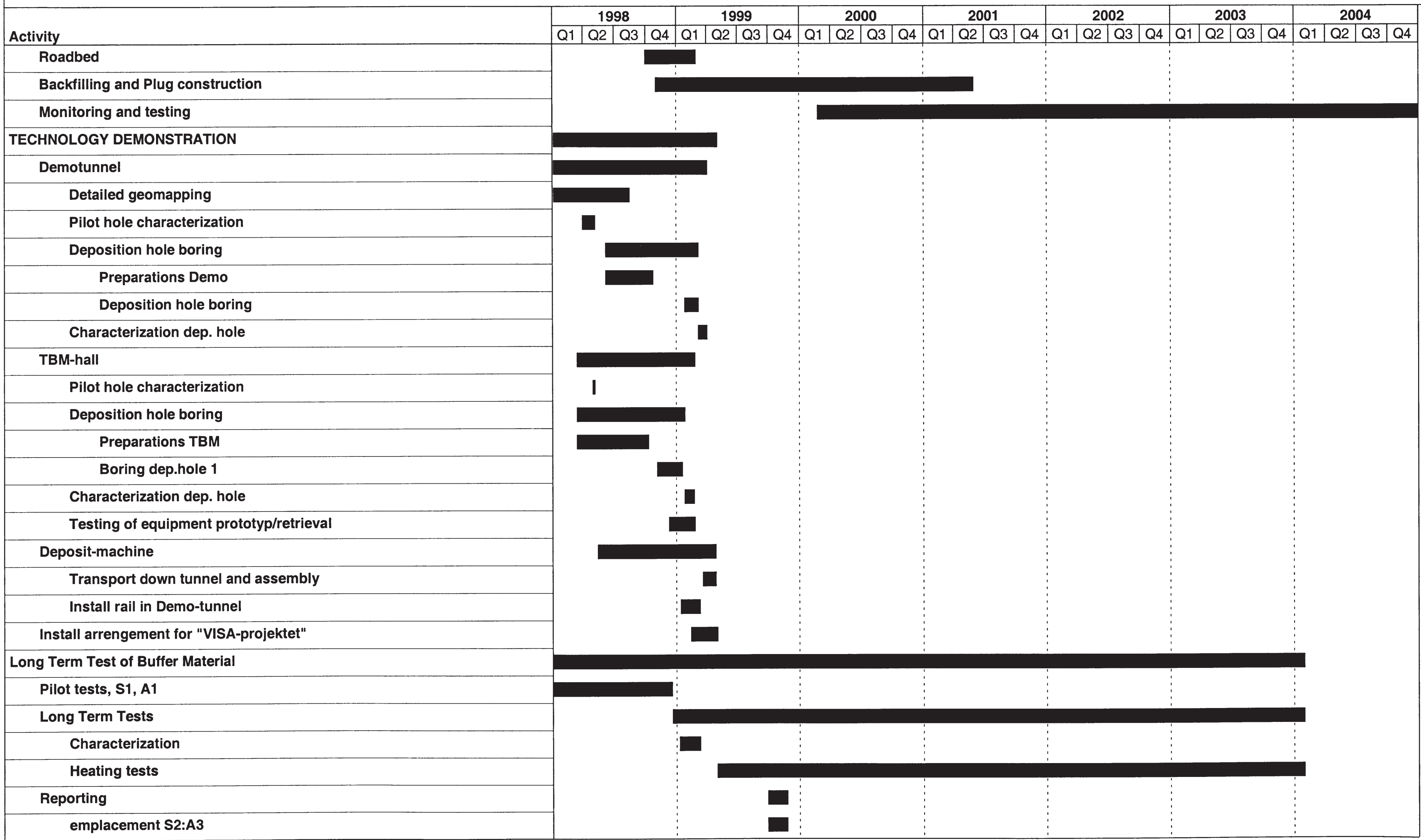

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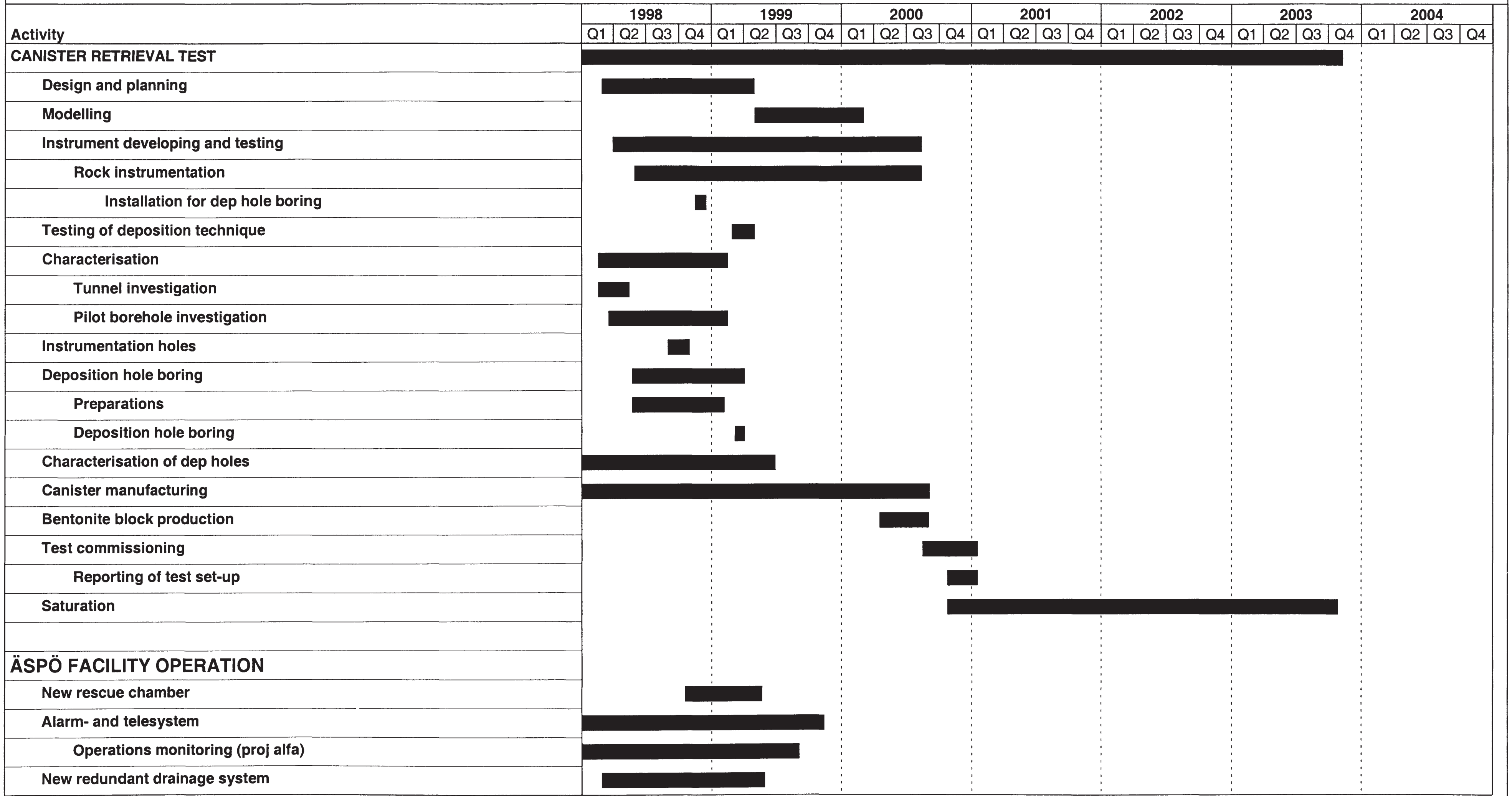

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