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Äspö Hard Rock Laboratory
Annual Report 1994

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ÄSPÖ HARD ROCK LABORATORY

ANNUAL REPORT 1994

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ABSTRACT

The Äspö Hard Rock Laboratory is being constructed as part of the preparations for the deep geological repository of spent nuclear fuel in Sweden. The Annual Report 1994 for the Äspö Hard Rock Laboratory contains an overview of the work conducted.

Present work is focused on verification of pre-investigation methods and development of detailed investigation methodology which is applied during tunnel construction. Construction of the facility and detailed characterization of the bedrock are performed in parallel. Excavation of the main access tunnel was completed during 1994 and at the end of the year only minor excavation work remained. The last 400 m of the main tunnel, which has a total length of 3600 m, was excavated by a 5 m diameter tunnel boring machine (TBM). The tunnel reaches a depth of 450 m below ground.

Preparations for the Operating Phase have started and detailed plans have been prepared for several experiments.

Nine organizations, including SKB, from eight countries are now participating in the work at the Äspö Hard Rock Laboratory and are contributing to the work performed and results achieved.

SAMMANFATTNING

Äspölaboratoriet anläggs som en förberedelse för djupförvaret av det svenska använda kärnbränslet. Denna årsrapport för 1994 ger en översikt av det genomförda arbetet.

Nuvarande arbete är inriktat på att verifiera förundersökningsmetoder och att utveckla detaljundersökningsmetodik. Byggande och undersökningar av berggrunden sker parallellt. Brytningen av huvudtunneln slutfördes 1994 och i slutet på året återstod endast mindre bergarbeten. De sista 400 metrarna av huvudtunneln, som har en total längd av 3600 m, bröts ut med en tunnelborrningsmaskin (TBM) med 5 meters diameter. Tunneln når ett djup av 450 m under markytan.

Förberedelserna för driftsfasen har påbörjats och detaljerade planer har tagits fram för flera experiment.

Nio organisationer, inklusive SKB, från åtta länder deltar nu i Äspölaboratoriets verksamhet och medverkar på olika sätt till de uppnådda resultaten.

EXECUTIVE SUMMARY

The Äspö Hard Rock Laboratory is being constructed as part of the preparations for the deep geological repository of spent nuclear fuel in Sweden.

The work with the Äspö Hard Rock Laboratory, HRL, has been divided into three phases; the pre-investigation, the construction, and the operating phase. The construction phase is now near completion and the operating phase will begin in 1995.

The pre-investigation phase aimed at site selection for the laboratory, descriptions of the natural conditions in the bedrock and prediction of changes that will occur during construction of the laboratory. The construction of the access ramp is used to check the predictive models set up from the pre-investigation phase, to develop methodology for construction and testing integration, and to increase the database on the bedrock properties in order to improve models on groundwater flow and radionuclide migration. The operating phase is aimed at research and development on models for groundwater flow and radionuclide transport, tests of methods for construction and handling of waste and pilot-tests of important parts of the repository system. Detailed plans have been now prepared for several of the projects planned for the operating phase.

Stage goal 1 – Verification of pre-investigation methods

Excavation of the main access tunnel was completed in September 1994 and the investigations tied to the construction work a few months thereafter. The main experiences gained during the first two phases of the Äspö HRL will be compiled in a report that will be completed in 1995. In general, the site characterization approach used has been found useful. The idea of dividing the investigations into different stages, scales and key issues has simplified the evaluation work considerably and further use of this approach is advocated.

In general, predictions of geologic and hydrogeologic conditions have been in agreement with observations made during the Construction Phase.

The predicted composition of the groundwater in major fracture zones and the salinity in the zones is different from the observation. There are different possible explanations such as mixing ahead of the tunnel front and/or incorrect conceptual models.

Stage goal 2 – Finalize detailed investigation methodology

The detailed characterization of a repository will encompass investigations during construction of shafts/tunnels to repository depth. Finalizing the detailed investigation methodology is Stage goal 2 of the Äspö project.

In the pre-investigation phase, the characterization of the rock was to a large extent based on data collected from boreholes. In the construction phase, a lot of data are collected by observations made in drifts. A study has been initiated in order to understand how the differences in data collected in boreholes and tunnels influence our understanding of the rock.

To obtain a better understanding of the properties of the disturbed zone and its dependence on the method of excavation ANDRA, UK Nirex, and SKB have decided to perform a joint study of disturbed zone effects. The project is named ZEDEX (Zone of Excavation Disturbance EXperiment).

The experiment is performed in two test drifts near the TBM Assembly hall at an approximate depth of 420 m below the ground surface. Measurements of rock properties have been made before, during, and after excavation. The investigation program includes measurements of fracturing, rock stress, seismic velocities, displacements, and permeability. The preliminary analysis of the results obtained so far indicates that the measurable changes in properties induced by excavation of the TBM tunnel are small to negligible.

Stage goal 3 – Tests of models for groundwater flow and radionuclide migration

It is necessary to demonstrate the safety of the deep repository over long spans of time. Important phenomena that must be taken into account in the safety assessment are:

- transport of corrodants to the canister, and
- possible transport of radioactive materials away from a defective canister.

These phenomena are in turn highly dependent on groundwater flow and chemistry.

The conductivity of a single rock fracture is governed by the geometry of the fracture aperture. The geometry of a fracture was studied in the Pore Volume Characterization project which was completed in 1994. The result from this study shows larger aperture values, larger aperture variation and longer correlation distances as compared to results from similar studies previously reported in the literature. The explanation for this is suggested to be the difference in type of fracture studied and the larger scale of these measurements. The frequency distribution of the aperture shows that a large part of the data lies below the measurement limit, i.e. that the "contact area" is large (approximately 40%).

A "Program for Tracer Retention Understanding Experiments" (TRUE) was outlined in 1994. The basic idea is that tracer experiments will be performed in cycles with an approximate duration of 2-3 years. At the end of each tracer test cycle, results and experiences gained will be evaluated and the overall program for TRUE revised accordingly. A test plan which details the work during the First TRUE Stage has been prepared.

The project Degassing of groundwater and two phase flow has been initiated to improve our understanding of 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. A pilot test did not show any degassing effects due to a very low gas contents and high transmissivity in the hole selected for the test.

The Redox experiment in Block Scale was completed in 1994. The purpose of the block scale redox experiment was to investigate the chemical changes when oxidizing water is penetrating previously reducing fracture systems and to evaluate if complete flow paths can be oxidized from the surface to the repository. The experiment started in 1991 and lasted until 1994. No oxygen breakthrough was observed and the chemical composition remained constant throughout the experimental time. The explanation for this is that the high content of organic matter in the infiltrating surface water has been biologically oxidized at the same time as the dissolved oxygen has been reduced.

A draft test plan for the experiment has been prepared for the detailed scale experiment (REX).

The CHEMLAB probe is built to conduct validation experiments in situ at undisturbed natural conditions. This 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 use of the formation groundwater surrounding the probe. The manufacturing of the probe is presently under way.

A "Task Force" with representatives of the project's international participants has been formed. The Task Force is a forum for the organizations 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. The evaluation of Task No 1, the LPT2 pumping and tracer tests, is in progress. A wide variety of conceptual as well as numerical models have been used to predict water flow and tracer breakthrough in this rather large scale. Task No 2 was finalized during 1994. This concerned design calculations for some of the planned tracer experiments at the Äspö site. The hydraulic impact of the tunnel excavation at Äspö HRL was defined as the 3rd Modelling Task. The objective will be to evaluate how the monitoring and the study of the hydraulic impact of the tunnel excavation may help for site characterization. This will be an exercise in forward as well as inverse modelling.

Stage goals 4 and 5 – Development of construction and handling methods, pilot tests

The safety of a repository is determined by:

- the properties of the site,
- the design of the barriers,
- the quality of work during construction of the deep repository.

The Äspö HRL provides an opportunity for demonstrating technology that will be used in the deep repository. The need to integrate existing knowledge and build an (inactive) prototype of a deep repository is recognized within SKB. A part of a deposition tunnel will be built and backfilled at Äspö. In conjunction with planning, design and construction, work descriptions and quality plans are being prepared which can later be used for the deep repository. The objectives include translating scientific knowledge into engineering practice, testing and demonstrating the feasibility of the various techniques, and demonstrating that it is possible to build with adequate quality. A programme for the prototype repository was prepared during 1994.

Engineering and construction work

A tunnel ramp has been excavated from the Simpevarp peninsula 1.5 km out under the Äspö Island. The tunnel begins in the vicinity of the Oskarshamn nuclear power plant. The research tunnel reaches the Äspö island at a depth of 200 m. The area of the tunnel section is 25 m^2. The tunnel then continues in a hexagonal spiral under Äspö down to a depth of 420 m. The tunnelling to this depth was done by means of conventional drill and blast. In the final part of the spiral full-face boring with a Tunnel Boring Machine, TBM, has been tested. A rock cavern was excavated at 420 m level for assembly of the TBM. The tunnel then goes down to the 450 m level close to the shafts and continues horizontally westward to an experimental volume. The diameter of the TBM drilled tunnel is 5 m.

Office and storage buildings have been built on the Äspö Island as well as buildings for ventilation equipment and machinery for the hoist. Together, these buildings comprise the "Äspö Research Village", which is designed to look like other small villages in the surrounding archipelago. The village was completed in 1994.

International participation

The construction of the Äspö Hard Rock Laboratory (HRL) has attracted significant international attention. Presently (April 1995) eight organizations from seven countries participate. They are:

- Atomic Energy of Canada Limited (AECL), Canada.
- The Power Reactor and Nuclear Fuel Development Co. (PNC), Japan.
- The Central Research Institute of the Electric Power Industry (CRIEPI), Japan.
- Teollisuuden Voima Oy (TVO), Finland.
- Agence National pour la Gestion des Dechets Radioactifs (ANDRA), France.
- United Kingdom Nirex Limited (NIREX), United Kingdom.
- National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland.
- United States Department of Energy (USDOE), USA.

During autumn 1994 negotiations with Bundesministerium für Forschung und Technologie (BMFT) in Germany has been taken place regarding cooperation in the Äspö Hard Rock Laboratory.

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1 INTRODUCTION

1.1 BACKGROUND

The scientific investigations within SKB's research program are part of the work of designing a deep repository and identifying and investigating a suitable site. This requires extensive field studies of the interaction between different engineered barriers and the host rock.

A balanced appraisal of the facts, requirements and evaluations presented in connection with the preparation of R&D-Programme 86 /1-1/ led to the proposal to construct an underground research laboratory. The proposal was very positively received by the reviewing bodies.

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 arrived at a decision in principle to site the facility on southern Äspö, about 2 km north of the Oskarshamn Nuclear Power Station, see Figure 1-1. After regulatory review, SKB began the excavation of the Äspö Hard Rock Laboratory facility in the autumn of 1990. A number of investigations have been conducted in conjunction with the excavation of the facility. The final part of the facility was excavated by a 5 m diameter Tunnel Boring Machine.

Most of the construction work for the laboratory was finalized during 1994. The Äspö Research Village was finished during summer 1994 and in August the Site Office was moved to the Äspö Island. The hoist and ventilation system were installed in the surface buildings and installations in the shaft are in progress.

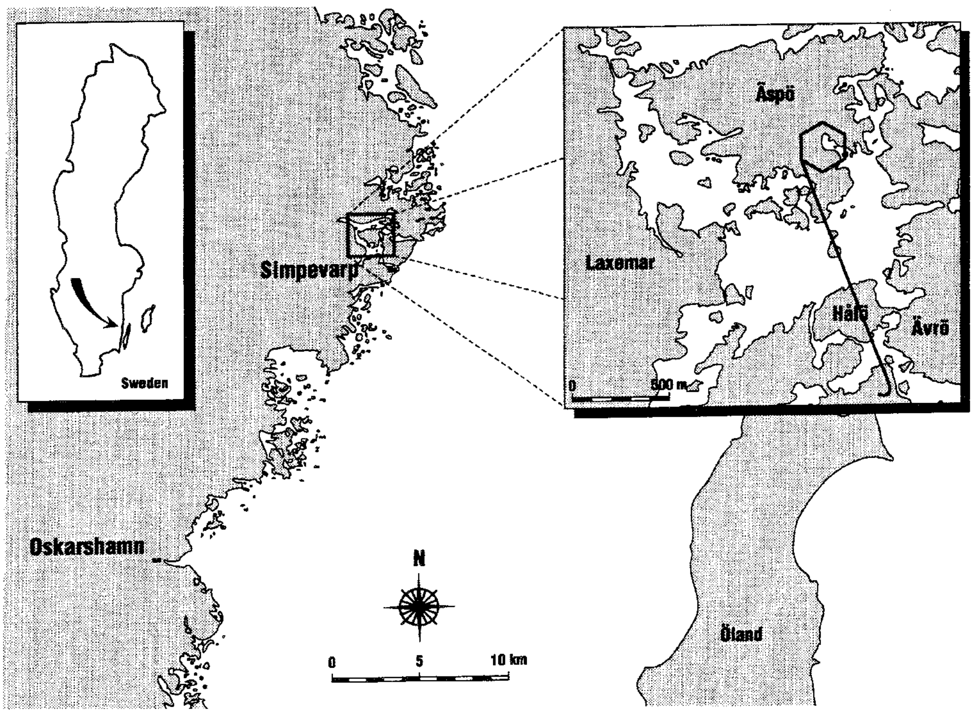

Figure 1-1. Location of the Äspö HRL.

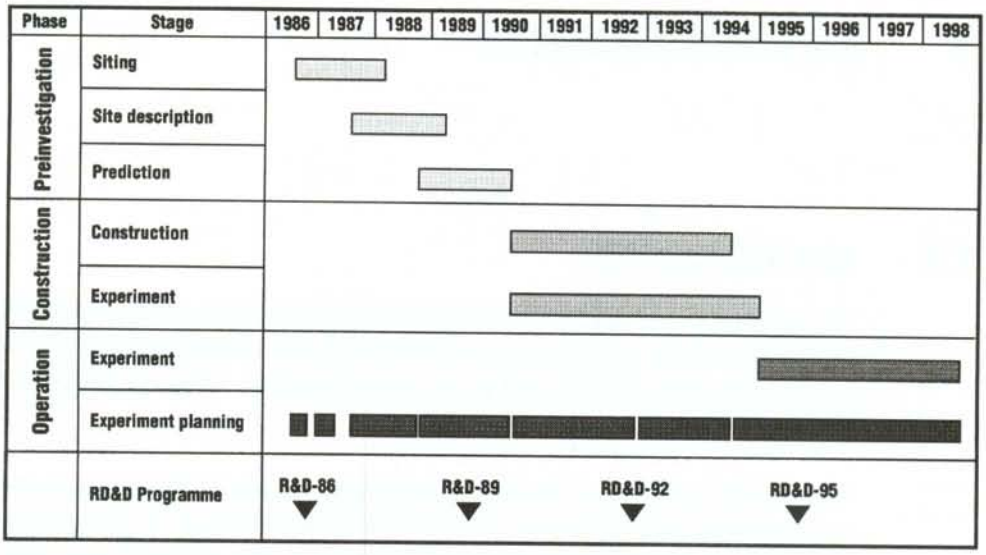

Figure 1-2. *Master time schedule for the Äspö HRL.*

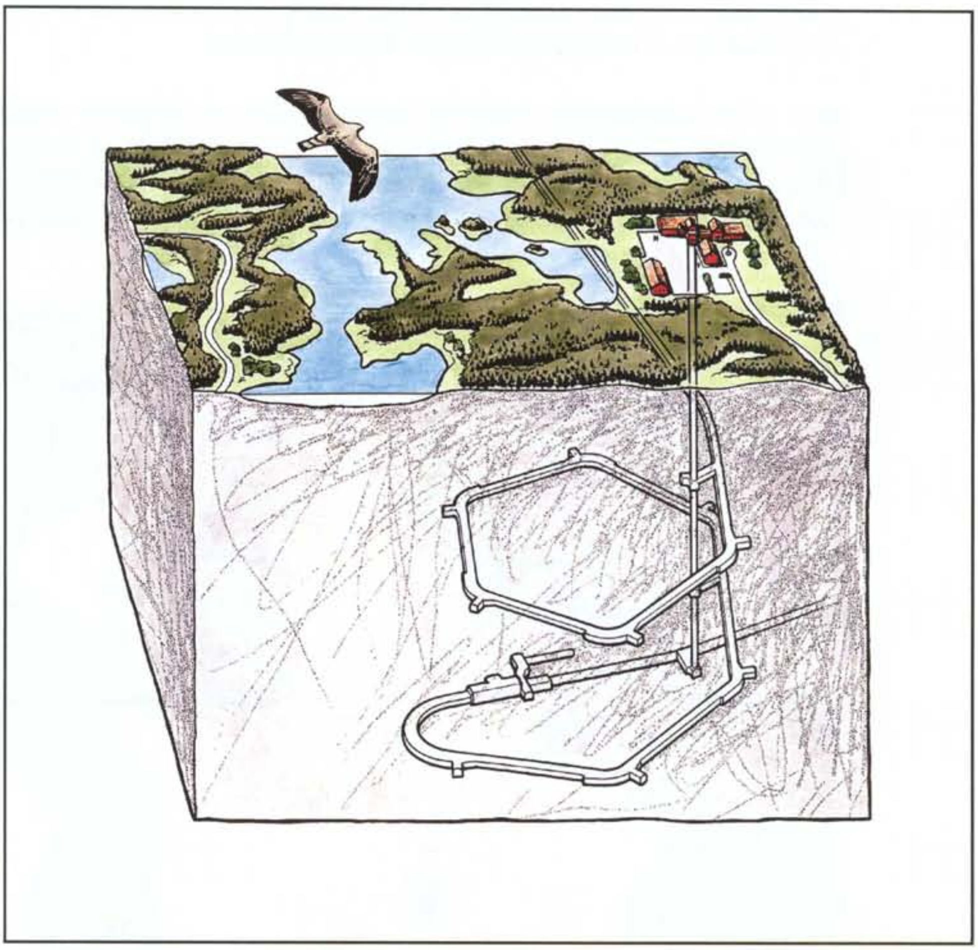

Figure 1-3. *Schematic design of the Äspö HRL. The lower part of the facility has been excavated by a 5 m diameter Tunnel Boring Machine.*

The work on the Äspö Hard Rock Laboratory, HRL, has been divided into three phases: the Pre-investigation phase, and the Construction and the Operating phases, see Figure 1-2.

The Pre-investigation phase was aimed at selecting a site for the laboratory, describing the natural conditions in the bedrock and predicting changes that will occur during construction of the laboratory. The results of the Pre-investigations have been summarized in eight Technical Reports /1-2–9/. The construction of the 3600 m long access ramp to a depth of c. 450 m, see Figure 1-3, is used to check the prediction models set up from the pre-investigation phase, to develop methodology for detailed characterization underground, including construction/testing integration, and to increase the database on the bedrock properties in order to improve models of groundwater flow and radionuclide migration. A preliminary program for the Operating phase was defined /1-10/ as part of the general SKB RD&D-Programme 92 /1-11/. The Operating phase will focus on research and the development of models for groundwater flow and radionuclide migration, tests of construction and handling methods and pilot tests of important parts of a repository system.

The project has so far attracted considerable international interest. As of February 1995, eight international organizations are participating in the Äspö HRL. They are Atomic Energy of Canada Limited (AECL, Canada), Teollisuuden Voima Oy (TVO, Finland), Agence nationale pour de gestion des déchets radioactifs, (ANDRA, France), Power Reactor and Nuclear Fuel Development (PNC, Japan), the Central Research Institute of the Electric Power Industry, (CRIEPI, Japan), NAGRA (Switzerland), UK NIREX Ltd, and the US Department of Energy. Negotiations on participation are in progress with Bundesministerium für Forschung und Technologie (Germany).

1.2 OBJECTIVES

A detailed outline of the project (goals, scope, schedules, organization, previous work) can be found in RD&D-Programme 92 /1-10/ and they are repeated here:

SKB has 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.

The Äspö Hard Rock Laboratory shall constitute an important complement to the other work being conducted within SKB's research program.

Demands on the quality of the research are very high and the overall ambition is that the laboratory shall be an internationally leading center of research, development and demonstration regarding the construction of final repositories for high-level nuclear waste.

1.2.1 Main goals

The main goals of the RD&D activities in the Äspö Hard Rock Laboratory are as follows:

- Test the quality and appropriateness of different methods for characterizing the bedrock with respect to conditions of importance for a deep repository.

- Refine and demonstrate methods for adapting a deep repository to the local properties of the rock in connection with planning and construction.
- Collect material and data of importance for the safety of the deep repository and for confidence in the quality of the safety assessments.

The last goal is general for SKB's entire RD&D program.

1.2.2 Stage goals

To meet the overall time schedule for SKB's RD&D work, the following stage goals have been defined for the activities at the Äspö Hard Rock Laboratory, Figure 1-4.

Prior to the siting of the deep geological repository for spent nuclear fuel in the mid-1990s, the activities at the Äspö Hard Rock Laboratory shall serve to:

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 Finalize detailed investigation methodology

- refine and verify the methods and the technology needed for characterization of the rock in the detailed site investigations.

As a basis for a good optimization of the repository system and for a safety assessment as a basis for the siting application, which is planned to be submitted a couple of years after 2000, it is necessary to:

3 Test models for groundwater flow and radionuclide migration

- refine and test on a large scale at repository depth methods and models for describing groundwater flow and radionuclide migration in rock.

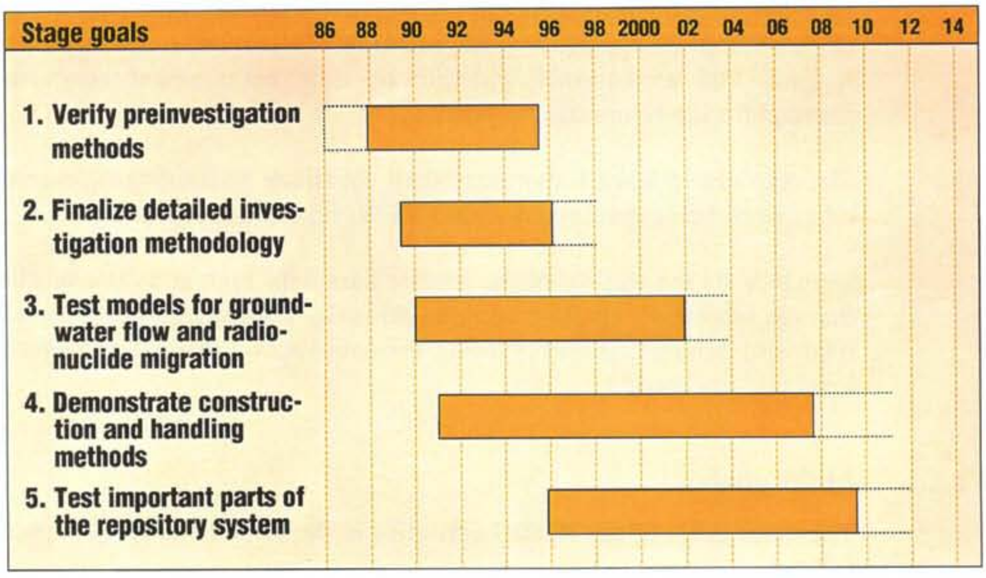

Figure 1-4. *Overview of the Äspö HRL stage goals.*

In preparation for the first phase of the deep repository, which is planned to begin in 2005, the following shall be done at planned repository depth and under representative conditions:

4 Demonstrate construction and handling methods

- provide access to rock where methods and technology can be refined and tested so that high quality can be guaranteed in the layout, construction and operation of the deep geological repository, and

5 Test important parts of the repository system

- test, investigate and demonstrate in a full scale different components of importance for the long-term safety of a deep repository system.

The objective of these tests is to provide the background material necessary for Government approval of the start of construction of the deep geological repository. Certain tests are therefore planned to start in the mid-90s.

1.3 ORGANIZATION

The work at the Äspö HRL has been managed as a multi-project operation. Now, as the Construction Phase is about to end, several organizational changes are planned to ensure quality of work, efficiency, time and cost management. A schematic chart of the organization of the Äspö HRL valid from January 1995 is shown in Figure 1-5.

1.3.1 The Program Committee for the Deep Repository

The committee is SKB's internal joint steering/advisory group for the deep repository project and the Äspö HRL project. The Program Committee proposes and/or discusses changes in the technical/scientific program and changes in quality, schedule and cost frames. Coordination with SKB's other RD&D work also takes place within the SKB Program Committee.

1.3.2 Advisory Groups

International coordination was previously done by the Technical Coordinating Board (TCB). Scientific review was done by the Scientific Advisory Committee (SAC).

SKB proposed a revised organization for the Operating Phase. 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 meetings.

For each experiment the project will establish a Peer Review Panel consisting of a very few members.

SKB has also established a Construction Advisory Committee (CAC) to give advice to the project. The group was abolished at the end of 1994 as the Construction Phase is reaching completion.

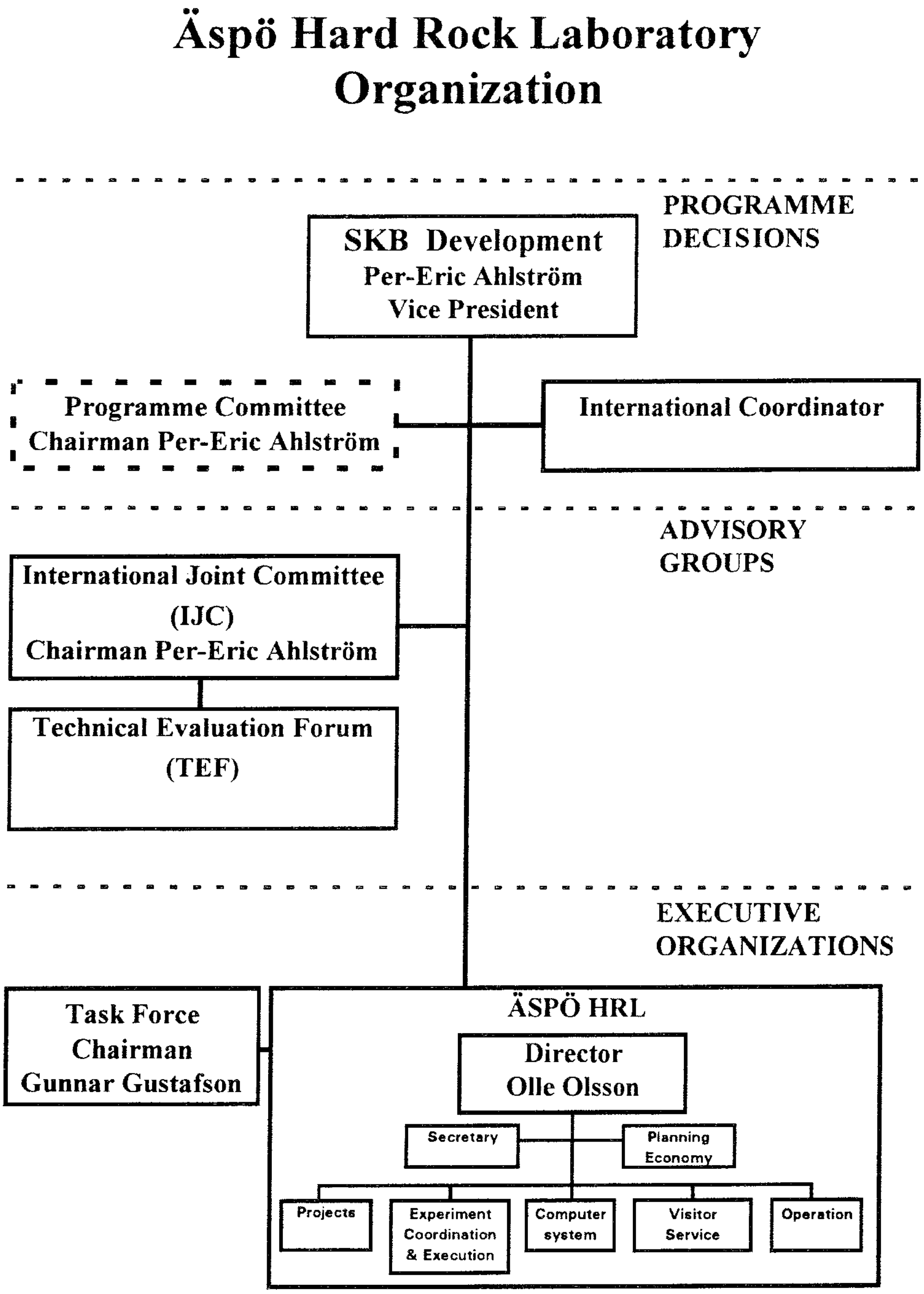

Figure 1-5. *Organization of the Äspö Hard Rock Laboratory valid from January 1995.*

1.3.3 Project Groups

Project Group 1986-1994

The Project Group that executed the Äspö Project during the period 1986-1994 will continue its efforts during 1995 to evaluate and publish the results and experience gained during the period 1986-1994.

Projects 1995–

For the Operating Phase the organization has been revised.

Each major research and development task is organized as a project which is led by a Project Manger. Each Project Manager will be assisted by a Project Coordinator from the Site Office with responsibility for coordination and execution of project tasks at the Äspö HRL.

The staff at the Site Office will be increased to ensure that efficient service and high quality work can be provided to the projects. The idea is that a staff of around 10 members will constitute a suitable core of resources.

The Äspö Hard Rock Laboratory and the associated research, development, and demonstration tasks are managed by the Director of the Äspö Hard Rock Laboratory. The Operations Manager is responsible for the operation and maintenance of the Äspö HRL facilities.

Work should be conducted according to the guidelines provided by the Äspö Quality Handbook (in Swedish) and the Äspö Handbook (in prep).

1.3.4 Task Force on modelling of groundwater flow and transport of solutes

The previous TCB established this 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. More than ten different modelling groups are now actively involved in the work. Chairman (February 1995) is Gunnar Gustafson, CTH and secretary Anders Ström, SKB.

1.4 FORMULATION OF EXPERIMENTAL PROGRAM

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 organization 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 Programs will be prepared outlining the objectives and overall scope of the programs, which will be divided into stages with a duration of 2-3 years. Detailed Test Plans will then be prepared successively for each stage, following an evaluation of results obtained so far. These evaluations may result in program revisions.

Initially, draft Test Plans will be prepared which will be submitted for review by a review panel of acknowledged experts. The plans are also discussed and evaluated by the Task Force, the IJC, and at TEF meetings. 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 flow and transport experiments.

Draft Test Plans for three of the experiments were distributed early 1993 and reviewed by the Task Force, the SAC, and the TCB. Based on these reviews the Test Plans were updated and reviewed by an expert panel. The reviews resulted in a restructuring of the proposed tracer tests into an integrated program. This program for Tracer Retention Understanding Experiments (TRUE) was prepared during 1994 /1-12/. The program was then supplemented by a detailed Test Plan /1-13/ for the first tracer test cycle outlined in the program. A Test Plan was also prepared for the project "Degassing of groundwater and two-phase flow" /1-14/.

A pilot study on the feasibility and need for a prototype repository at Äspö was finalized during 1994. Based on the pilot study and discussions in the SKB Program Committee a Program for a Prototype Repository Project was presented /1-15/.

2 VERIFICATION OF PRE-INVESTIGATION METHODS

2.1 GENERAL

The purpose of pre-investigations or site investigations is to:

- show whether a site has suitable geological properties,
- provide data and knowledge concerning the bedrock on the site so that a preliminary emplacement of the repository in a suitable rock volume can be done as a basis for constructability analysis,
- provide the necessary data for a preliminary safety assessment, which shall serve as support for an application under NRL (the Act Concerning the Management of Natural Resources) to carry out detailed site characterization,
- provide data for planning of detailed site characterization.

It is thus important to show that pre-investigations provide reasonable and robust results.

In order to verify the pre-investigations methods, a strategy was set up, see Figure 2-1.

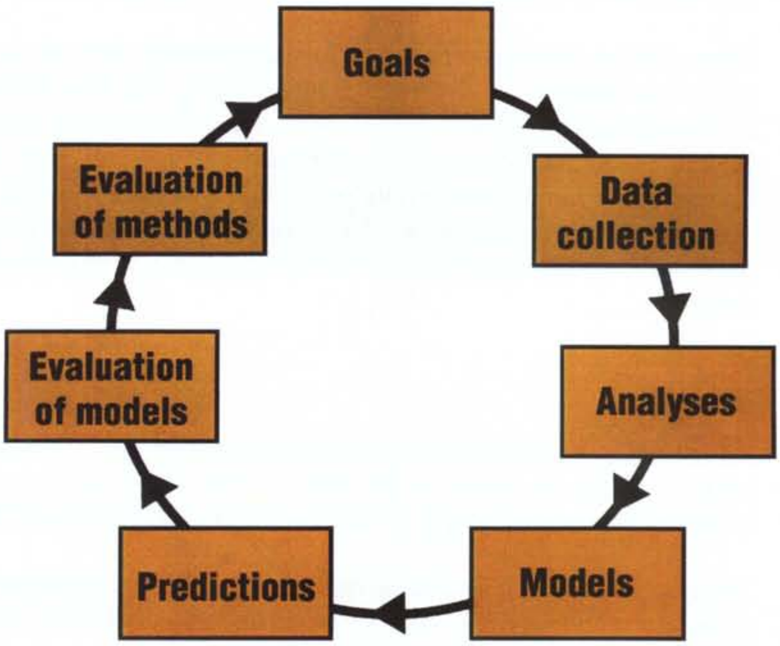

Figure 2-1. *The strategy for verification of the pre-investigation methods.*

This strategy entails predictive statements of certain rock properties. These statements have been structured to different geometrical scales for different key issues. The predictions have been reported in /2-1/. During construction of the facility these predictions of the bedrock are checked against the data collected during the construction work.

The work in 1995 will basically focus on

- evaluation of the predictive models set up prior to the start of excavation,
- the final site-specific model of the Äspö area,
- evaluation of the methods used in the pre-investigation phase. This evaluation covers strategy for the pre-investigation, methods for data collection, analyses, predictions and evaluations.

The knowledge will be applied in the planning for and execution of site investigations on the candidate sites for the deep repository.

2.2 DATA COLLECTION AT THE SITE OFFICE

2.2.1 Background

Characterization in the tunnel is performed by the Characterization Team at the Site Office. Overview of the geological mapping, data on geohydrology, groundwater chemistry and bedrock stability and reinforcement/grouting are presented after every 150 metres of tunnel excavation in three different sheets.

Separate tables on groundwater chemistry data (pH, Cl, and HCO_3) are reported as well. Activities that have taken place in the tunnel, blasting, grouting, probe hole drilling, coring, packer settings and so on are reported in a Site Activity Data Base.

Groundwater level data from all core-drilled and most of the percussion-drilled boreholes located on Äspö are transmitted to the Site Office by radio to the Hydromonitoring system (HMS). A measuring central B positioned close to the shaft level at -220 metres level, chainage 1650 m, collects data from boreholes located in the tunnel, from weirs positioned at regular intervals, measures velocity of ventilation air and tunnel air, humidity, amount of water pumped in to and out of the tunnel, see Figures 2-2 and 2-3. This data are used for water balance determinations.

2.2.2 Results

From chainage 2872 m the characterization of the tunnel has been performed after tunnel excavation down to the start of the TBM tunnel at chainage 3191 m, including the assembly hall for the Tunnel Boring Machine (TBM).

The manual for the characterization work has been updated and revised according to the introduction of the Tunnel Boring Machine (TBM). This manual has been drafted and will be printed in March 1995.

Mapping of the TBM tunnel from chainage 3191 to 3599 m has been performed as well as mapping of shafts between the level -450 to -330 m.

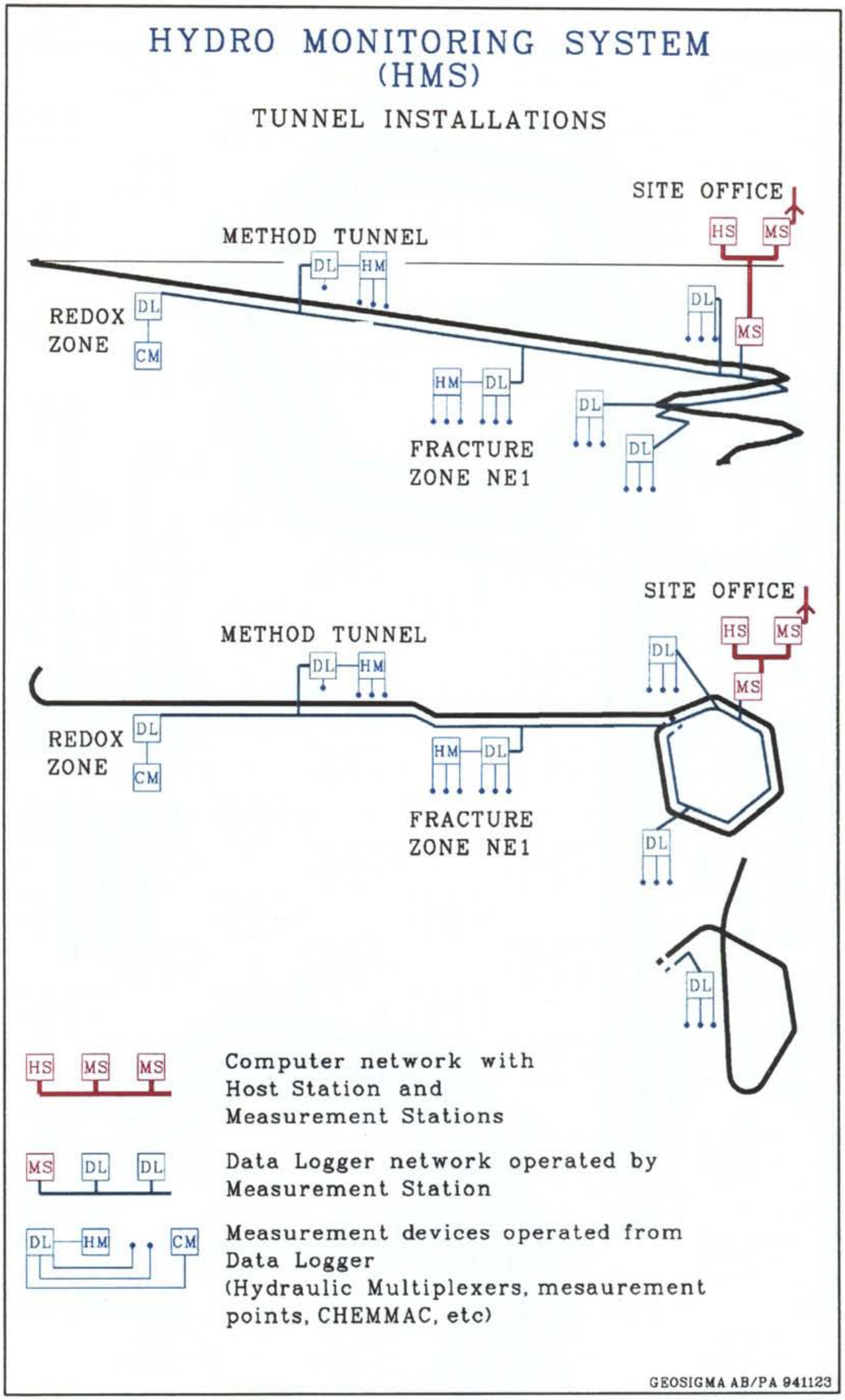

Figure 2-2. Hydro Monitoring System (HMS), tunnel installations.

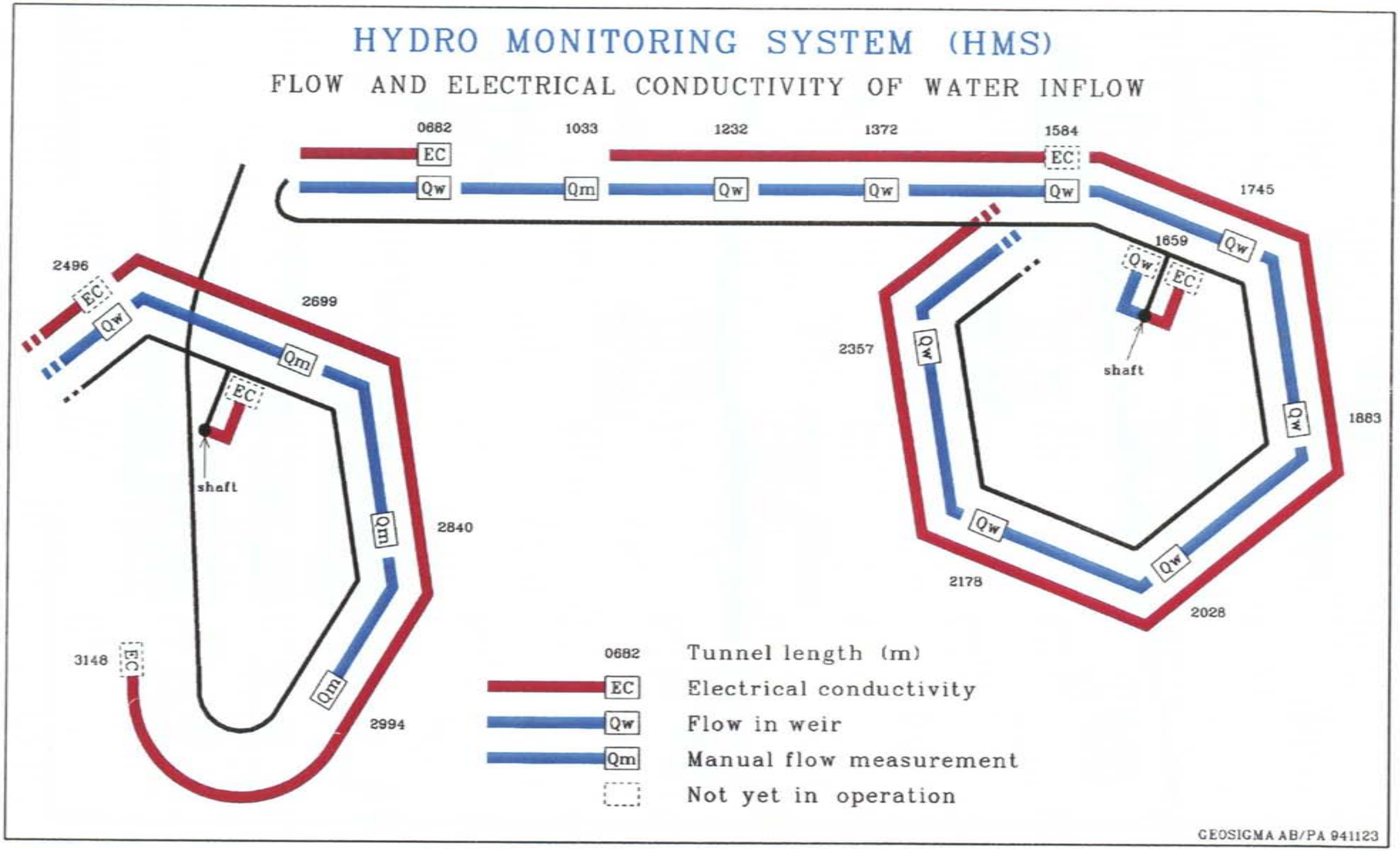

Figure 2-3. *Hydromonitoring System (HMS), installations for measurement of flow and electrical conductivity of inflowing water.*

A follow-up of pressures in all packed-off sections in most of the probe-holes in the tunnel has been performed in spring and autumn 1994. Short drilled probe holes, 8 m, have been drilled in the TBM tunnel, for studies of the pressure distribution around the TBM tunnel.

Absolute calibration of ground water levels of all sections in all boreholes was performed in January, March, and September.

The characterization team has also performed core logging and supervision of the core drilling of the cored hole KA1755A. This borehole was drilled to investigate the fracture zone EW-1 in detail and provide sections for groundwater level monitoring, water circulation, and dilution measurements.

Core logging, TV-inspection, and supervision of the core drilling have been done in connection with the ZEDEX experiment, two-phase flow experiment and the first phase of TRUE- experiment (SELECT).

2.2.3 Planned work

Distribution of all data collected, including the TBM-tunnel, will be done for the evaluation of Stage goal 1: Verification of preinvestigation methods and models.

Packer installations for monitoring of the pressure around the TBM- tunnel will be done. Monitoring of pressures in all packed-off sections in most of the probe-holes in the access and spiral tunnel will also be performed.

Monitoring of water inflow into the tunnel to the weirs and maintenance of dams and weirs will continue.

2.3 EVALUATION OF MODELS AND METHODS

2.3.1 Background

The first stage goal for Äspö HRL is:

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.

Reporting on the comparison of predictions based on surface and borehole data and observations (outcome) in the tunnel has been made in order to evaluate the reliability and correctness of the prediction models. The reporting has been divided into four parts, related to the length coordinate along the tunnel.

An assessment of the agreement between prediction and outcome has been made for the first part, 0-700 m (depth 100 m), /2-2/. The comparison of prediction and outcome up to tunnel section 700-2874 m (depth 200 m) has been reported /2-3–14/.

2.3.2 Results

Reporting of experiences

The final reporting of experiences from the ongoing work has started in autumn 1993. The outline of the report was presented at the SAC meeting in December 1993. The report is based on thirteen questions which are considered important for the planning and construction of a future deep repository.

The report is not intended to give complete answers but the intention is to highlight important experiences. The report will be issued summer 1995. Below some of the experiences gained are presented.

The site characterization approach used has been useful. The idea of dividing the investigations into different stages, scales and key issues has simplified the evaluation work considerably and further use of this approach is advocated.

Due to the lithological heterogeneity, it seems that block scale predictions were not as useful as site and detailed scale predictions.

Constructability analysis should be added as a key issue to ascertain a good coupling between site characterization and the engineering work.

Based on a general site investigation strategy, the site specific strategy shall not be fixed until some preliminary field work has been evaluated, recognizing e.g. that major fracture zones can be hydraulically low-conductive and minor fracture zones can be highly conductive.

Based on data from the pre-investigation phase it was found difficult to determine:

- The exact position and orientation of minor sub-vertical fracture zones (e.g. NNW-structures at Äspö).
- The detailed character and importance of sub-vertical fracture zones.
- The relative importance of the different sub-horizontal fracture zone indications.
- The location and distribution of minor rock units at depth (e.g. greenstone lenses and veins of fine-grained granite).
- The validity of the theoretical model of the scale dependency of hydraulic properties.
- The hydraulic properties of minor rock types.
- The absolute water pressures in boreholes at great depth due to varying salinity with depth.
- The groundwater chemistry in low conductive rock masses.

There is a need for a more stringent methodology for assessment of the accuracy of measurement and evaluation methods.

The need for appropriate classification systems should not be underestimated. The fracture zone classification used has been useful /2-15/.

The nomenclature for theories, models and conceptual models was found out to be confusing. A nomenclature for SKB work has now been established /2-16/.

Three major drilling campaigns were carried out at Äspö prior to construction. The first three holes basically showed most of all the important general characteristics of the rock to be found at Äspö. These three holes also provided a good basis for parameter estimation of both average values and the variance of the parameters. The second and third campaigns (11 deep cored holes) were basically useful for increasing confidence in the geometry of major fracture zones and learning more about the minor fracture zones at Äspö. The geometry of the major fracture zones was very important for the layout of the Äspö facility, which was made to ensure that it was located in good rock.

Rock stress measurements

During the pre-investigation phase, stress measurements were conducted in some of the deep surface boreholes. Based on these early results, stress conditions at a number of locations along the access ramp were predicted.

Further stress measurements have been conducted in short holes drilled from selected locations along the access ramp. The CSIRO Hollow Inclusion overcoring technique has been used, and 3-5 overcoring tests were made in each borehole at a distance from the ramp sufficient to ensure that data are not influenced by excavation-induced stresses. The objectives are:

- To evaluate predictions made prior to excavation.
- To provide background data required to establish stress conditions on a site scale. The overall state of stress determines the mechanical boundary conditions for the various experiments that are to be conducted.

Measurements have been conducted from niches at tunnel sections 2860 and 3070. Adding these new tests to previous data, overcoring results are now available from a total of eleven locations distributed along the tunnel. The depth interval covered is from about 140 m to 400 m.

Some of the data obtained are indicated in Figure 2-4. The most striking characteristic is a consistent, near-horizontal, NW-SE orientation of the maximum stress. This is in accordance with results from the surface boreholes and seems to apply to the entire site. The stress field is highly anisotropic with differences between the maximum and minimum principal stresses of a factor of three or more. The maximum stress increases rapidly with depth, resulting in magnitudes of some 30 MPa at 400 m depths. This is in the high range as compared to general background data from Scandinavia.

A program has been established that details remaining, excavation-stage activities relating to rock stress investigations. Work to be done includes scrutinizing and compiling of all stress data from Äspö and an overall evaluation of stress conditions on the site scale.

Fracture zone EW-1

The island of Äspö is divided into two main granite blocks by the more than 100 m wide fracture zone EW-1 (Äspö shear-zone) trending NE.

The zone EW-1 was indicated very early in the pre-investigation phase by aerogeophysical measurements. Geological and ground geophysical investigations complemented with an inclined core borehole (KAS04) contributed to a more exact localization and characterization of EW-1.

After excavation of the tunnel on southern Äspö another cored borehole (KA1755A) was drilled through the fracture zone EW-1 on the level c. 250-350 m, see Figure 2-5. Borehole data mainly support the prediction of EW-1 as a complex

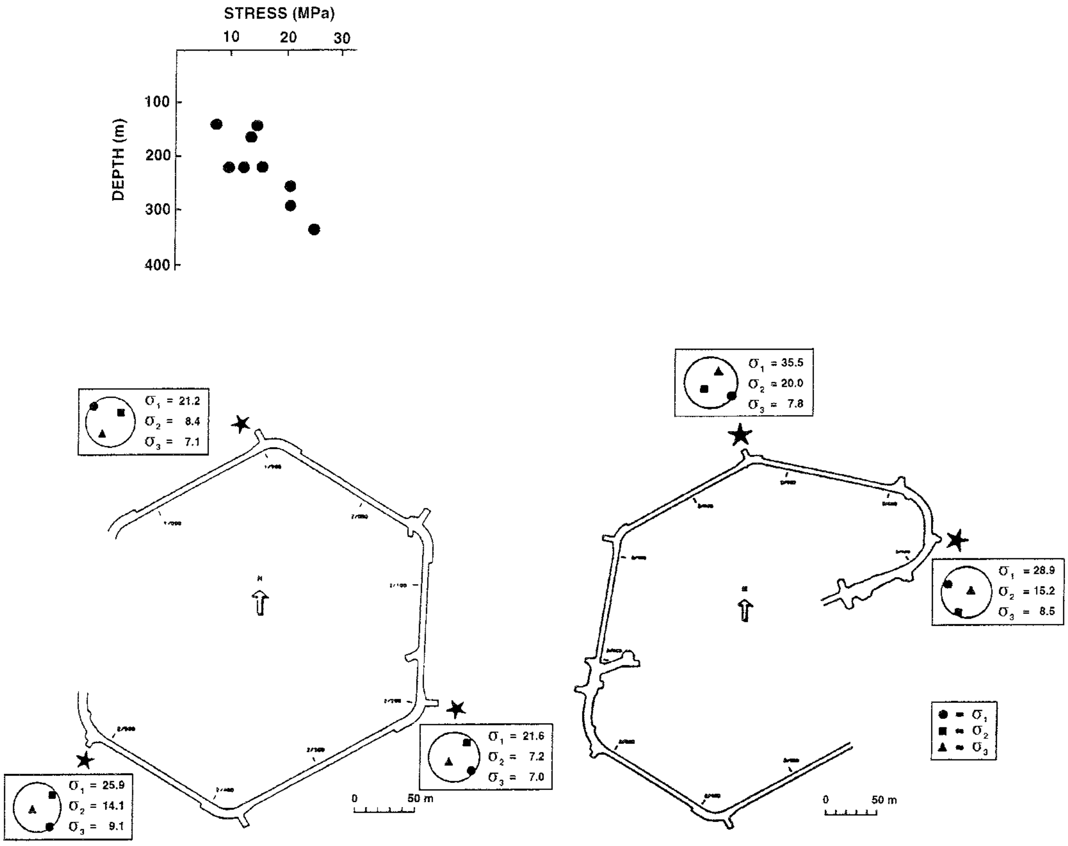

Figure 2-4. *Compilation of overcoring stress measurement results. Overall trend with depth for the maximum principal stress (upper) and data from recently completed tests (lower).*

fracture zone comprising two intense highly fractured branches – partly mylonitized – in very divergent rock mass.

Hydraulic conductivity tunnel section 2265-2875 m

The statistical distribution of the hydraulic conductivity for tunnel section 2265-2875 agrees approximately with the predictions, see Figure 2-6. However, the estimated hydraulic conductivity in the tunnel is somewhat less than the hydraulic conductivity estimated from the surface holes. The difference may be due to the boreholes being not quite representative of the tunnel, but it may also be a scale problem. Predictions were based on 3 m injection tests and the results were scaled up to about 14 m, which was the test length along the tunnel.

Groundwater chemistry

The predicted composition of the groundwater in major fracture zones and the salinity in the zones is different from the observation. The reason for this is unknown. There are, however, different possible explanations such as mixing ahead of the tunnel front and/or incorrect conceptual models.

In Table 2-1 are listed the main ion concentrations of analyses of water samples taken in tunnel section 2751-2772 m, representing the NNW fracture system.

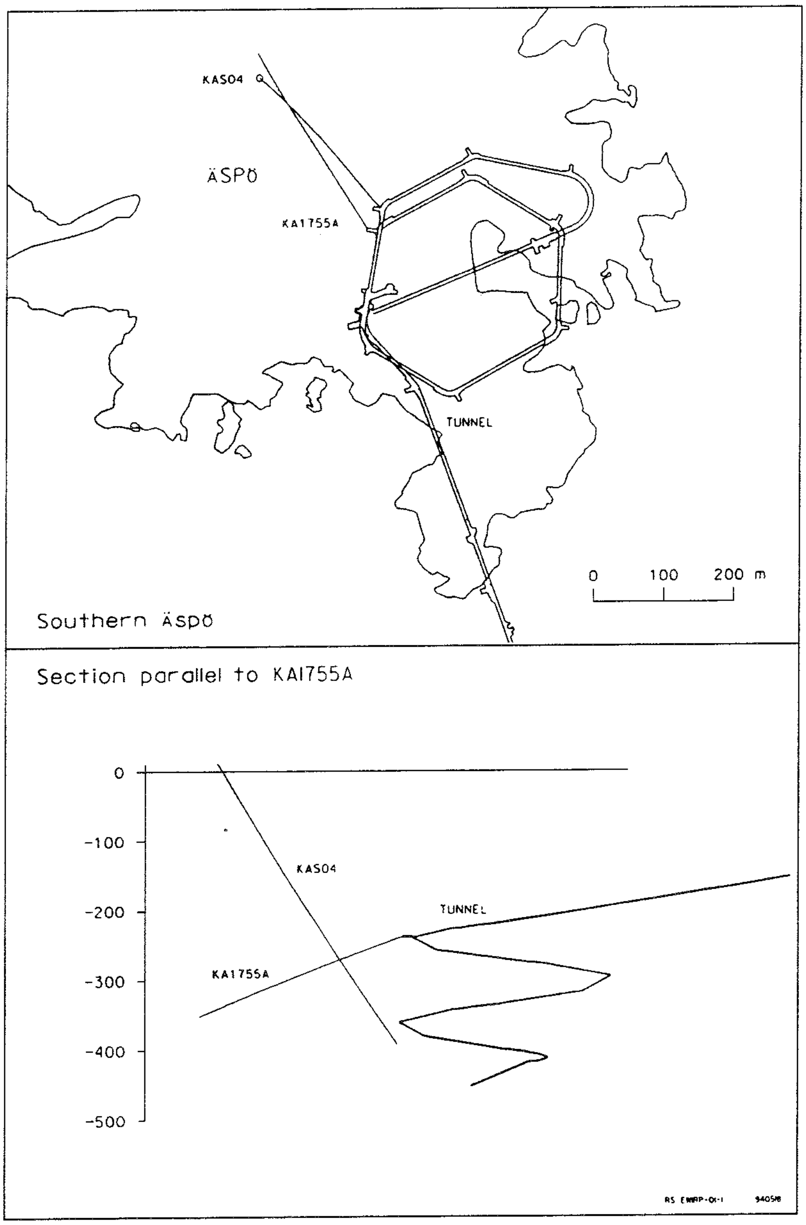

Figure 2-5. Borehole location for investigations of fracture zone EW-1.

For comparison, the values predicted for the water composition before the start of the tunnel construction are also given in Table 2-1. For EW-5 only the predicted values are given since that fracture zone has not been observed in the tunnel.

In Table 2-2 the predicted and the measured salinity of the water sampled in conductive zones are presented. It can be seen that the observed salinity is generally larger than the predicted one. One reason for this could be that the steady state conditions assumed in the numerical modelling have not been established.

2.3.3 Planned work

As a base for the final evaluation of the pre-investigations methods and the new model over the Äspö site, a large number of reports will be published during the

Table 2-1. Observed and predicted concentration of main constituents, redox constituents and pH. Predicted values are in italics.

Conductive zones mg/l	NA^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO^- mg/l	SO_4^{2-} mg/l	Fe^{tot} –	pH mV	Eh
NNW-4	*800*	*7*	*800*	*40*	*2500*	*170*	*120*	*0.3*	*7.7*	*-290*
predicted	*±300*	*±5*	*±300*	*±30*	*±1000*	*±70*	*±80*	*±0.3*	*±0.3*	*±25*
NNW	2300	9	2600	68	8400	12	170	0.1	7.9	–
2751-2772	±200	±2	±400	±8	±600	±2	±20	±0.05	±0.2	–
EW-5	*1300*	*5*	*1200*	*30*	*4100*	*70*	*150*	*0.3*	*7.8*	*-300*
predicted	*±300*	*±5*	*±300*	*±30*	*±800*	*±20*	*±50*	±0.3	*±0.2*	*±25*

Table 2-2. The predicted and the observed salinity of the fracture zones encountered in the tunnel section 2265-2874 m.

Zones: Salinity

Zone	Section* [m]	Predicted salinity [SFX(°/oo)] Skin** = 0	Skin** = 10	Measured
NNW-2	2260-2280	7.0	7.0	8.3
EW-5	2450-2510	7.7	7.8	11.2
NNW-1	2240-2660	11.3	11.0	16.2
NNW-2	2720-2750	8.9	9.2	12.5
NNW-4	2860-2940	8.2	8.3	

Salinity estimated with a numerical groundwater flow model /2-17/.
* approximate section for zone according to numerical model.
** skin for tunnel, zones excluded.

spring 1995 (see *Planning Report 1995* for more details). The final evaluation of the pre-investigation methods, the new model over Äspö and an overview of the investigations performed will be published in three Technical Reports with the tentative titles:

- An overview of investigations performed 1986-1995.
- Evaluation of the Äspö pre-investigations.
- Äspö bedrock models based on the site characterization 1986-1994.

These Technical Reports are planned to be published late 1995.

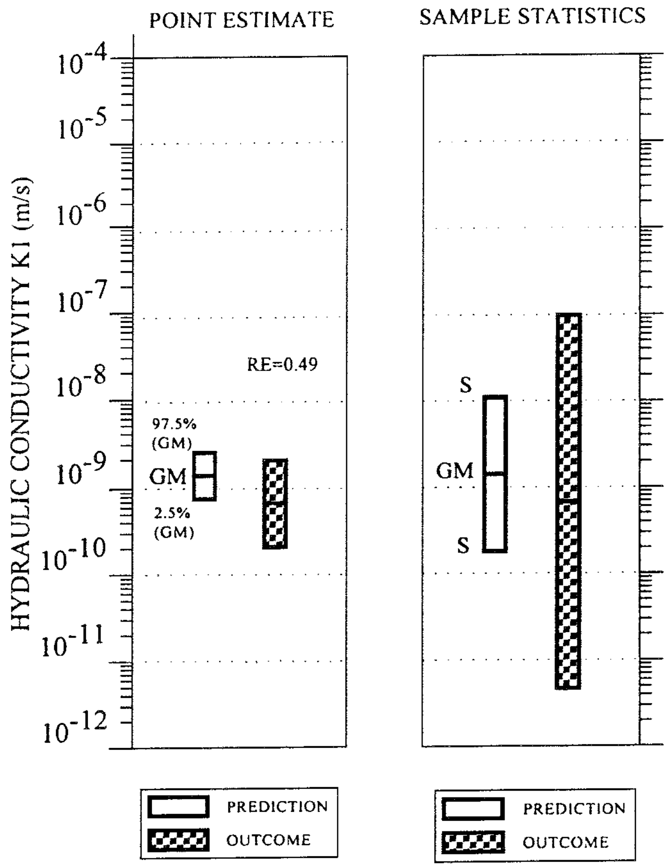

Figure 2-6. Hydraulic conductivity in tunnel section 2265 – 2874 m. Site scale. Test scale 14 m. GM = geometric mean, S = one standard deviation, RE = outcome/prediction of geometric mean.

In order to see if it was possible to get more evidence of the position and character of the NNW structures, 18 percussion boreholes have been drilled between chainage 1405 m and 2780 m. In these holes TV-inspection and pressure build up tests have been done. The evaluation is ongoing and will be reported in spring 1995.

Some of the major characteristics of the mapped fracture zones will be summarized in a "catalogue" in order to make it easier for future investigations in the tunnel and to be a part of the final evaluation. The work is in progress.

2.4 CODE DEVELOPMENT / MODELLING

2.4.1 Background

As a basis for a good optimization of the repository system and for a safety assessment as a basis for the siting application, which is planned to be submitted a couple of years after 2000, it is necessary to:

Test models for groundwater flow and radionuclide migration

- refine and test on a large scale at repository depth methods and models for describing groundwater flow and radionuclide migration in rock.

At Äspö HRL several numerical models have been tested and are tested and developed in order to meet this stage goal.

2.4.2 Results

The recalculations of the drawdowns caused by the construction of Äspö HRL using the measured flow into the tunnel and with the same numerical model as was used for the predictions has now been published in /2-18/. The purpose of the calculations was to provide a better possibility to judge the goodness of the numerical model and the realization of the pre-investigation results in the numerical model.

The simulations indicate for example that there should be a conductive structure crossing the elevator shaft above -215 m to get reasonable drawdowns close to the shaft with the given flow rates into the shafts, see Figure 2-7.

2.4.3 Planned work

Further tests and developments of visualization and the coupling of the numerical groundwater flow model to the CAD-data base are being made and will be reported in the beginning of 1995.

In the spring new recalculations of the drawdowns, as the one described in Section 2.4.2, will be done for tunnel face position 2875 m. A sensitivity study of the developed program for groundwater recharge will also be made. These two projects will be reported in summer 1995.

In the summer and autumn of 1995 Äspö HRL will be modelled in a similar way as was done for the predictions /2-17/ but based on the updated model of Äspö.

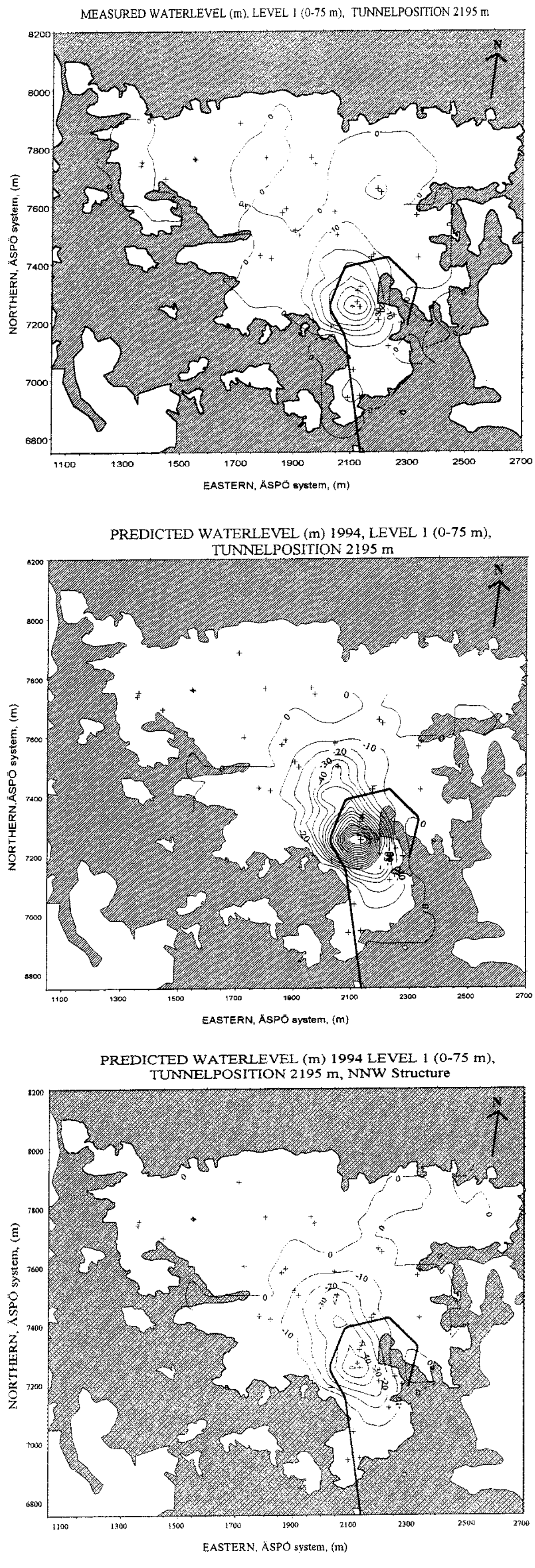

Figure 2-7. *Water level with tunnel face at chainage 2195. Top: Outcome, Middle: Prediction 1994 with measured flow. Bottom: Prediction 1994 with measured flow and with NNW structure.*

3 METHODOLOGY FOR DETAILED CHARACTERIZATION OF ROCK UNDERGROUND

3.1 GENERAL

The selection of candidate sites for the deep repository will be based on the fundamental requirements that must be made on a deep repository site from safety-related, technical, societal, and legal viewpoints. It must be possible to demonstrate that the safety requirements stipulated by the regulatory authorities are complied with, and that the repository can be built and the disposal concept executed from a technical point of view. Siting, investigations, and construction should be carried out so that all legal and planning requirements are met. And last, but not least, it should be possible to carry out the project in collaboration with the municipality and the local population.

The detailed characterizations will encompass investigations during construction of shafts and/or tunnels to repository depth. Finalizing the detailed investigation methodology is Stage goal 2 of the Äspö project.

The purpose of detailed site characterization is to:

- finally confirm the suitability of the selected site and rock volume,
- provide the necessary data for a safety assessment, which shall serve as support for an application under NRL (the Act Concerning the Management of Natural Resources) and KTL (the Act on Nuclear Activities) to construct a deep repository on the selected site,
- provide data and knowledge concerning the bedrock on the site for planning and execution of the rock construction work for the deep repository.

Important skills are to be able to build and investigate in both the bad and the good rock with adequate personal safety. Data shall be collected and evaluated in parallel with the tunnelling.

Experience from Äspö serves as a basis for planning of SKB's coming detailed characterization of a possible deep repository site.

The detailed characterization will give a refined picture of the conceptual models obtained from the pre-construction investigations. These conceptual models will be used to up-date the layout of the repository. Due to the heterogeneity of the rock, the layout can and shall be adapted to the gradually refined models of the rock. This approach has a long tradition in underground construction and it should also be used for a deep geological repository.

The Äspö Hard Rock Laboratory will demonstrate the deepening of knowledge that is possible to achieve in relation to the evaluation made during the pre-investigation phase. The Äspö Hard Rock Laboratory is also being used to test and develop the necessary techniques before they are applied at the candidate sites. Routines for data collection, documentation and reporting of results and evaluations can be tested under fairly realistic conditions at the Äspö HRL. The work described earlier in Chapter 2 constitutes the bulk of the work needed to test underground characterization technology.

The management of the large quantities of data has been developed to the point where SKB is now in possession of a data production methodology that meets exacting requirements on quality and overview. This methodology is directly applicable to the planned detailed characterization work for a deep repository. The methodology has been developed for conventional tunnelling. Starting at a depth of about 420 m, the tunnel has been excavated using full-face boring – TBM. The introduction of the TBM has facilitated a test of different excavation methods and associated modifications of data collection methodology and procedures.

Testing of TBM entails considerable added value for achieving this stage goal of the project. The methodology of coordinating TBM tunnelling and investigations has been tested under realistic conditions, in addition to the methodology that had already been tested in conjunction with the conventional blasting.

A comparative study is under way to compare tunnel and borehole data, Section 3.3.

The mechanical disturbances to the surrounding rock caused by tunneling are compared between a Drill&Blast and a TBM drift, Section 3.4.

3.2 INVESTIGATIONS IN THE TBM TUNNEL

3.2.1 Results

The borehole KA3191F was drilled from the TBM assembly hall in the center line of the TBM tunnel down to the lowest position of the excavation at a depth of 450 meters below ground surface in the vicinity of the shafts. The borehole was 210 m long. The objective of this borehole was to:

- provide data in advance of TBM-tunnelling for characterization of the rock properties and fracture zones which can give additional information of value in advance of the TBM boring.
- provide additional data for geological, geohydrological and ground-water chemical modelling within the whole spiral loop and give additional data to test and upgrade the structural conceptual model of Äspö.
- provide geological, geohydrological and groundwater chemical data necessary for the siting process of the experimental volumes.
- provide data for comparison of the evaluation of geological and geophysical data collected from a borehole compared to the same data collected from the tunnel.

Characterization work in conjunction with the TBM excavation was planned to have the same ambition as for the drill and blast tunnel. The main difference was that the mapping was carried out when the tunnel was finished.

Investigations in the cored borehole along the planned TBM-tunnel (core mapping and geophysical logging) indicate one dominating rock type (Äspö Diorite), rather low fracture frequency – except in a few sections – and high RQD (>75) for most of the borehole length.

The objectives with the geohydrological investigations were to determine the transmissivity of the larger waterbearing structures and make an attempt to decide their orientation and finally determine the transmissivity distribution along the borehole KA3191F.

The most conductive parts in the cored borehole were 0-15 m, 90-135 m, and 195-210 m. The results from the test in section 90-135 m were uncertain but the structure can possibly be very conductive.

3.2.2 Planned work

The data from the documentation of the TBM tunnel and the results from the investigations in the borehole KA3191F is evaluated during spring 1995 and will be reported summer 1995.

Approximately 20 percussion-drilled boreholes, 8 m long, have been drilled in the TBM tunnel. Pressure observations in these boreholes will be done during spring 1995 and reported together with the reporting of the documentation of the tunnel section (2874-3600 m).

3.3 COMPARATIVE STUDY ON THE USE OF TUNNEL AND BOREHOLE DATA

3.3.1 Background

In the pre-investigation phase, the characterization of the rock was to a large extent based on data collected from boreholes. In the construction phase, a lot of data are collected by observations made directly in the drift. However, observations made in boreholes and in tunnels differ with respect to the quality and density of data collected for a specific parameter and also with respect to what types of data that can be collected. It is essential to understand how the differences in data collected in boreholes and tunnels influence our understanding of the rock. For this purpose, an evaluation of data from Äspö will be performed with the objectives:

- To evaluate the differences in information content of the data sets normally collected in cored boreholes and tunnels excavated by drill and blast technique respectively TBM tunnels.
- To assess the differences in data quality for specific parameters (e. g. fracture frequency) that can be measured in both tunnels and boreholes.

3.3.2 New results

The main purpose with the work in the first step was to investigate if geophysical borehole logging methods can be used as a tool to determine lithology, RQD, RMR and type of alteration in a borehole. Another purpose was to compare the information obtained from a borehole and the actual situation in a tunnel parallel to the borehole. The investigation was done in two 200 m cored boreholes parallel to the tunnel (KA1131B and KA2048B).

The techniques used in the investigation included geophysical borehole logging with electrical, radioactive, sonic and electromagnetic methods, core mapping with the computer based system, Petro Core, and tunnel mapping. Data from the core mapping and data from the geophysical logging were compiled, and analysed with two different computer assisted pattern recognition techniques, discriminant analysis and neural networks. The purpose of using pattern recognition was to create models that enable direct interpretations of lithology, RQD, RMR, and alteration in the borehole from geophysical measurements. The information obtained from the geophysical prediction models and the core mapping was then compared with the actual situation in the tunnel.

The results show that geophysical borehole logging together with interpretations based on pattern recognition techniques can be used in order to determine lithology and RQD in a borehole. Prediction models of alteration could not be established, since the core mapping did not provide a good estimate of alteration. In one borehole, RMR was estimated using geophysical measurements and information obtained from the drilling report. The results from this test indicates that a good estimate of RMR in the borehole can be obtained. Results in this thesis also demonstrate that boreholes give very useful information but must not be used as an infallible information source, especially for structures that may change character away from the borehole. Moreover, there is a need to use a borehole radar with directional antenna or an oriented core, unless a unique or recognisable feature is present for which orientations are known.

A draft report on the results, "Pattern Recognition Techniques Applied to Borehole Geophysical Data in Site Investigations", has been prepared by Per Nilsson, Dept of Applied Geophysics, University of Luleå.

3.3.3 Planned work

In a second step, data collected in the cored test borehole KA3191F along the first 200 m extension of the TBM tunnel will be compared to data from the TBM tunnel. This study is scheduled for start in January and expected to be reported in April 1995.

3.4 ZEDEX – COMPARATIVE STUDY OF EXCAVATION INDUCED DISTURBANCE OF TBM vs DRILL & BLAST EXCAVATION

3.4.1 Background

To obtain a better understanding of the properties of the disturbed zone and its dependence on the method of excavation ANDRA, UK Nirex, and SKB have decided to perform a joint study of disturbed zone effects. The project is named ZEDEX (Zone of Excavation Disturbance EXperiment). The objectives of ZEDEX are:

- to understand the mechanical behavior of the Excavation Disturbed Zone (EDZ) with respect to its origin, character, magnitude of property change, extent, and dependence on excavation method,
- to perform supporting studies to increase understanding of the hydraulic significance of the EDZ, and
- to test equipment and methodology for quantifying the EDZ.

The ZEDEX project is performed in conjunction with the change of excavation method from drill & blast to tunnel boring that took place during the summer of

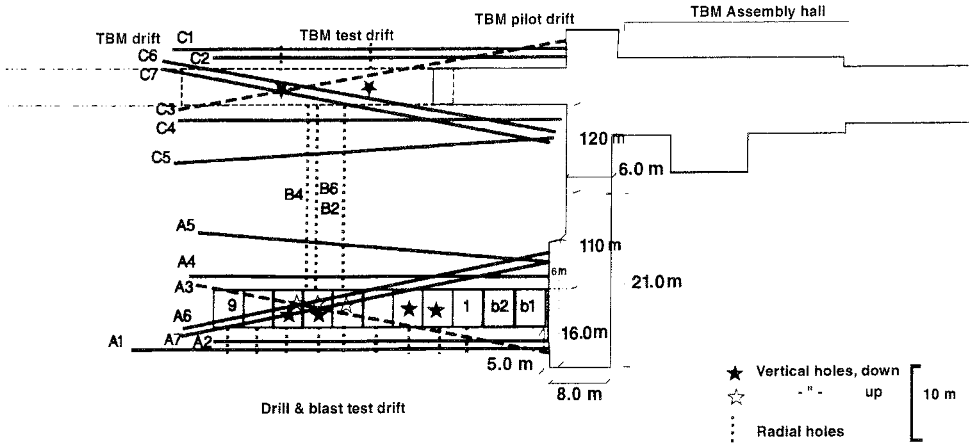

Figure 3-1. *Configuration of test drifts and investigation boreholes for the ZEDEX study.*

1994. The experiment is expected to provide a better understanding of the EDZ that will contribute to the basis for selecting or optimizing construction methods for a deep repository and its subsequent sealing.

The experiment is performed in two test drifts near the TBM Assembly hall at an approximate depth of 420 m below the ground surface. Measurements of rock properties will be made before, during, and after excavation. The investigation program includes measurements of fracturing, rock stress, seismic velocities, displacements, and permeability. The experimental configuration is outlined in Figure 3-1.

3.4.2 Performed work

A total of 7 boreholes, named C1-C7, were drilled axially along the TBM drift, see Figures 3-1 and 3-2, before it was excavated. In addition, a short borehole, KA3068A, was drilled for the purpose of performing stress measurements.

To assess rock properties before excavation the following measurements were made before excavation of the TBM drift during an intense period during May and June 1994:

- Directional radar in boreholes C2, C3, and C6.
- High resolution seismic tomography in borehole sections C4-C5 and C6-C7.
- Permeability measurements with a packer spacing of 3.5 m in boreholes C4 and C5.
- Core mapping.
- Stress measurements in borehole KA3068A which is located near the Assembly Hall.

During excavation of the TBM drift the following measurements were made:

- Vibration and temperature were monitored by instrumentation placed in borehole C1.
- Acoustic Emission monitoring was made by instrumentation placed in boreholes C2, C3, C4, and C6.

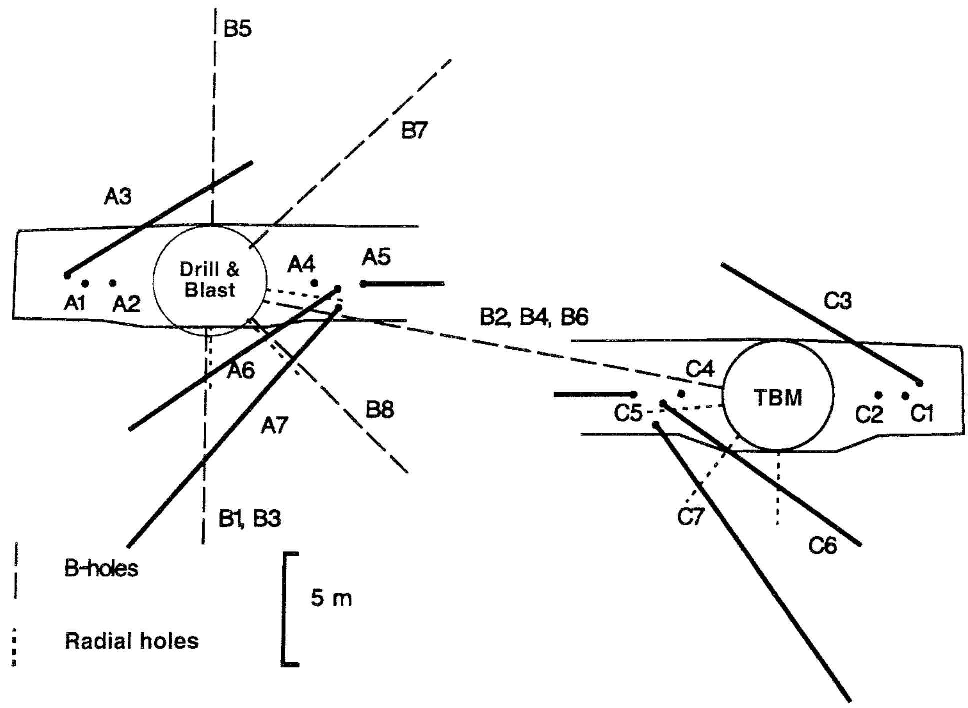

Figure 3-2. *Vertical section showing location of boreholes in relation to the test drifts.*

- Convergence pins were installed at the tunnel front at 2 locations in the TBM tunnel to measure displacements. Readings were then repeated after excavation had been completed.

After excavation had been completed 6 radial boreholes, each 3 m long, were drilled to study the EDZ properties in the near field. Boreholes B2, B4, and B6 were drilled to study EDZ properties as a function of radius for both test drifts.

After excavation of the TBM drift, the permeability and seismic tomography measurements were repeated. In addition geological and geotechnical mapping was made of the test drift and permeability measurements with a resolution of 50 mm made in the short radial holes.

All the planned measurements were completed successfully.

3.4.3 Results

So far only a preliminary analysis has been performed of the results from the TBM drift and based on this some preliminary conclusions have been drawn. It should be noted that these preliminary conclusions may change as results are more thoroughly analyzed.

The core logging and drift mapping shows that the ZEDEX experiments were carried out in a volume of rock which is predominantly Äspö Diorite. Two main sets of dikes have been observed at the beginning and end of the test section of the TBM Tunnel, which have self consistent orientations (i.e. NorthWest). The rock types and fracturing observed in the TBM and D&B drift are shown in Figure 3-3.

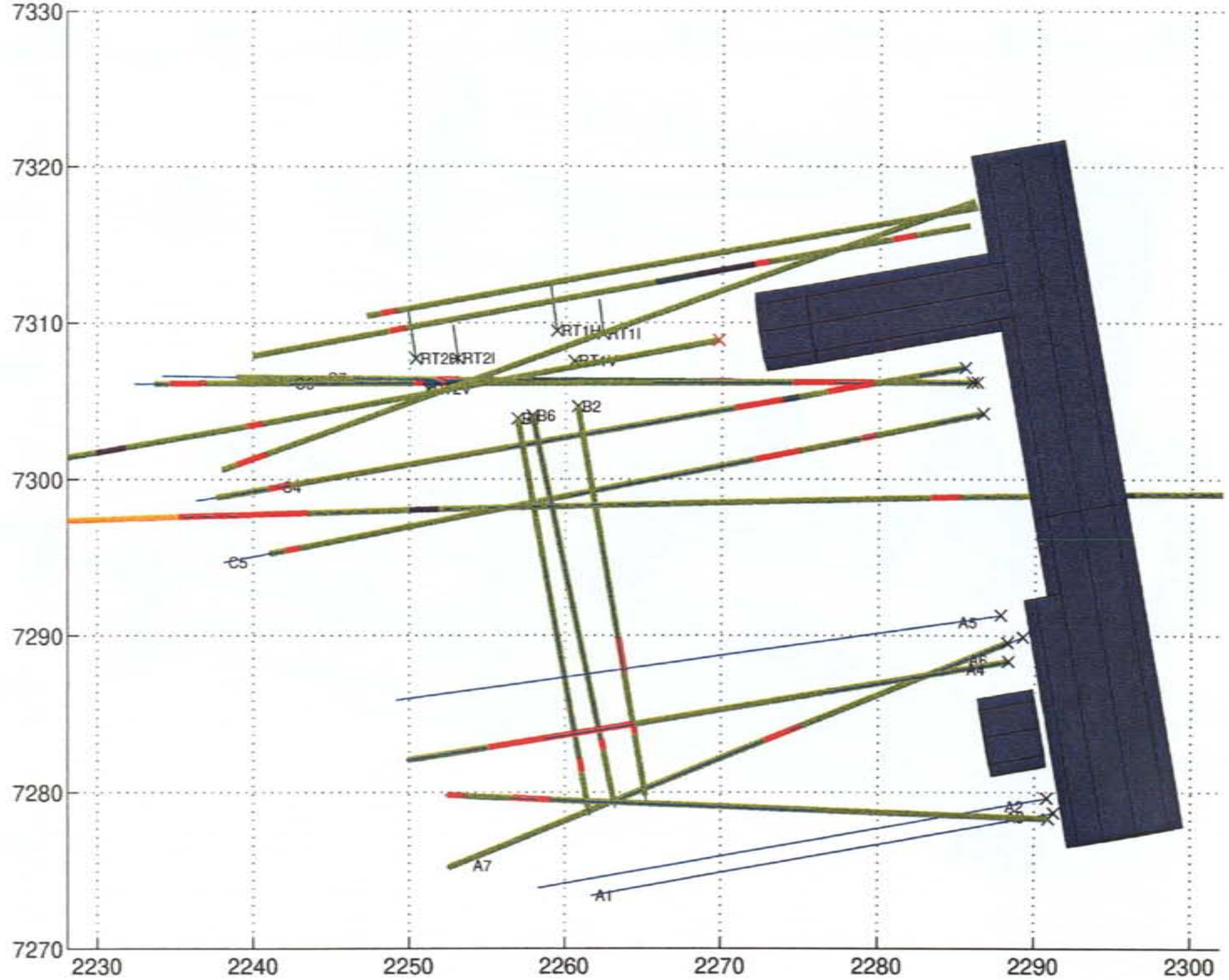

Figure 3-3. *Rock type distribution at the ZEDEX site. Äspö diorite, green; Fine-grained granite, red.*

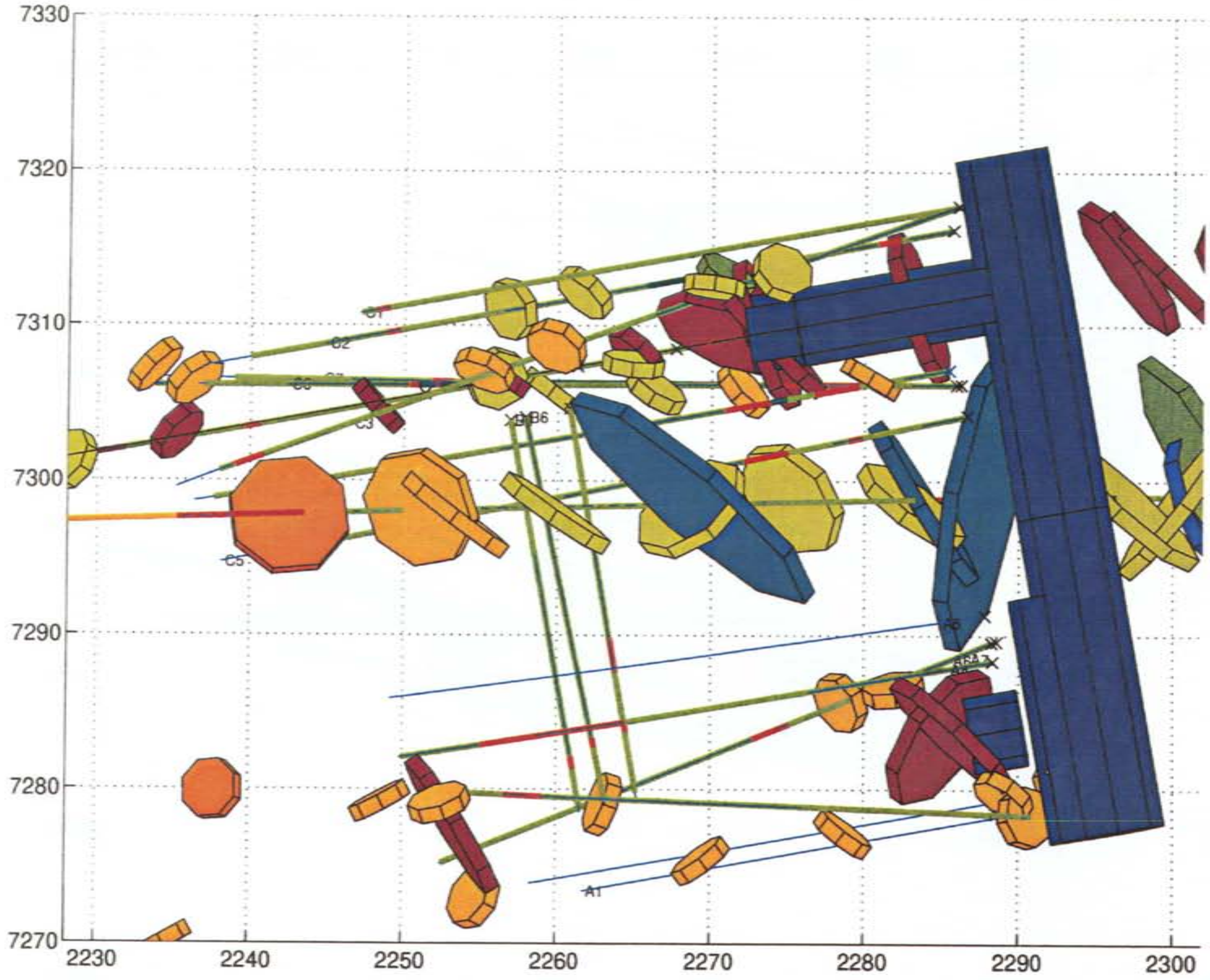

Figure 3-4. Radar and seismic reflectors observed in boreholes at the ZEDEX site. Reflectors are plotted as octagonal disks. Radar, orange or yellow; seismic, light blue. Purple disks along TBM tunnel correspond to mapped fractures.

The rock quality is rather uniform throughout the considered boreholes (C1 – C8) and belongs in general to rock mass Class B which means a Q-value of 10 – 40. The RMR-values are usually 61 – 80 which means rock mass Class II.

Stress measurements have been performed in borehole KA3068A located at the Assembly hall close to the ZEDEX site /3-1/. Based on an analysis of all stress measurements at Äspö Sjöberg and Rådberg /3-2/ estimated the magnitude of the main principal stress (σ_1) to 32 MPa at the ZEDEX site.

The direction of σ_1 is approximately NW and horizontal. The magnitudes of σ_2 and σ_3 are estimated to 17 and 10 MPa, respectively. Stress modelling has been performed of the ZEDEX site to evaluate the number of blind rounds required in order to perform the tests in a relatively well defined stress field. The results showed that at least two rounds are required to avoid major disturbances from the access drift to the D&B test drift /3-2/.

P-wave and S-wave velocity measurements were made on two planes around the TBM tunnel. Measurements in a horizontal plane South of the tunnel were made between boreholes C4 and C5, and in a vertical plane beneath the tunnel between boreholes C6 and C7. In both planes the velocity results were strongly anisotropic for a homogeneous granitic rock. The horizontal measurements showed an average P-wave velocity of 5925 ms^{-1}. Anisotropy was approximately 7-8%. The direction of maximum velocity was at about 135^{o} azimuth and the slow direction was at 45^{o} azimuth. The fast direction corresponds roughly to the predominant NW striking sub-vertical joint set. The seismic measurements made after excavation showed very small changes in velocity.

Mapping of fractures in the first 50 meters of the TBM tunnel and in boreholes C3, C4, and C6 close to the tunnel, has revealed the presence of two main joint sets and several less prominent fracture sets. The predominant set in the volume of intensive study is a NW striking, sub-vertical joint set.

Four major NorthWest trending features and one NorthEast trending feature were identified from the Tunnel Mapping and Radar reflections, with good correlation between the two methods. The location of radar and seismic reflectors at the ZEDEX site is shown in Figure 3-4.

The vibration data was measured in the C1 borehole, 3 meters away from the tunnel. The vibration measurements were made using tri-axial velocity transducers deployed at four stations which were 3 meters apart. Data were recorded both in the time and frequency domain. The maximum vibration level is reported to be 1 mm/sec. The radiated seismic energy from the TBM during drilling was estimated to 400 W which is a small fraction of the total energy put into crushing the rock, which is about 1 MW.

Acoustic Emission (AE) monitoring was made when TBM excavation was stopped overnight at 9 m, 15 m, 22 m, and 25 m measured from the start of the TBM tunnel. When the TBM stopped at 9.0 meters the majority of the recorded and subsequently located AE activity (232 events) defined a narrow zone directly in front of the position of the TBM face (Figure 3-5). Additionally other events located around the tunnel, generally within 1 meter of the tunnel perimeter and ahead of the tunnel face. The events recorded and subsequently located when the face stopped at 15 m (115 events), 21.8 m (78 events) and 25.3 m (18 events) are located generally around the tunnel.

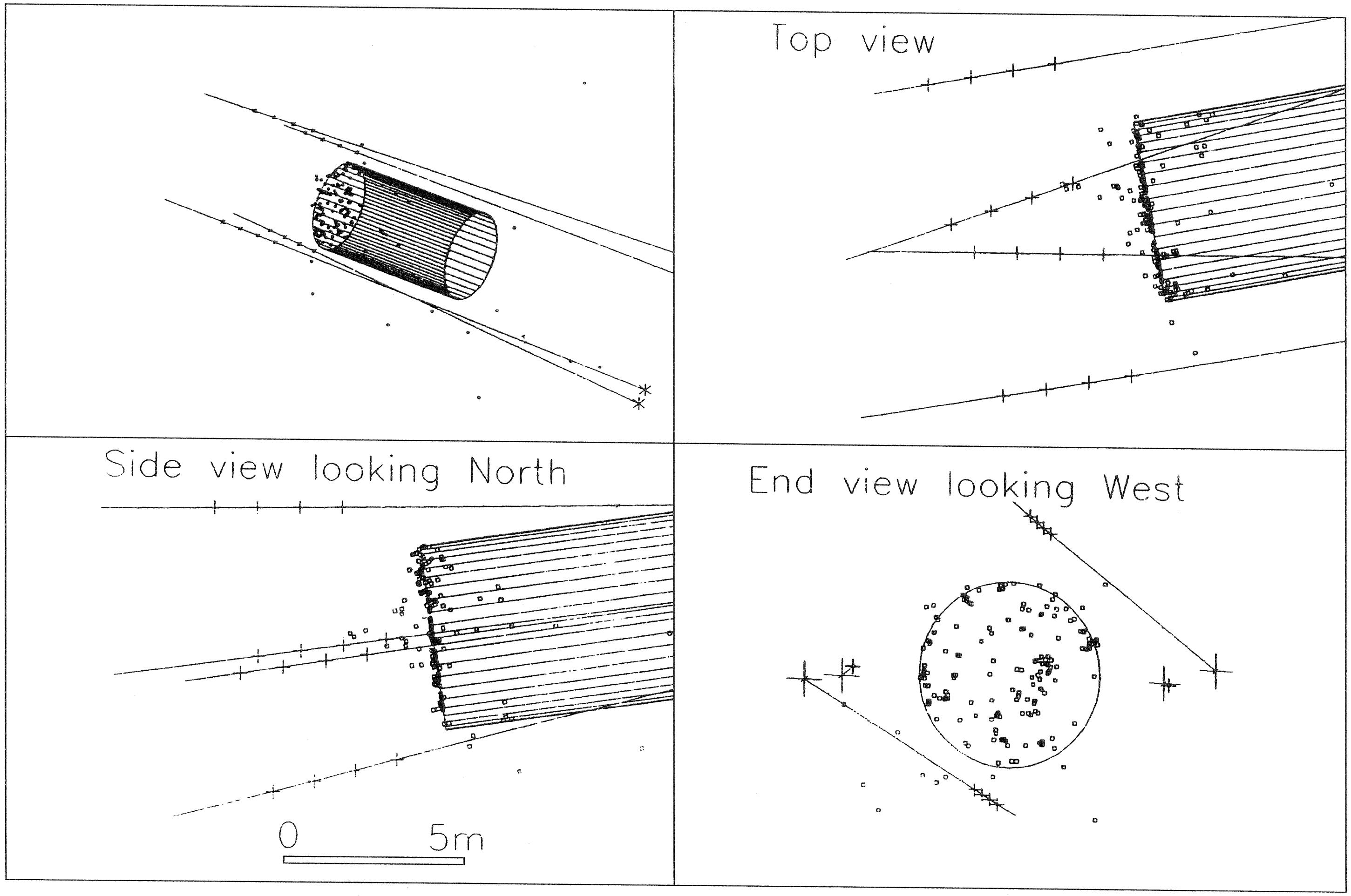

Figure 3-5. AE source lcoations within the 10x10x10 m volume centered on the sensor array from monitoring while the tunnel was stopped overnight at 9 m from its starting position (232 events).

Convergence measurements were made at TBM-tunnel lengths of 9 m and 24 m. The results indicate predominantly horizontal convergence (3.6 mm and 1.3 mm, respectively) in both sections, with little displacement in the vertical direction. This pattern of displacements is consistent with the *in situ* stress measurements which indicate a horizontal to vertical stress ratio of about 3:1. The magnitude of the displacements is also consistent with expected magnitudes of the mass modulus.

Hydraulic pressure build-up tests in C4 and C5 showed a general decrease of permeability after the excavation. Hydraulic tests in radial boreholes did not show any notable induced effect by excavation on matrix permeability.

The preliminary analysis of the results indicates that the measurable changes in properties induced by excavation of the TBM tunnel are small to negligible.

Excavation of the access drift to the D&B test drift was performed in late October and the first days of November 1994. During excavation the Smooth Blasting Experiment was carried out in order to adjust blast design parameters for the future tests in the D&B drift. Six rounds were blasted with several combinations of candidate explosives. Air Pressure and Vibration measurements were successfully performed and showed good correlation with the firing sequence.

Drilling of the A-boreholes has been completed as well as the measurements before excavation of the D&B test drift. The measurement program was identical to that used for the TBM drift.

3.4.4 Planned work

Evaluation of results obtained from the TBM tunnel will continue.

Excavation of the D&B test drift was made in January 1995. During excavation, AE-monitoring and acceleration measurements was made as planned. This will be followed by repeat measurements in the A-holes after excavation and seismic and hydraulic measurements in a number of short radial holes. The field work is estimated to be completed by the end of April 1995.

4 TEST OF MODELS FOR GROUNDWATER FLOW AND RADIONUCLIDE MIGRATION

4.1 GENERAL

The rock surrounding the repository constitutes a natural barrier to radionuclides released from a deep geological repository. The most important function of the natural barrier is to provide protection for the engineered barriers in order to ensure isolation of the waste for long periods of time. To provide long term isolation, the waste container and the buffer material need to be placed in a favourable and stable chemical environment. In the event the engineered barriers have been damaged, the ability of the rock to retain and/or retard transport of radionuclides is an important safety factor. The rock mass in combination with the buffer and the waste container are the main components of the multiple barriers on which the repository concept is based.

In this context it is important to be able to understand and describe

- the nature and evolution of the chemical environment for the engineered barriers,
- transport of corrodants to the waste containers, and
- transport of radionuclides through the host rock

in order to assess the safety of a deep repository for spent fuel. Another important aspect is to ensure that the changes in mechanical and chemical conditions induced by construction and operation of the repository before closure do not have negative effects on long term safety. An understanding of chemical conditions at repository level and transport of radionuclides is also essential for assessing the environmental impact of other long-lived waste planned to be stored in a separate part of the deep Swedish repository.

Performance and safety assessments are based on models describing processes considered to be of relevance for transport of contaminants in fractured rock. These assessment models are being further developed, where necessary, as a part of SKB's program for research and development. In addition, the relationship between model parameters and field data needs to be described more accurately. The issue of conceptual model uncertainty is also a major concern.

In this context, the main purpose of the experiments planned to achieve the third Stage Goal of the Äspö HRL Project, i.e. to test models for groundwater flow and radionuclide migration, is to provide a better basis for the safety assessments required for licensing of the deep repository. Experiments will be performed to:

- improve understanding of important processes affecting radionuclide transport and chemical conditions at repository lever,
- test to what extent model concepts and data provide realistic descriptions of radionuclide transport, and
- evaluate the usefulness and feasibility of different modelling approaches.

A "Task Force on Numerical Modelling of Groundwater Flow and Transport of Solutes" has been formed with representatives of the Äspö HRL Project's international participants. The Task Force offers opportunities for testing alternative modelling approaches to the ones developed within SKB's research and development program.

4.2 THE REDOX EXPERIMENT IN BLOCK SCALE

4.2.1 Background

During the operating phase when a repository is kept open for the emplacement of the spent fuel canisters, the inflow of groundwater to the tunnels will cause an enhanced water circulation in the surrounding rock mass. This water circulation causes oxygenated surface water to be transported to great depth. An increase of the infiltrating surface water by one order of magnitude might cause oxygenated water, which is normally reduced at a few tens of meters, to be drawn to several hundred meters depth. Such a situation might cause an oxidation of the fracture minerals in the water conducting fractures all the way from the surface down to the repository. The consequences of this would be that, in the post closure phase, radionuclides oxidized by the radiolysis might be transported in an oxic form through the geosphere.

In the KBS-3 safety analyses a comparison between oxidizing and reducing conditions was made. The calculations at in all other aspects equal conditions showed that the dose to man was two orders of magnitude higher in the oxidizing than in the reducing conditions.

The geochemical data obtained from the site investigations made during the past ten years all over Sweden, clearly indicate that the oxygen in the infiltrating surface water is reduced in the soil and in the uppermost part of the bedrock. At a depth of 100 meters the water is reducing with a typical iron concentration of 1 – 10 mg/l. Only in one borehole out of 30 – 40 has oxygen been measured in samples from more than 100 m depth. The prevailing reducing conditions are also seen in mines and tunnels in the rock as iron precipitates on the walls where the reducing iron rich water has flown in to the tunnel.

The purpose of the block scale redox experiment was to investigate the chemical changes when oxidizing water is penetrating previously reducing fracture systems and to evaluate if complete flow paths can be oxidized from the surface to the repository. This is an unwanted scenario for two reasons. It would be easier for oxygenated surface water to penetrate to the repository along such a path, which has already been oxidized. Secondly redox sensitive radionuclides may potentially be more mobile if the flow goes in the other direction from the repository up to the biosphere.

4.2.2 Results

The experiment started in 1991 and lasted until 1994. The monitoring phase of the project ended in 1993. During this three year period emphasis has been put on describing the chemical processes in the investigated fracture zone. The most important processes have been identified to be mixing and microbial oxygen reduction.

The results of the first two years have been reported /4-1/. The results so far have indicated that most likely the enhanced water circulation in the fracture zone has not caused any significant penetration of oxidizing surface water. No oxygen breakthrough was observed and the chemical composition remained constant throughout the experimental time. The explanation for this is that the high content of organic matter in the infiltrating surface water has been biologically oxidized at the same time as the dissolved oxygen has been reduced. The population of bacteria has increased in order to be able to match the increased water circulation.

A tracer test was carried out in early 1994, with the purpose of verifying the assumptions of groundwater flow distribution and direction in the investigated fracture zone /4-2/. Figure 4-1 illustrates the layout and configuration of the experiment.

4.2.3 Planned work

A Progress Report summarizing the results and a Technical Report presenting the conclusions and the implications for a deep repository are in progress.

4.3 PORE VOLUME CHARACTERIZATION

4.3.1 Background

The conductivity of a single rock fracture is governed by the geometry of the fracture aperture. It has therefore been the aim of several researchers during the last decade to find parameters to describe the aperture distribution of rock fractures. The objective of this project has been to characterize the aperture distribution, including the spatial correlation, of a fracture at the Äspö Hard Rock Laboratory. The aperture distribution should provide insight on the heterogeneity and connectivity of flow paths within fractures. In this project such data have been obtained by drilling core samples from a previously grouted fracture. The work within this project was completed and reported in 1994 /4-3/.

4.3.2 Performed work

A highly conductive, minor fault at the tunnel section 1/140 was selected for the study. The fracture strike is about N-S and the dip is almost vertical. Before excavation of this section of the tunnel, the fracture had been grouted with a red-colored cement grout. After excavation the fracture could be clearly seen in the wall of the tunnel. Five boreholes with a diameter of 200 mm were drilled parallel to the fracture plane in order to obtain core samples containing segments of the fracture plane.

The intact pieces of the drill cores were collected and used for laboratory studies of the aperture. The core pieces were moulded in concrete and cut into slices. Each slice was documented with a video camera. The grout layer thickness is assumed to be a measure of the fracture aperture, b. The aperture was measured every 5 mm along the fracture section in the close-up pictures.

As a different technique, successive photographs were taken along the fracture intersection in the walls of the boreholes. The overlapping photographs were put together forming a continuous profile of the fracture and the aperture was determined from the grout layer thickness.

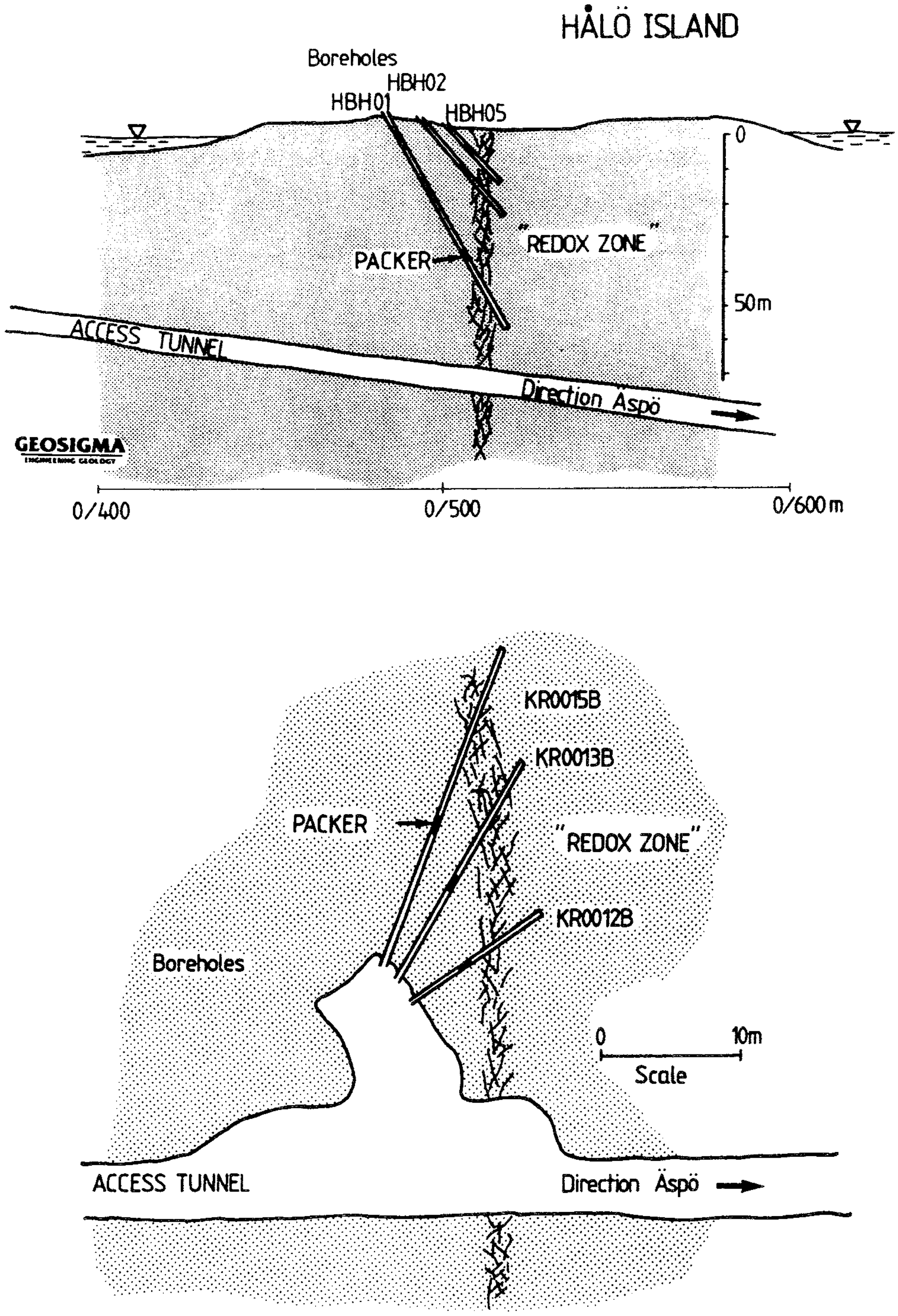

Figure 4-1. *Section and plan views of the access tunnel, fracture zone and intersecting boreholes. The plan view shows the side tunnel used for instrumentation of the three investigation boreholes drilled into the fracture zone.*

4.3.3 Results

The average aperture for the drill core section data is 2.3 mm and the average aperture for the borehole photograph data is 2.0 mm. The coefficient of variation (σ/μ) is 124% and 133% respectively. The frequency histograms of the aperture data from both methods are positively skewed and about 40% of the apertures are smaller than 0.1 mm.

If the apertures larger than 0.1 mm are studied separately, their probability distribution can be approximately described with a log-normal function. The average log(b) (b >0.1 mm) is 0.36 for the drill core section data and 0.24 for the borehole photograph data; and the standard deviation of log(b) is 0.42 and 0.46 for the two methods respectively.

Geostatistical methods were used to study the spatial correlation of the aperture on the fracture surface. The result from variogram analysis indicates that the fracture surface of each sample has a few areas where very small apertures are concentrated. Also, the largest apertures are concentrated in a few areas on the fracture surface.

To specifically study the spatial pattern of the "contact areas", indicator variograms were used (indicator variable threshold = 0.1 mm). It was found that the contact areas tend to have an elongated shape in the direction plunging 60 south on the vertical fracture plane. The distance between contact areas is on the order of 25 centimeters, see Figure 4-2.

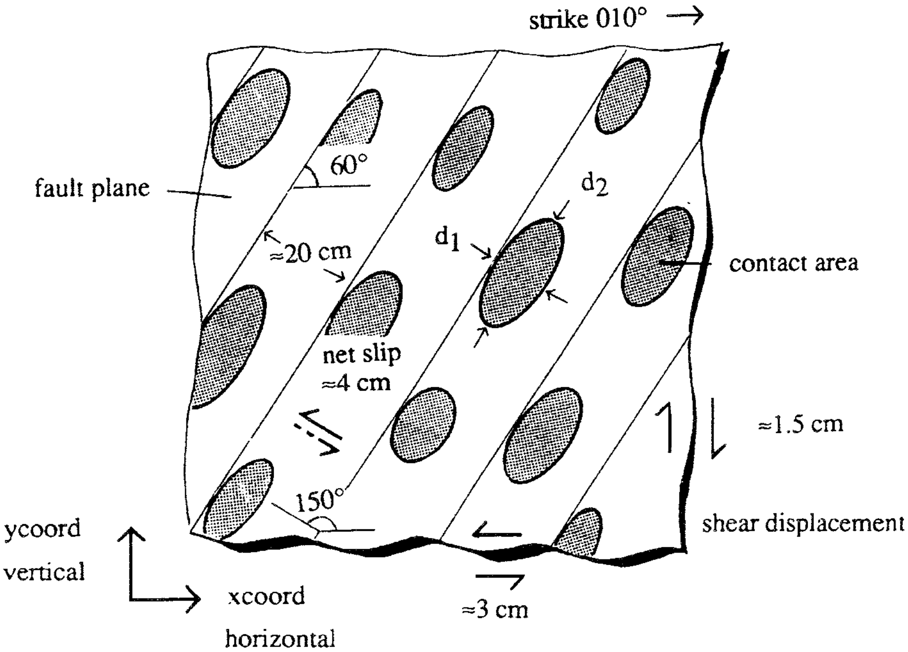

Figure 4-2. Conceptual model of the aperture distribution of the sampled fault. The aperture variation is simplified in the model into open areas (white; b>0.1 mm) and contact areas (b≤0.1 mm).

The result from the variogram analyses corresponds to the direction and magnitude of the fracture shear displacement as inferred from fracture aperture geometry features in horizontal and vertical profiles. The aperture geometry observed in the photographs indicate that the undulating fault surfaces have experienced a dextral strike-slip movement of approximately four centimeters.

The result from this study shows larger aperture values, larger aperture variation and longer correlation distances as compared to result from similar studies reported in the literature. The explanation for this is suggested to be the difference in type of fracture studied and the difference in scale of measurements. The frequency distribution of the aperture shows that a large part of the data lies below the measurement limit, i.e. that the "contact area" is large (approximately 40%). Hence, the result of this study demonstrates the importance of a correct description of the contact area in fracture characterization.

Both measurement methods used were found to work satisfactorily. The borehole photograph method is cost effective but requires successful drilling parallel to the fracture plane. This method gives information only in the direction along the borehole intersection. The drill core sectioning method is more time-consuming but gives better accuracy on the aperture data. This method gives information in all directions and therefore may reveal anisotropic features on a small scale.

In future fracture characterization studies, it is recommended that the measurement scale should be chosen with respect to the expected average aperture of the fracture. The borehole photograph technique is preferable for highly conductive fractures where large correlation distances can be expected. For tighter fractures the core sectioning technique is recommended.

4.4 FRACTURE CLASSIFICATION AND CHARACTERIZATION (FCC)

4.4.1 Background

Small-scale geological, hydrological and hydrochemical features are highly variable in nature. However, radionuclide transport models must rely on simple concepts, e.g., water flow through a channel with constant water chemistry, hydraulic gradient, wall rock mineralogy and porosity across the whole flow path.

Groundwater flow and nuclide transport is taking place in water conducting paths that are transmissive due to their genesis. Therefore eventually parameter values used in the numerical transport calculations should reflect the type of water conducting feature.

Fracture characterization and classification aim at suggesting suitable types of fractures for the planned tracer tests and at giving parameter values for modelling of relevant flow paths for nuclide migration.

The objectives of the study are:

- to develop a methodology for characterization of fractures with respect to rock type, tectonic evolution, infillings, and wall rock alteration, and by means of this characterization be able:

- to classify different fractures in terms of their importance for parameter assignment for the radionuclide transport and retardation modelling.

4.4.2 Results

An initial classification of the fractures in the tunnel has given two classes, simple and complex. A preliminary characterization of some 100 fractures in the tunnel is used to test and calibrate the predictive capability of the method. The important question is whether a distinction between simple and complex is feasible and if simple fractures can be predicted on this basis. The report is the basis for the selection of suitable sites for future tracer test in the TRUE program.

4.4.3 Planned work

Further examination of the fractures will be related towards the properties that are important for modelling of nuclide migration. The fractures of the experimental sites will be characterized and classified according to the preparations mentioned above. Within the evaluation and analyzing phases of the experiments it is very important to carefully study the correlations between the fracture classifications and results in terms of dispersion, channeling effects, sorption, and diffusion. Dependent on the results the classification may be modified. A conceptual model based on the characterization and classification should then be proposed for the safety assessment activities. The characterization and classification project will be finally reported at the end of 1995.

4.5 THE SELECT PROJECT

4.5.1 Background

Several experiments are planned for the Operating Phase of the Äspö HRL. These experiments require sites which meet specific requirements with respect to rock conditions and groundwater properties. A separate project was carried out which provided base data and recommendations for locating experiments /4-4/. Based on this work a provisional allocation was made of experimental sites for the Radionuclide Retention Experiment (RNR), the Redox Experiment on a local scale (REX) and the Tracer Retention Understanding Experiment (TRUE) at the experimental level (340-360 m level). It was identified that access to the allocated rock volumes, with one exception, is facilitated by drilling 20-30 m long boreholes from existing niches along the tunnel spiral. A separate project, the SELECT project, was set up to realize the above intention.

The following objectives were defined for the SELECT project;

- to perform geological, hydrogeological and hydrogeochemical characterization of designated experimental volumes,
- to establish whether the studied experimental volumes meet the specific needs of the planned experiments, and
- to provide the necessary information by which specific experimental sites can be selected.

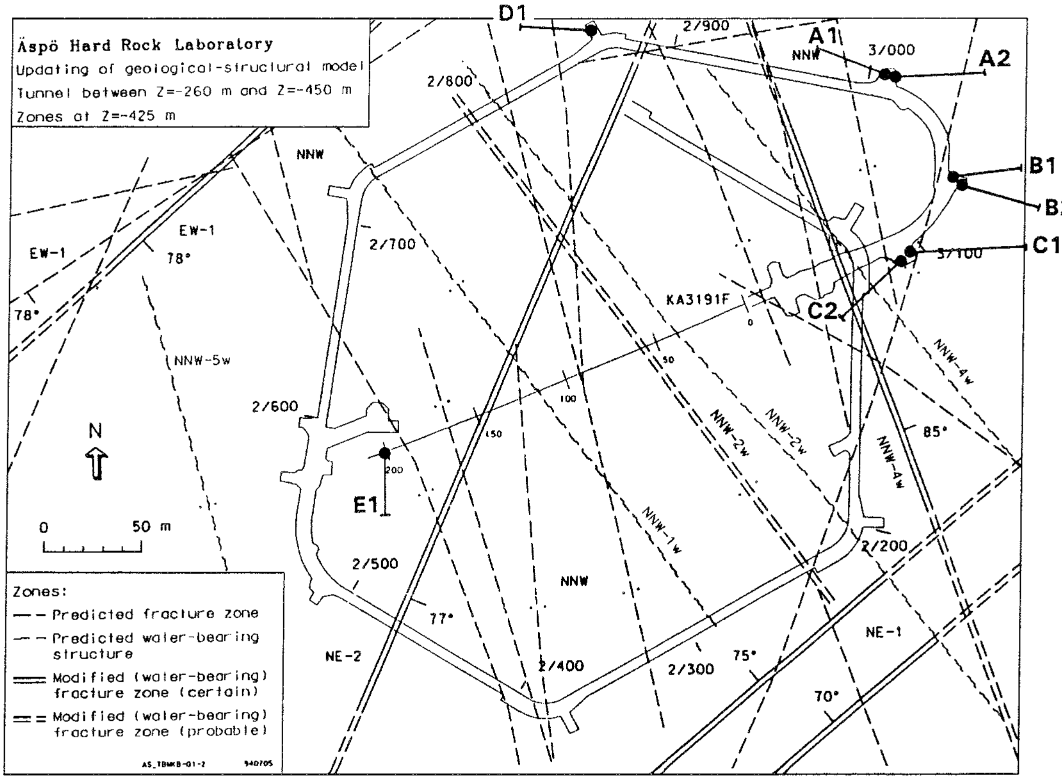

Figure 4-3. Location of pilot boreholes drilled within the SELECT project.

The general strategy for substantiating the allocated experimental volumes and identifying suitable sites for experiments within the includes the following components;

- drilling of 8 pilot boreholes into the allocated experimental volumes targeting members of the NNW fracture system,
- complementary geological and structural mapping of the niches from which drilling into allocated experimental volumes will be performed,
- logging of cores (lithology, structures, fracture minerals),
- borehole TV inspection, borehole deviation and spinner measurements,
- borehole radar measurements (directional antenna),
- pressure build-up tests in selected intervals,
- installation of packer system,
- water sampling upon completion of drilling, and of selected packed-off intervals, including reference sampling of microbes,
- monitoring of pressure responses during drilling and interference test programme after instrumentation,
- evaluation of site suitability, selection of suitable target volumes or fractures for the planned experiments.

During drilling and prior to any down-hole activity measures were taken to clean the down-hole equipment with pressurized steam in order to minimize input of microbes into the boreholes.

4.5.2 Results

The drilling programme has been completed with the drilling of boreholes KA2858A, KA2862A, KA3005A, KA3010A, KA3067A, KA3105A, KA3110A and KA3385A, where the number corresponds to an approximate length coordinate along the Äspö access tunnel. The locations of these boreholes are shown in Figure 4-3. The core logging showed that the bulk of the investigated rock is Äspö diorite. It was also found that the dominating fracture set which carries water is oriented in NW rather than the presumed NNW system. The images from the new BIPS borehole TV system proved to be a valuable complement to the core logs in identifying potentially conductive features. Figure 4-4 shows an unfolded BIPS-image of the section 36.9-37.9 m in KA3005A. It was also observed that gas was present in the groundwaters sampled in most of the pilot holes (1-3% by volume). Initial analysis of sampled groundwaters for microbial activity show that the total number of microbes shortly after drilling are varying between 10000 and 30000, with one exception (KA3110) which showed a total of 800000 microbes.

4.5.3 Planned work

During the first quarter of 1995 pressure build-up tests will be performed in selected sections of the boreholes. These sections are selected on the basis of information collected during drilling, borehole flowmeter data (spinner), and the

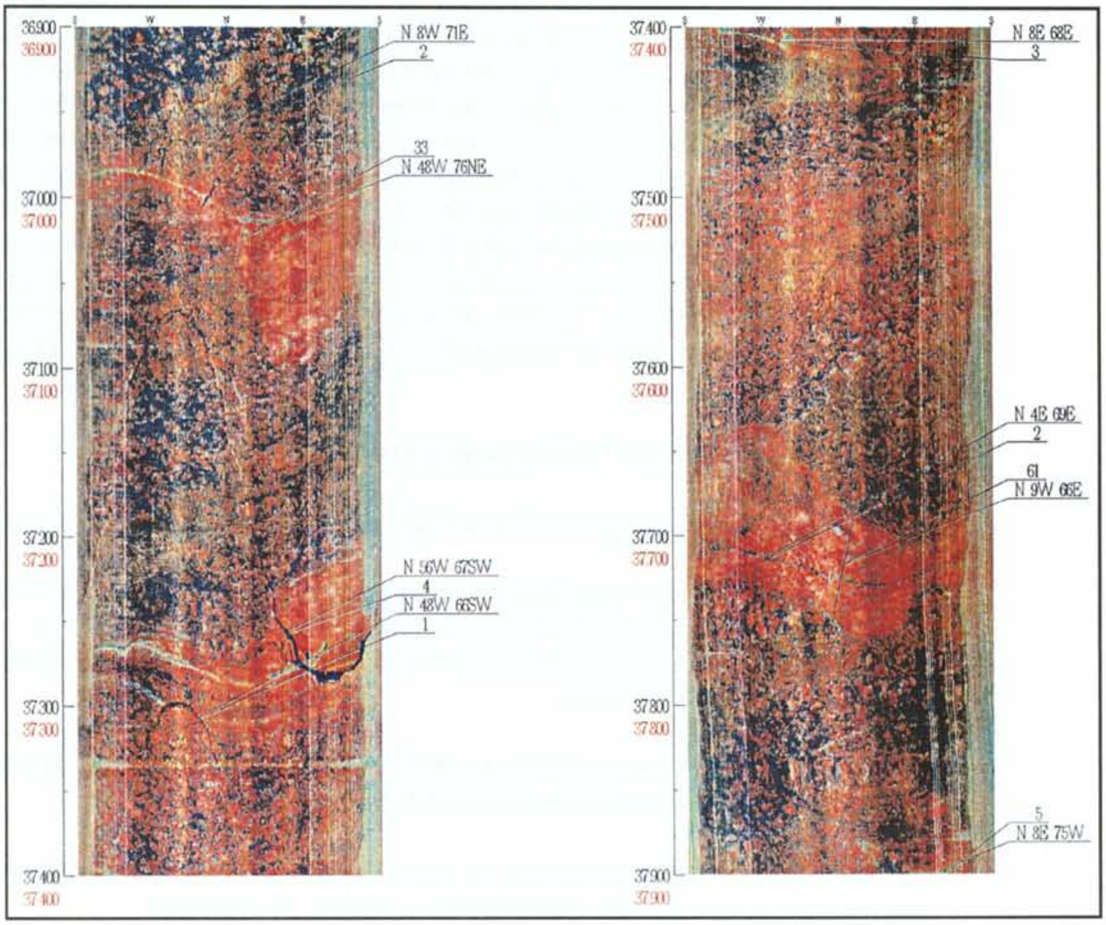

Figure 4-4. Borehole-TV image (BIPS) of the section 36.9 – 37.9 m in SELECT pilot borehole KA3005A. The main rock type is Äspö diorite. The more reddish parts indicate altered (oxidized) rock.

core and borehole TV data. On the basis of the collected data, the boreholes will be instrumented with multi-packer systems. Following a shorter monitoring period of ambient groundwater pressure, a sequence of interference tests will be performed with the aim to establish intra-hole connection between features of interest, and cross-hole interference between potential experimental sites. An integrated evaluation will be performed of the collected data and experimental sites will be allocated.

4.6 TRACER RETENTION UNDERSTANDING EXPERIMENTS

4.6.1 Background

The safety of a KBS-3 type repository relies heavily on the engineered barrier system that contains the waste. In the case that the engineered barrier fails, the geosphere provides the remaining waste containment. Realistic estimates and predictions of transport times through the geosphere and release rates to the biosphere are thus critical for any safety assessment. Of particular interest in this regard is the rock adjacent to the canister holes and storage tunnels.

The plans for tracer experiments outlined in the SKB RD&D-Programme 92 comprised experiments in the Detailed and Block Scales. The experiments in the Detailed Scale consisted of three; Pore Volume Characterization (PVC), Multiple-Well Tracer Experiment (MWTE), and the Matrix Diffusion Experiment (MDE). During 1994 detailed Test Plans were prepared for MWTE and MDE. Following review and evaluation the SKB HRL Project management decided to integrate the Detailed and Block Scale experiments within a common framework. This framework is described in a "Program for Tracer Retention Understanding Experiments" (TRUE) /4-5/. The basic idea is that tracer experiments will be performed in cycles with an approximate duration of 2 years. At the end of each tracer test cycle, results and experiences gained will be evaluated and the overall program for TRUE revised accordingly.

The general objectives of the TRUE experiments /4-5/ are to;

- Develop the understanding of radionuclide migration and retention in fractured rock.
- Evaluate to what extent concepts used in models are based on realistic descriptions of rock and if adequate data can be collected in site characterization.
- Evaluate the usefulness and feasibility of different approaches to model radionuclide migration and retention.

A testplan which details the work during the First TRUE Stage has been prepared /4-6/. The defined objectives of the First TRUE Stage are;

- to conceptualize and parametrize an experimental site on a detailed scale (L~5 m) using conservative tracer tests in a simple test geometry,
- to improve tracer test methodologies for conservative tracer tests in 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 subsequent analysis,

- to test sampling- and analysis technologies to be employed in the analysis of matrix diffusion, and
- to assess the usefulness of applied models.

The SELECT project with the aim i.a. to allocate an experimental volume for the First TRUE Stage is presented elsewhere in this volume, c.f. Section 4.5. The SELECT project is scheduled to present suitable target volumes for the REX, RNR, and TRUE projects in March 1995.

4.6.2 Results

The in-situ experimental results applicable to the First TRUE Stage are embedded in the presented results of the SELECT project, c.f. Section 4.5.

Work to establish a conceptual platform for resin technology and a feasibility study of resin technology is in progress. Contacts have been established with groups in Sweden, Canada, and Switzerland in order to customize an approach on pore volume characterization using epoxy resin.

Modelling work was initiated in 1994 but results are not yet available.

4.6.3 Planned work

Completion of the SELECT project and selection of target experimental volume for the First TRUE Stage. A first descriptive model will be established of the selected site. Then predictive modelling will be made of radially converging tracer tests which are scheduled to begin during the autumn of 1995.

4.7 DEVELOPMENT OF TRACERS

4.7.1 Background

A number of in-situ tracer experiments are planned for the Operating Phase of the Äspö HRL. In these experiments the transport of weakly sorbing tracers will be studied. A project of supporting laboratory tests has been defined to develop and test such tracers before they are used in-situ. The objectives of this project are:

- to develop and test performance of new (or rarely used) tracers before they are applied in the in-situ experiments,
- to provide laboratory data on transport parameters (distribution coefficients and diffusivities) for comparison with in-situ derived parameters and/or for evaluation of in-situ results, and
- to show that the tracers do not sorb on equipment used in the in-situ experiments.

4.7.2 Results

Batch sorption experiments have been performed with radioactive tracers of Na^+, K^+, Rb^+, Cs^+, Ca^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, and Br^-, using Finnsjö-granite, chlorite, and calcite as solid phases and a high saline groundwater representative for the Finnsjön-area. The results of this investigation was presented at the XVIII International Symposium on the Scientific Basis for Nuclear Waste Management in October 1994.

Studies of the sorption behavior of cesium to fine grained granite from Äspö are in progress. The reversibility of the sorption is studied by desorption experiments using several different chemical reaction agents. Preliminary results show a discrepancy between the different methods used for the desorption studies.

Diffusion cells have been prepared to study the diffusion of weakly sorbing tracers through Äspö-diorite and fine grained granite. Diffusion experiments with sodium ($^{22}Na^{+}$) and tritiated water (HTO) have been started. Three different thicknesses of Äspö-diorite and fine grained granite are used (10, 20, and 40 mm). A problem with cross-contamination of tritium between water samples within the glove box has been observed. The first breakthrough of tritiated water in the 10 mm thick diffusion cells have, however, been observed. Counteractions to avoid cross-contamination will be taken before new diffusion experiments are started.

4.7.3 Planned work

The laboratory studies to determine the distribution coefficients and diffusivities of these tracers will continue.

4.8 DEGASSING AND TWO-PHASE FLOW

4.8.1 Background

The objectives for the investigations of degassing of groundwater and two-phase flow are /4-8/:

- 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 in regionally saturated rocks 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 contents, chemical composition of groundwater, fracture characteristics (aperture distribution and transmissivities), and flow conditions.
- To get a measure of time scales required for resaturation of a repository.
- To develop technology for measurements of parameters under unsaturated conditions.

This knowledge 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.

In-situ testing of degassing and changes in hydraulic conductivity will be performed by measuring the inflow to a borehole at different pressures. Non-linearities in the flow-pressure relationship should be indicative of two-phase flow effects. The boreholes will be subject to air invasion to simulate ventilation of drifts and transport of gas from gas-generating waste.

This project is performed as one of the bilateral cooperation projects between USDOE and SKB for studies at the Äspö Hard Rock Laboratory in the Areas of

Site Characterization and Repository Performance. Contributions to the project are also provided by NAGRA and PNC.

4.8.2 Results

To provide a basis for defining the scope of the project a literature review has recently been completed and reported /4-7/. This report also presents results of some initial laboratory tests on two-phase flow properties in artificial fractures. These tests show flow reductions by approximately a factor of two for two-phase flow conditions compared to single phase (water) flow.

The in-situ test program began with a pilot test with the objective to get data on the magnitude of degassing effects on permeability, time scales required for resaturation, and requirements on equipment for subsequent tests.

It was considered essential to perform the pilot test in a rock mass where degassing had never occurred, i.e. the rock mass should not have been subjected to pressures below the bubble pressure. To meet this requirement a special valve system was developed which made it possible to drill the pilot borehole without letting the borehole pressure down to atmospheric during the entire drilling. The pilot borehole, KA2512A with a diameter of 101 mm, was drilled horizontally at a depth of about 335 m. Drilling of the borehole was completed successfully without ever letting the pressure in the borehole fall below 1500 kPa. Hence, it was possible to complete the drilling without introducing two-phase flow conditions which could influence the subsequent hydraulic testing.

The pilot test comprised a sequence of hydraulic tests in borehole KA2512A and was performed at Äspö HRL during December 1994. The primary objective of the pilot hole test was to test the hypothesis that two phase flow conditions evolve as a result of groundwater degassing upon pressure reduction. This was tested by measuring the inflow to a single borehole as a function of borehole pressure. The flow pressure-relationship is linear for single liquid phase conditions and deviations at low borehole pressure should indicate the presence of a gas phase. In addition, the need for development and construction of a packer system that could be installed without depressurization of a borehole should be evaluated as such a system would be costly and its performance uncertain. The pilot hole test also provided the opportunity to investigate whether other mechanisms at low borehole pressures could cause changes in transmissivity, such as effective stress changes, calcite precipitation, and turbulence.

The pilot hole test had four phases: 1) characterization of the flow system for single-phase conditions by a series of tests at borehole pressures above the estimated bubble pressure; 2) allow two-phase flow conditions to develop by reducing the borehole pressure to atmospheric pressure and measure the chance in transmissivity; 3) repeat tests of the first phase to observe any hysteresis as the flow system returned to single liquid phase conditions and measure the time required for resaturation; and 4) a test at atmospheric borehole pressure to observe long-term changes.

The relationship between borehole pressure and inflow rate was linear over borehole pressures ranging from 1500 kPa down to atmospheric pressure. Subsequent measurements indicated that the gas contents of KA2512A (0.5% v/v) was probably too low to cause two-phase flow effects. The results show no evidence of other processes that might reduce transmissivity at low borehole pressures, such as calcite precipitation, increase in effective stress, or turbulence. A transmissivity of

$3 \cdot 10^{-7}$ m^2/s for the tested fracture was obtained from the steady state flowrates as a function of borehole pressure. An analysis of the transient constant pressure test data by type curve matching to a 3D flow model gave a hydraulic conductivity value of $1.2 \cdot 10^{-6}$ m/s which did not vary significantly with borehole pressure.

Step changes in flow rates were observed which coincided with blasts occurring at the 450 m level below the test site. The magnitude of changes were larger at lower borehole pressures. Pressure increases in monitoring well KA2511A also coincided with the blasts.

Volumetric gas contents measured in other boreholes were variable and higher than in KA2512A, ranging from 1 to 3% v/v. This raises questions regarding the origin of dissolved gasses in the groundwater at Äspö.

4.8.3 Planned work

Additional gas sampling for quantitative analysis will be made during January 1995. Moreover, the borehole pressure in KA2512A will be lowered again to 120 kPa for monitoring the flowrate at sub-bubbling conditions on a longer-term basis.

A report on the procedures and basic data analysis of the initial degassing test is scheduled for the middle of February. Laboratory experiments on fracture replicas from the Äspö HRL-site will be performed at LBL during January – August 1995.

4.9 REX (=REDOX EXPERIMENT IN DETAILED SCALE)

4.9.1 Background

The Block Scale Redox experiment was carried out in a fracture zone under Hålö in the entrance tunnel to Äspö. In spite of massive surface water input, the fracture zone remained persistently anoxic. The main conclusion from this study is that the increased inflow of relatively organic-rich shallow groundwater added organic carbon as a reductant, rather than dissolved oxygen as an oxidant, to the deeper parts of the fracture zone. Simultaneous production of biogenic fracture minerals (calcite, siderite, magnetite) is possible. These conclusions are specific to this particular fracture zone, experimental conditions and the time scale (3 years) of the experiment, see Section 4.2.

The detailed scale experiment (REX) is planned to focus the question of oxygen and other redox active material that is trapped in the tunnels when the repository is closed. 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?
- 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?
- What is the role of microbes in the transient stage after closure of the repository.

4.9.2 Results

A draft test plan for the experiment has been prepared. The test plan outlines the details of the experiment. A possible layout will include a few boreholes into a fracture zone in the deeper parts of the tunnel. Redox processes mainly oxygen reduction will be studied through injection in one borehole and recovery in an other borehole. One or several boreholes might be drilled further off from the disturbed surrounding as reference holes for monitoring of redox conditions.

4.9.3 Planned work

The experimental work is scheduled to begin in the middle of 1995. Before that a predictive modelling is planned to be done using the simplest possible coupled transport and reaction model.

Investigations include:

1 Penetration of air, and an oxygen redox front, into the walls of a repository.

2 Excavation of a single fracture to observe distribution of flow paths and flow-wetted fracture minerals as a sorption barrier to radionuclide migration.

3 Redox capacity of granite to molecular oxygen (or other radiolysis products) uptake.

4 Generation of an oxidizing front on meter scale to study Uranium mobility and distribution across the front.

5 Detailed sampling of drillcores taken from a fracture zone, using "nondestructive" drilling techniques on a localized scale, to observe the distribution and abundance of fracture-filling clays (possible sorption barrier) without their loss in drilling water.

6 Generation of calcite, siderite and/or magnetite by microbial processes in active fractures, and the influence on radionuclide distribution and mobility.

4.10 RADIONUCLIDE RETENTION

4.10.1 Background

The retention of radionuclides in the rock is the most effective protection mechanism if the engineering barriers have failed. 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 Tc, Np, Pu and others 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 retardation processes the sorption could well be irreversible and thus the propagation of the front 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 be able to demonstrate the results of the laboratory studies in situ. It is possible to have the natural contents of colloids, of organic matter, of bacteria etc in the experiments. Laboratory investigations have difficulties to simulate the natural conditions in the groundwater and are therefore dubious as validation

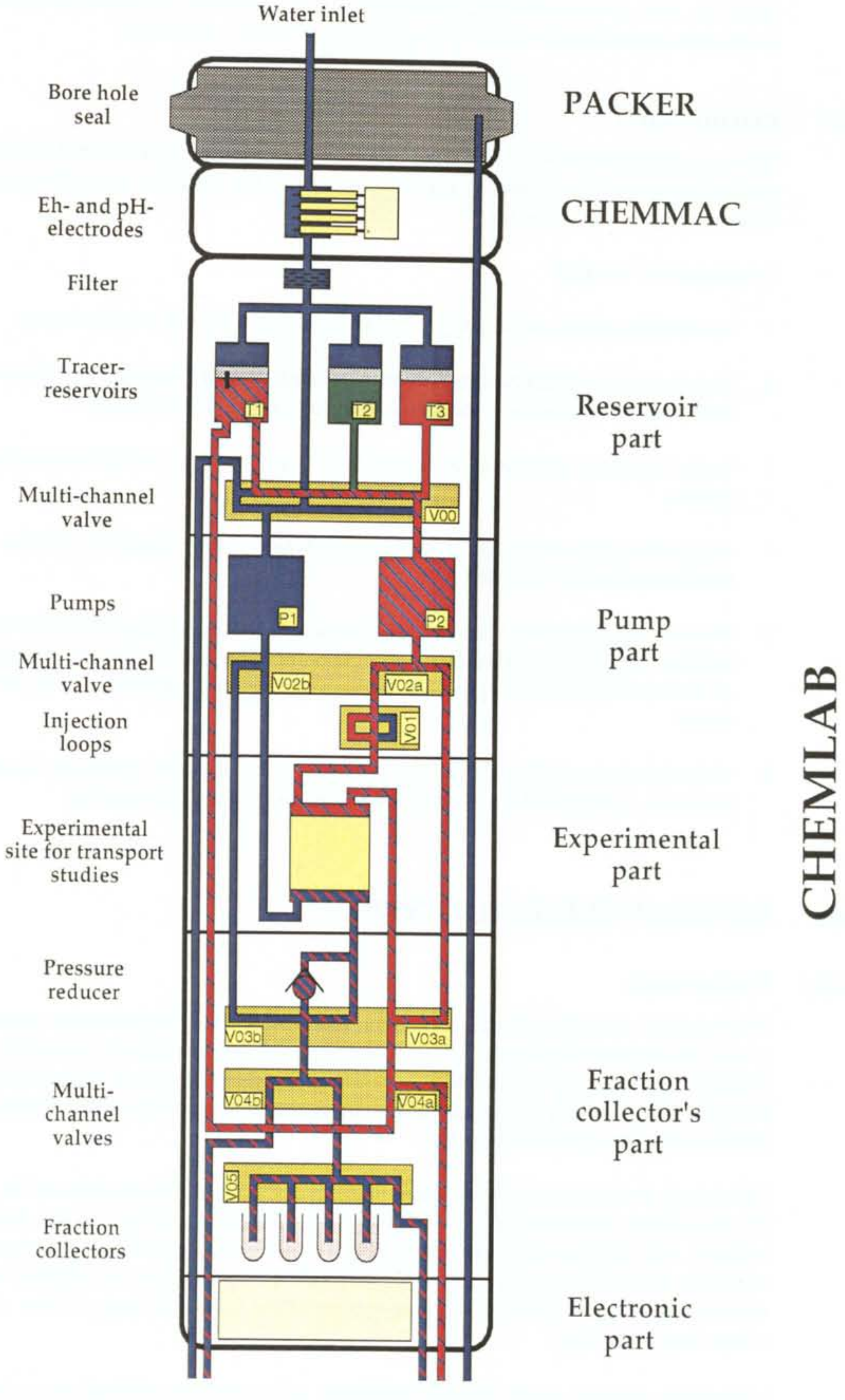

Figure 4-5. Schematic illustration of the CHEMLAB probe.

exercises. It is therefore suggested to use the CHEMLAB probe, see Figure 4-5, to conduct validation experiments in situ at undisturbed natural conditions.

4.10.2 Results

The CHEMLAB probe 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 use of the formation groundwater surrounding the probe. The manufacturing of the probe is presently under way at Metro Mesures in France.

A radiological laboratory is presently established in the CLAB interim storage facility. The laboratory will be used for the preparation of the CHEMLAB probe and for the handling of short-lived nuclides to be used in tracer tests.

At the deepest level, 450 m, in the tunnel a 20 m deep niche has been blasted and a probing hole has been drilled, as a preparation for the experiments to be conducted.

4.10.3 Planned work

The manufacturing of the probe is scheduled for completion in July 1995. A delivery test and inactive tests are scheduled to be conducted during autumn 1995. Active tests are scheduled to begin in 1996.

4.11 RESULTS OF WORK IN THE TASK FORCE ON MODELLING OF GROUNDWATER FLOW AND TRANSPORT OF SOLUTES

4.11.1 Background

The Task Force shall be a forum for the organizations 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.

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

4.11.2 Results

During 1994 the fourth and the fifth meetings of the Äspö Task Force (TF) were held. The fourth meeting was arranged by SKB close to the Äspö site and the fifth meeting took place in Kuhmo, Finland, with TVO as host organization.

The long term strategy of the Äspö TF has been discussed. It has been concluded that the work in the TF should be tied to the experimental work performed at the Äspö HRL. Furthermore, the work should be performed within the framework of well defined and focused Modelling Tasks. The TF group should attempt to evaluate different concepts and modelling approaches. Finally, the TF should provide advice on experimental design to the Project Teams, responsible for different experiments.

Table 4-1. Äspö Task Force. Modelling reports on Task No. 1, the LPT-2 experiment.

ORGANIZATION	MODELLING TEAM	REPORTS
ANDRA	BRGM(I) MARTHE/SESAME	DRAFT
	BRGM(II) ROCKFLOW	DRAFT
	ITASCA CHANNET/TRIPAR	ICR 94-14
CRIEPI	CRIEPI FEGM/FERM	ICR 94-08
PNC	PNC/Golder FracMan/MAFIC	ICR 94-09
	Hazama SETRA/ARRANG	ICR 94-07
SKB	CFE PHOENICS/PARTRACK	SKB TR 92-32
	KTH CNM	ICR 94-05
TVO	VTT FEFLOW (flow)	ICR 94-12
	VTT – (transport)	ICR 94-11

A subgroup of the Äspö TF has worked out an Issue Evaluation Table which will provide valuable help in relating performance assessment as well as characterization key issues to the actual, forthcoming experiments.

The evaluation of Task No 1, the LPT2 pumping and tracer tests, is in progress. The different modelling activities have been reported in the Äspö International Cooperation Report (ICR) Series. Table 4-1 gives an overview of the reporting for this Task and it is seen that eight reports have been distributed so far. A wide variety of conceptual as well as numerical models have been used to predict water flow and tracer breakthrough in this rather large scale. The very large data base available have been utilized to different extent and the calibration efforts are varying.

However, all modelling groups have produced relatively accurate simulation results as compared to the experimental outcome. It has to be kept in mind that this first task was no blind prediction. The results were available beforehand and the amount of calibration efforts with existing data has to be considered. Forth-coming tasks will be performed as blind predictions where the modelling and the experimental work will be done in parallel.

To facilitate evaluation of Task No 1 a number of critical questions were addressed to the modelling groups. The Questionnaire focused on differences in conceptual modelling approaches, on the data base used for the modelling work, on comparison of results/simulations and on interpretation of any observed differences. A first version of an evaluation report on Task No 1 has been produced and distributed to the TF group for comments.

Task No 2 was finalized during 1994. This concerned design calculations for some of the planned experiments at the Äspö site, for the Matrix Diffusion Experiment and for the Multiple Well Test Experiment. Five reports concerning Task No 2 have been printed in the Äspö ICR series.

The hydraulic impact of the tunnel excavation at Äspö HRL was defined as the 3rd Modelling Task. The objective will be to evaluate how the monitoring and the study of the hydraulic impact of the tunnel excavation may help for site characterization. Task No 3 will be an exercise in forward as well as inverse modelling. A rather extensive data set has been distributed. This included tunnel layout, tunnel inflow, piezometric levels, salinity measurements etc, described in the SKB HRL PR 25-94-16. Very preliminary results were presented by four modelling groups at the last TF meeting.

A 4th Modelling Task was defined as predictive analyses of the TRUE 1st stage experiment in the detailed scale. Site characterization data will become available next year and these data are the basis for the predictions.

4.11.3 Planned work

The evaluation report on Task No 1 will be finalized during the spring of 1995.

An updated geological structure model of the Äspö site as well as geohydrological interpretation will be delivered to the modelling groups. A structure model in a regional scale will also be delivered during the spring of 1995.

A number of modelling groups are expected to report their modelling work on Task No 3.

Regarding Task No 4, a special modelling group meeting is expected to take place at Äspö in April next year when data becomes available from the first pilot hole for the TRUE experiment on the detailed scale.

The next TF meeting will take place in Sweden close to Äspö on June 14-16, 1995.

4.12 HYDROCHEMISTRY MODELLING

4.12.1 Background

An international geochemistry workshop was held on June 2-3 at the Äspö Hard Rock Laboratory (HRL). Participants included SKB investigators and international partners in the project. Proceedings have been published in the ICR-series /4-9/.

The outcome of the workshop was the definition of two modelling exercises to be carried out by different teams, with the intention to present and compare results on completion of the work. Modelling will concentrate on available data from the Äspö site; for this purpose a thorough geochemical database was distributed to the various modelling participants based on published and unpublished data. The main objective of these exercises is to develop a site model for integrated geochemical and hydrogeological processes at Äspö. This will entail two approaches:

1. One exercise will focus on the present day situation, using the existing data base, where modelled hydraulic pathways controlling groundwater flow through the Äspö site will be compared with observed natural hydrogeochemical tracer data, for example, conservative elements such as Cl and isotopes such as deuterium, oxygen-18, carbon-14 and tritium. These parameters should indicate whether water has flowed from point "A" to point "B", therefore providing supporting evidence for the hydraulic groundwater flow model.

2. The second exercise will address the recent geological history of the Äspö site by studying the past evolution of the groundwater chemistry in time and space with the help of established palaeoclimatic signatures, both chemical (e.g. salinity) and

isotopic (e.g. deuterium, oxygen-18, carbon-14). And the opposite: Using present-day geochemical and hydrogeological data to interpret the palaeogroundwater flow and palaeohydrochemical conditions aiming at "process identification".

The reasons for separating palaeohydrochemistry; process identification from the groundwater-rock interaction exercise is that some of the data, i.e. especially the age determining isotopic parameters, relate to conditions so far back in the past that it is impossible to reconstruct a hydraulic model to match the palaeohydrochemical description.

It has also been proposed that the modelled output of these two exercises should form the basis for a safety performance assessment of Äspö as a deep repository site, concentrating on the long term/large scale issues, e.g. chemical stability, groundwater flow and nuclide transport.

4.12.2 Results

The modelling tasks have been discussed and the objectives more specified at separate working group meetings in autumn of 1994.

The integrated modelling will aim at:

- Improving the models or the basis for the models describing the performance of a repository and the migration of radionuclides from a leaky repository to the biosphere.

The specific objectives are to:

- Evaluate the consistency of the hydrological groundwater flow models and the geochemical mixing/reaction models.
- Study the interrelations between present day hydrogeological models and geochemical models.
- Increase the reliability in the models describing groundwater flow by combining indicators (chemical tracers) and hydrological conditions.
- Develop procedures for comparison of these models and develop methods to build confidence in simulation of groundwater flow.

Palaeohydrochemistry; process identification will aim at:

- Refinement and improvement of the models or the basis for the models predicting future evolution in groundwater flow and hydrogeochemistry.
- Application of these models to predict, under realistic time scales, the future performance of a repository system assuming that the migration of radionuclides from a leaky repository to the biosphere will ultimately occur.

The objectives of the modelling task are:

- To differentiate between groundwaters of varying age and origin and their interaction.
- To define the different water/salinity end-members of the 0-500 m groundwater mixing system.
- To determine the origin of salinity characterizing the groundwaters at depths greater than 500 m (regional sources?).
- Select source groundwater members linked with known age ranges (e.g. Permian, Litorina origin etc.) to test the hypothesis of palaeogroundwater mixing and to better define the boundary conditions of these processes.

4.12.3 Planned work

The modelling tasks are coordinated to a project involving SKB's international partners in the Äspö project. They are also tightly linked to the reporting of "Verification of pre-investigation methods" a stage goal of the Äspö project.

The modelling project is aiming at producing a report by 1 September 1995. One project meeting and one workshop are scheduled.

5 DEVELOPMENT OF CONSTRUCTION AND HANDLING METHODS, PILOT TEST

5.1 GENERAL

The safety of a repository is determined by:

- the properties of the site,
- the design of the barriers,
- the quality of execution of the deep repository.

A KBS-3-type deep repository is supposed to hold about 4500 canisters in rock caverns at a depth of about 500 m. The different barriers (canister, buffer, rock) work together to isolate the waste. Backfilling/plugging of tunnels, shafts and boreholes limits the flow of groundwater via the potential flow paths opened up by the construction and investigation work, thereby making it more difficult for corrodants and any escaping radionuclides to be transported up to or away from the canisters/waste. All of this work with barriers, plugs etc. must be executed with a given minimum quality.

The Äspö HRL provides an opportunity for demonstrating technology that will provide this necessary quality.

Current experience from the construction of the Äspö facility will be evaluated and reported. Plans for future work have also been outlined.

Plans for construction of an initial stage of a deep repository were presented in RD&D-Programme 92. These plans have been received positively by the reviewing bodies. The need to integrate existing knowledge and build an (inactive) prototype of a deep repository is recognized within SKB. For example: A part of a deposition tunnel will be built and backfilled at Äspö. In conjunction with planning, design and construction, work descriptions and quality plans are being prepared which can later be used for the deep repository. The objectives include translating scientific knowledge into engineering practice, testing and demonstrating the feasibility of the various techniques, and demonstrating that it is possible to build with adequate quality.

In conjunction with construction of the prototype proposed above, different types of models will be used to describe the performance of the prototype in conjunction with water absorption and restoration of groundwater pressures, etc. The performance of the prototype will then be monitored at a large number of measurement points for a period of 5-15 years. Following this there will be an opportunity to study in detail any chemical and physical changes in e.g. the bentonite surrounding the canisters.

In addition to the prototype repository, studies will be undertaken to test alternative materials and methods for backfill of deposition tunnels.

The prototype will be tested for "normal" conditions. Adverse conditions will also be tested in special tests.

5.2 EVALUATION OF UNDERGROUND DESIGN AND CONSTRUCTION WORK

The experience from the first phase of the design and construction work (down to the 340 m level) has been compiled, evaluated, and reported /5-1/.

To this depth tunnel excavation was made using the drill and blast method. A completely computerized drill rig was used initially but it did not meet expectations and was replaced with a manual rig with a computerized directioning device (Beaver Control). Mucking out has been performed with an electric hauler. The details of the excavation procedure has been developed successively including thorough tests of blasting patterns and explosive as well as grouting materials and methods.

The high ground water pressures in combination with large inflows have caused a lot of problems during probe drilling and subsequent measurements in these holes.

5.3 SITING OF SUITABLE NEAR FIELDS

The concept of rock volume descriptions within the SKB program for suitable nearfield design is being developed to provide a basis for planning, design, and construction of a repository. The term rock volume descriptions has not a strict definition, but is aimed at using existing information on geology, stability, building conditions, hydrogeology, and groundwater chemistry at every investigation stage of repository establishment. The parameters for rock volume descriptions should to the greatest extent possible be similar to the final design parameters, e.g. maximum number of canisters per kilometer tunnel at a specific temperature, groundwater flow, and lithology.

The maximum number of canisters on a specific length of the repository tunnel is given with respect to practical conditions, e.g. tunnel-dimensions and drilling equipment. An important issue is how well this maximum capacity can be used, depending on geology, stability, hydrogeology, and geochemistry. A measure, or index, of the capacity relative to the maximum capacity may be referred to as **C**anister **P**ositioning index (CPI). Since CPI has not yet been strictly defined, **P**rovisional **P**ositioning **I**ndex (PPI) may be used until consensus has been achieved on the definition of CPI. The PPI is defined as the probability at a specific confidence level that a canister position within a given rock volume is acceptable.

A Markov-Bayes Geostatistical Model, partly developed within the SKB siting program, was modified and applied to PPI-calculations /5-2/. The methodology differs from conventional geostatistical methods in 1) being non-parametric to be able to handle classified information with unknown statistical distributions, and 2) using Baysian statistics to formally handle professional judgements of the evaluator. The first stage of the project was primarily directed towards methodology development and less towards analysis and interpretation of data.

5.4 CONSTRUCTABILITY ANALYSIS

The design and construction of a repository must meet a number of requirements. A systematic analysis of constructability is essential to make sure that the requirements can be met /5-3/.

An on-going study of constructability analysis was completed during 1994 for parts of the TBM tunnel /5-4/. The second stage, using data from a borehole along the TBM tunnel, will be utilized to compare the constructability analysis using different data sets. The Markov-Bayes geostatistical approach will be used as an input to the second stage study.

5.5 DEVELOPMENT OF A PROTOTYPE REPOSITORY AT ÄSPÖ/TESTS OF ALTERNATIVE BACKFILL MATERIALS AND METHODS

The benefits of a prototype repository at Äspö are currently being discussed within SKB. The tentative idea is outlined in the following.

5.5.1 Background

The overall ambition of the Äspö HRL is to test, develop and demonstrate the technology that will be used for the siting, construction and analysis of the deep geological repository for spent fuel in Sweden.

It is of particular importance to test and demonstrate the interaction between the engineered barriers and the rock in as realistic an environment as possible. This will primarily involve long-term tests and demonstration tests on a full or representative scale.

The design, construction and testing of the prototype repository is aimed at a simulated deposition sequence starting from detailed characterization of the host rock to resaturation of the backfilled deposition holes and tunnel in order to fulfil the following specific objectives:

- To translate scientific knowledge and state-of-the-art technology into engineering practice that can be applied in a real repository.
- To test and demonstrate the practicability of integrating the different steps of a deposition sequence in a realistic environment.
- To show that the deposition sequence can be performed with sufficient quality in relation to relevant standards.
- To develop and test the appropriateness of the engineering standards and the quality assurance plan.
- To test and demonstrate the integrated performance of the prototype repository.
- To demonstrate methods for design, construction, excavation, near-field characterization, backfilling, sealing, plugging, monitoring and retrievability.
- The purpose of these tests is to provide the background material necessary for Government approval of the start of construction of the deep geological repository.

The prototype will be limited in the following respects:

- No handling of spent fuel.
- The handling will not simulate radioactive canister dummies, i. e. no remote operation.
- The prototype repository cannot demonstrate the long-term safety of a repository.
- Heating will have to be scaled in time.

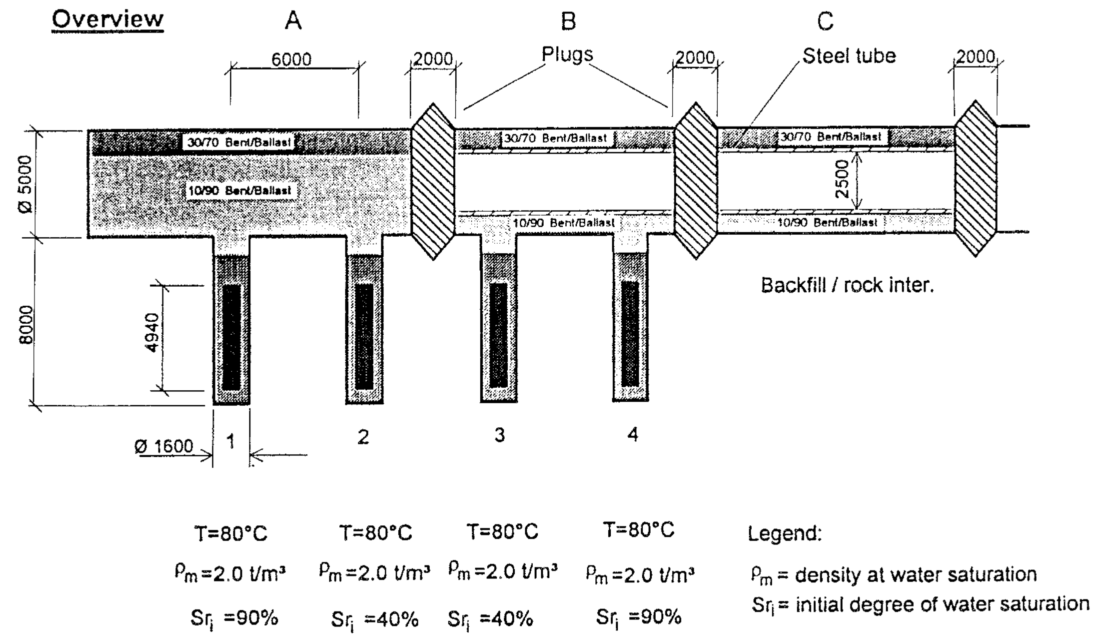

Figure 5-1. *Tentative layout of the Äspö prototype repository.*

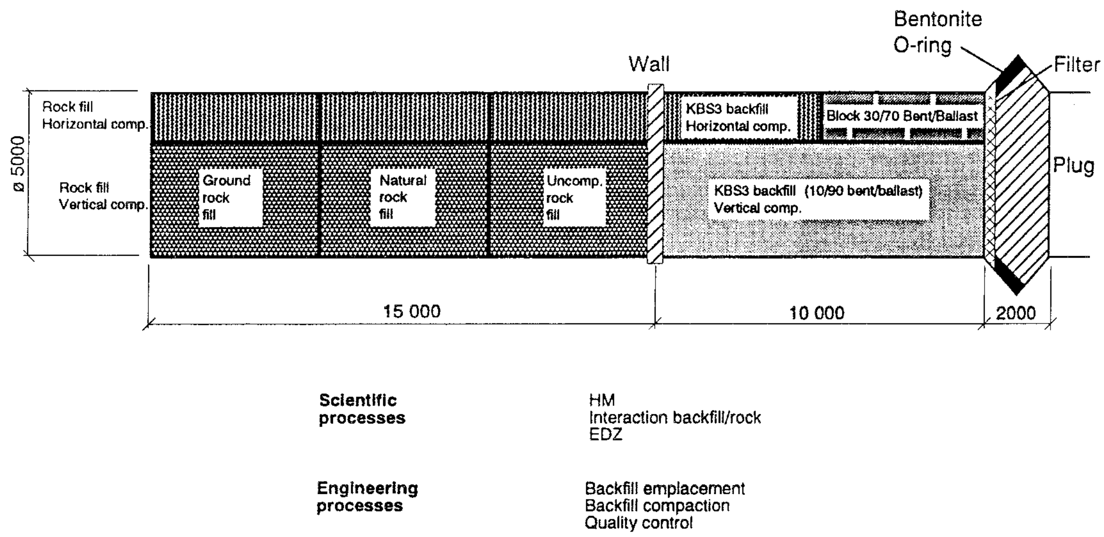

Figure 5-2. *Tentative layout of tests for backfill materials and methods.*

5.5.2 Results

The general idea is to design, construct and test a prototype repository at Äspö. The execution is a dress rehearsal for a deep repository. It includes characterization, layout, design, backfilling, resaturation and retrieval. It shall make full use of performance assessments and safety assessments at appropriate stages of the test.

A program has been prepared /5-5/, divided into four stages. Stage 1 Backfill tests, preparation, Stage 2 is Prototype construction and Stage 3 Monitoring. Stage 4 is Retrieval.

Stage 1 includes tests of backfill emplacement technology for a few types of backfill material.

The "Rock Fill Test" will make use of mechanically excavated rock debris from the TBM (Tunnel Boring Machine)- drift at Äspö. It will be compacted by standard methods for the lower parts of the backfilled drift. New technology to be developed will be used to compact the backfill in the upper part of the drift.

The "KBS-3" test will utilize the same TBM-rock, but it will be graded to a certain specification and mixed with 10% bentonite in the lower ¾ of the drift. In the upper part 30% bentonite will be used. Two different emplacement techniques will be used, either horizontal in situ compaction or using pre-compacted blocks.

A mechanical plug will be constructed.

The expected outcome of the backfill tests in Stage 1 are e.g.:

- Practical specifications for emplacement of several backfill materials.
- Practical in situ tests of several possible backfill materials.
- Pre-testing of instruments and sampling methods.
- Development and pre-testing of methodology for measuring the interaction buffer/backfill/rock interaction.

Stage 2 will basically comprise prototype construction and instrument installation. Modelling of processes is an integral part.

In connection with prototype construction monitoring will be initiated. The results from sampling and monitoring will be reported and evaluated periodically, Stage 3.

The prototype will preliminarily consist of four deposition holes and three tunnel sections, cf Figure 5-1.

Backfill technology will be tested for different ranges of properties to test compaction methods. A tentative layout is depicted in Figure 5-2.

Detailed Test Plans will be prepared for each stage.

5.5.3 Planned work

The current work is directed to developing the detailed plans for Stage 1 so that the backfill tests can start in the ZEDEX-tunnel during 1995.

5.6 TESTS OF ADVERSE REPOSITORY CONDITIONS

While normal repository conditions will be tested in the Äspö prototype, adverse or upset conditions will be studied in separate tests. Some of them will be performed on full scale, others in smaller scale tests.

Adverse conditions will be tested depending on the conclusions of performance assessment and safety analyses and depending on available resources, like manpower.

A detailed program will be set in 1995 to possibly include:

- *Canister hole in fractured rock.* A hole will be made in fractured rock to test emplacement technology in a very wet hole that may also be irregular in shape.
- *Altered buffer.* The effect of alteration of the buffer material in a hole to a less effective material (e.g. illite) will be studied. Such a buffer material can be prepared either by accelerated in-situ alteration at a high temperature (200^{o}C which requires a larger distance to the other holes) and addition of potassium, or by direct emplacement of a buffer with low smectite content.
- *Canister failure.* A canister hole will later be used for studying the effect of having a copper canister that has lost part of its inner supporting steel canister. This test also provides an opportunity to verify the models and calculation tools for the rheological behavior of the buffer and its hydrologic interaction with the rock.
- *Gas penetration.* Gas penetration through the buffer, backfill and rock by applying a high gas pressure at the surface of the canister will be tested. First phase will be conducted in small scale. The second phase will be made in full scale at a deposition hole.
- *Salt enrichment.* Salt accumulation and salt in-diffusion under a temperature gradient of 1-2^{o}C/cm and with a maximum temperature of 80^{o}C will be tested in a small-scale test. In this test some part of the buffer material may be emplaced with a high salt content in the pore water from the beginning (salt added to the water at compaction). Other chemical tests can also be made in these holes.

6 DEVELOPMENTS AT THE SITE OFFICE

6.1 GENERAL

The main improvement has been in the field of data management.

An agreement with OKG (the local nuclear power plant) concerning the operation of the facility has been signed.

The excavation was almost finished during the year and as a result a change in the organization took place, see Section 1.3.

The construction of Äspö Research Village was completed during the summer and in August the site office was moved to Äspö.

6.2 DATA MANAGEMENT

6.2.1 Background

One of the main objectives with the Äspö Hard Rock Laboratory is to test and develop necessary techniques before they are applied at the candidate sites. Efficient techniques are required to handle, interpret and archive the huge amount of data collected at a site.

SKB has more than ten years experience concerning how to utilize the concept of relational databases. The SKB investigation database GEOTAB was first based on the Swedish relational database system called MIMER. During 1991 SKB decided to replace MIMER. Since the spring 1992, GEOTAB has been based on Ingres.

The Äspö HRL Site Activity Database (SADB) was first developed to be a complement to GEOTAB. The central data table in SADB is a complete event list describing all performed measurements and engineering activities at the site in sequence, like the contents in an ordinary diary. The first version of SADB was ready on October 5th, 1993.

In the spring 1994 SKB decided to develop a new database by combining the concepts of GEOTAB and SADB. A project was defined and the work started June 21st.

There is another extensive data project running in parallel to the database project. The realization of SKB Rock Visualization System. The need for a powerful visualization system has been discussed many years, but no suitable system has been available on the market. In the fall 1993 SKB decided to prepare system specifications for a visualization system based on the general CAD-system MicroStation.

The Rock Visualization System is built on the eight subsystems listed below:

- Main Menu (Login, Modell /Site selection, ...).
- Data Interface (Export/Import of data).
- Database Administration (Interface to the new database).
- Borehole (Borehole visualization).
- Modelling (Modelling of the rock volume(site)).
- Design (Design of the Deep Repository).
- Animation (Time dependent data and fly throughs).
- View (Visualization of prepared data/models).

The main task in the visualization project is to establish an effective, reliable and database independent connection between subsystem "Database Administration" and the new investigation database.

6.2.2 Results

Integration of GEOTAB and SADB

A prototype of the new database concept, a combination of effective database structures and functions in GEOTAB and SADB, has been developed. An extensive planning work has also been carried out to make it possible to move all data from GEOTAB and SADB to the new database system. The work with the data transfer started December 7th.

Rock Visualization System

The SKB Rock Visualization System will be based on the CAD-system MicroStation, developed by Bently Systems, Inc in USA. MicroStation is a modern and powerful 3D-modelling system, running on computers with the most common operating systems as DOS, Windows, Windows 95, Windows NT and UNIX (Sun, Silicon Graphics....).

System specifications were compiled by the members of the project group (Mats Ohlsson, Ebbe Eriksson, and Ingemar Markström) during the first half of 1994. The Principal Investigators in the Äspö Project and other geoscientific experts in SKB's organization have greatly been involved in defining many of the functions needed in the system.

In June the system specifications were sent to seven Swedish software developing companies experienced in programming MicroStation. In medio August four offers arrived to SKB before the agreed date. The offer from Arctic Software AB in Luleå was the most competitive one. Arctic Software is cooperating with CAD Perfect Development Lab in Stockholm. CAD Perfect is a small company specialized in the area of advanced visualization and animation by using the CAD system MicroStation. An agreement between SKB and Arctic was signed November 14th, 1994. The agreement excludes programming of the system. The programming work will be ordered when the system has been systematized.

The Yourdon-method will be used by Arctic in the work to systematize the Rock Visualization System.

Medio December Arctic presented a “Project Start Report (draft)” and a report describing the common “Programming Rules (draft)”. The “Programming Rules” is one of the key documents in this project, because the goal at the very end is to own a uniform code which is easy to maintain.

6.2.3 Planned work

Integration of GEOTAB and SADB

All data now stored in GEOTAB and SADB are planned to be accessible in the new database at February 28th, 1995. At the end of June 1995 the new system is planned to be in operation. At that date the "User's Guide" and several other supporting manuals should be available.

Rock Visualization System

The first version of the "User's Manual" is planned to be delivered May 5th, 1995. The complete pseudo-code, which is the final result of the systematizing work, is planned to be delivered by Arctic in August 25th, 1995, and the first version of the SKB Rock Visualization System is planned to be released at the end of the year 1995.

7 DEVELOPMENT OF INSTRUMENTS AND METHODS

7.1 GENERAL

The overall goal for development of instruments and methods during the Construction phase is to assure that suitable and reliable measuring instruments and methods are available for the basic documentation and monitoring for the validation program and for the detailed investigation work that will be carried out. Activities defined to achieve this goal are described below.

For the Operational phase most instrument and method development work will be handled within the different experiments, and are therefore described under these sections of this report.

7.2 DRILLING- AND BOREHOLE-RELATED EQUIPMENT

7.2.1 Background

The Annual Report 1993 discussed the problem related to drilling of investigation boreholes through waterbearing fractures or fracture zones from an underground facility. In particular, the problem is related to what kind of measurements shall be carried out in the borehole. High out-flows of water at high groundwater pressures reduces the possibilities of moving testing probes into and along the borehole.

To resolve the problem, a technique for selective grouting of the boreholes were developed. A single packer grouting equipment to be used for grouting during drilling were reported for 1993.

7.2.2 Results

A double packer grouting equipment is now also in function, aimed at grouting sections of the borehole after the drilling is finished, if necessary.

To summarize, the strategy and existing technique to manage problematic water-flowing boreholes is as follows: When the drilling penetrates a water-flowing section, resulting in water out-flows exceeding an acceptable value, single packer grouting will be made over the waterflowing section. The grouted section will then be re-drilled and the drilling will continue. If a new water flowing section will be penetrated the procedure will be repeated. However, if the total water outflow (from all small fractures) is too large after the drilling is completed, a double packer grouting will be made over the most conductive part of the borehole. Depending on the objective of the individual borehole, and if it is possible, some measurements, like water sampling, flow logging, borehole radar, etc, will be made before each grouting work.

7.3 HYDRAULIC TESTING METHODS AT HIGH GROUNDWATER PRESSURES

7.3.1 Background

Hydraulic testing in boreholes drilled from underground is associated with special problems. The high water pressure in the borehole, relative to the tunnel, sometimes in combination with large water outflows from the boreholes, are conditions which must be handled, (se also Section 7.1). The problems get worse the higher the groundwater pressure is. In the lowest part of the Äspö tunnel approximately 45 bars differential pressure must be handled.

The Annual Report 1993 discussed the development of a special sealing device, for sealing boreholes, with or without testing equipment being installed in the borehole, enabling testing equipments to be moved in the borehole without de-pressurizing the entire borehole. Techniques for the standardized pressure build-up tests in the probe holes were gradually modified to manage the high pressures.

7.3.2 Results

Hydraulic testing techniques for other investigation boreholes also had to be adopted to the higher differential pressures. Hence, the hydraulic testing methodology and equipment which were used in the pilot hole for the TBM tunnel and in the ZEDEX experiment had to be modified. New packers and a new design of the pipe string, with O-ring seats at both sides of the coupling threads, were constructed in order to withstand differential pressures of more than 45 bars. Also a downhole mechanically operated testvalve for shut-in of the test section during the pressure build-up tests were constructed. The equipment worked well, even if some modifications of the equipment for even better practical functionality are foreseen.

7.4 HYDRAULIC TESTING OF PROBE HOLES DURING THE TBM-DRILLING

7.4.1 Background

In order to test the possibilities of doing hydraulic tests in front of the TBM tunnel, in a similar way as in the drill and blasted tunnel, the test equipment was modified so it would be possible to use the drill-rig to install the testing equipment through and beside the TBM-head and into the probe holes. The possibility of doing documentation of the drilling was also tested.

7.4.2 Results

Only a few tests were made and the results were not promising. There is very little space at the working place (between the TBM-head and the TBM-grippers) and it is rather wet, dirty and warm, which reduced the feasibility of doing such tests almost to zero. There were also very limited possibilities to drill in specified directions. A consequence of this was that the boreholes drilled through the TBM-head became air filled when the TBM-tunnel went slightly upwards in the last part of the tunnel. With the test equipment used the air in the borehole could not be removed before the test and the TBM drilling period was to short to make necessary modifications.

It can be concluded that if hydraulic tests of good quality are to be performed close to and ahead of the tunnel face when TBM-boring, the TBM has to be designed in another way. The preparatory work also must include more interactive planning between the TBM constructors and the testing people.

7.5 THE HYDRO MONITORING SYSTEM (HMS)

7.5.1 Background

Monitoring of groundwater changes (hydraulic and chemical) during the construction of the laboratory is an essential part of the documentation work intended to verify pre-investigation methods. The large amount of data calls for efficient data collection system and data management procedures. Hence, the Hydro Monitoring System (HMS) for on-line recording of these data was developed in 1991 and will be continuously expanded along as the tunnelling work progresses and the number of monitoring points increases (Almén and Johansson, 1992). Thereafter groundwater observations with the HMS will be used for general control as well as for certain tests in the individual experiments.

7.5.2 Results

During the spring 1994 a new expansion step of the HMS was made, covering the tunnel from 2360 m to 3200 m. The data logger network, supported by the existing Measurement Station B at 1600 m, was expanded and a new data logger installed. Some 25 pressure measuring points in multi-packer installed investigation holes and probe holes were connected to two new hydraulic multiplexers or direct to a data logger. Also new measuring points of water inflows to the tunnel legs of the new tunnel interval and electrical conductivity of the water at strategic points of the drainage water pumping system were included in this expansion step.

In conjunction with the moving of the site office to the Äspö village on the Äspö island the Host Station of the HMS was moved and the signal communication network by radio and cable was also modified.

By the end of 1994 the planning for another new expansion step of the HMS was started. This expansion step concerns increased number of monitoring holes for the experiments, in particular the SELECT program. The installation work will be made early during 1995.

7.6 THE CHEMLAB PROBE

7.6.1 Background

In order to prepare for radionuclide migration experiments during the operational phase of the project a special equipment (see section 4.10), the CHEMLAB is under development. The CHEMLAB will be a borehole laboratory contained in a probe, in which migration experiments on core samples will be carried out under ambient conditions regarding pressure and temperature and with use of the formation groundwater surrounding the probe.

7.6.2 Ongoing work

A contract with Metro-Mesures, France, for manufacturing the CHEMLAB probe was signed in July, 1994. The manufacturing is defined by the design of the CHEMLAB which was developed in an earlier step of the project, see Figure 4-5. The manufacturing is planned to cover a period of approximate 14 months, ending with performance and acceptance tests in Äspö during September 1995.

7.7 BOREHOLE TV TECHNIQUES

At the beginning of 1994 a new borehole TV was purchased, replacing the videoscope which earlier was used for inspection of short boreholes, but which was failed due to water leakage into the camera.

The new TV is a Pearpoint system with stiff cable of 240 m length, which makes it very feasible for borehole inspection. This TV, as well as the former one has mostly been used to indicate grout materials in fractures, but also for fracture orientation, even if this is very time consuming.

However, in order to increase the efficiency of fracture orientation by TV logging, a BIP System from RaaX, Japan, was delivered to SKB at the end of 1994. The system was improved in order to fulfil the requirements of SKB, and will be further described in SKB Annual Report 1994 /7-1/ as it was not purchased specifically for the Äspö HRL. Besides logging in boreholes, the BIP System can also be used for "tunnel-logging" (with a special camera unit), which also was tested in the Äspö TBM-tunnel, see Figure 7-1.

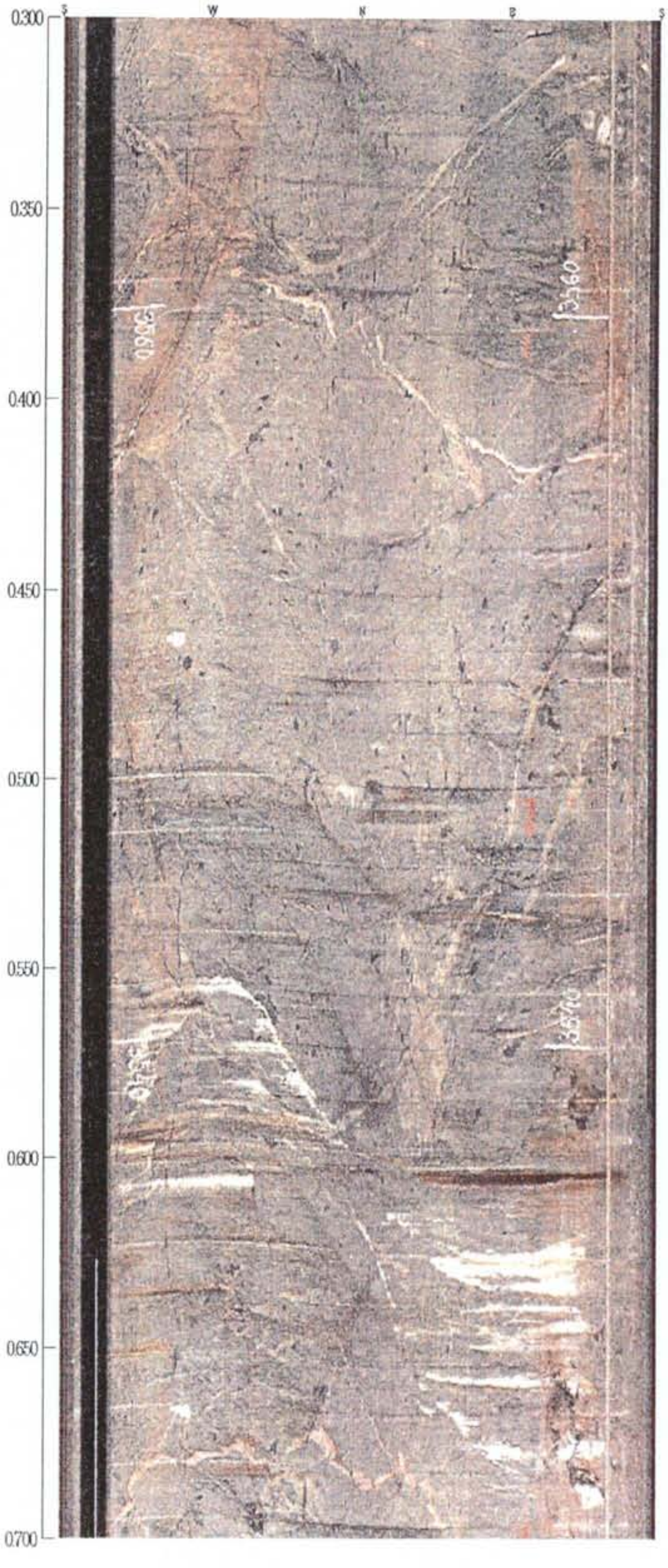

Figure 7-1. Results from television logging of the end of the TBM tunnel using the BIPS/RaaX borehole TV camera.

8 CONSTRUCTION AND ENGINEERING WORK

8.1 OVERVIEW OF GOALS AND MAIN TASKS

The construction of the Äspö HRL comprises several parts and stages. A tunnel ramp has been excavated from the Simpevarp peninsula 1.5 km out under the Äspö. The descent to the tunnel is situated in the vicinity of the Oskarshamn nuclear power plant. The research tunnel reaches the Äspö island at a depth of 200 m. The area of the tunnel section is 25 m^2. The tunnel then continues in a hexagonal spiral under Äspö. The first turn of the spiral was completed in the summer of 1993. The depth at that point is 340 m below sea level and the total length of the tunnel is 2600 m from the tunnel entrance. The tunnelling of this first construction part was done by means of conventional drill and blast.

For the second part of the spiral (from 340 to 460 m level), full-face boring with a Tunnel Boring Machine, TBM, has been tested. The first part of the second spiral follows a hexagonal shape and was done by drill and blast. A rock cavern was excavated at 420 m level for assembly of the TBM. The tunnel then goes down to the 450 m level close to the shafts and continues horizontally westward to an experimental volume. The diameter of the TBM drilled tunnel is 5 m. Figure 1-3 shows an overview of the facility.

Three shafts have been built for communication and supplies to the experimental levels. Two shafts (diam 1.5 m) are built for ventilation, and one shaft (diam 3.8 m) is built for the hoist. The shafts are excavated by raise-boring technique.

Office and storage buildings have been built on the Äspö Island as well as buildings for ventilation equipment and machinery for the hoist. Together, these buildings comprise the "Äspö Research Village", which is designed to look like other small villages in the surrounding archipelago.

The ventilation system for the underground facilities is installed in one of the buildings on ground level. The system is designed to supply up to 20 m^3 of fresh air per second to the tunnels and caverns. The lift is designed to take 20 persons or 2000 kg and will operate at a maximum speed of 5 m/s.

8.2 EXCAVATIONS AND CONSTRUCTIONS BELOW GROUND

The tunnelling from the 340 m level down to the cavern for assembly of the TBM started in November 1993 and was finalized in March 1994. The rock cavern was excavated in April and the assembly of the TBM started in May.

The TBM drilling started on June 14th and was completed on September 16th. 420 m of tunnel was excavated by the TBM, see Figure 8-1. Boreholes for grouting and hydrotests have been performed successfully from the TBM, with two drilling rigs. Holes have also been bored through the drilling head.

Figure 8-1. *The TBM machine used was a 5 m diameter ATLAS COPCO JARVA MK15.*

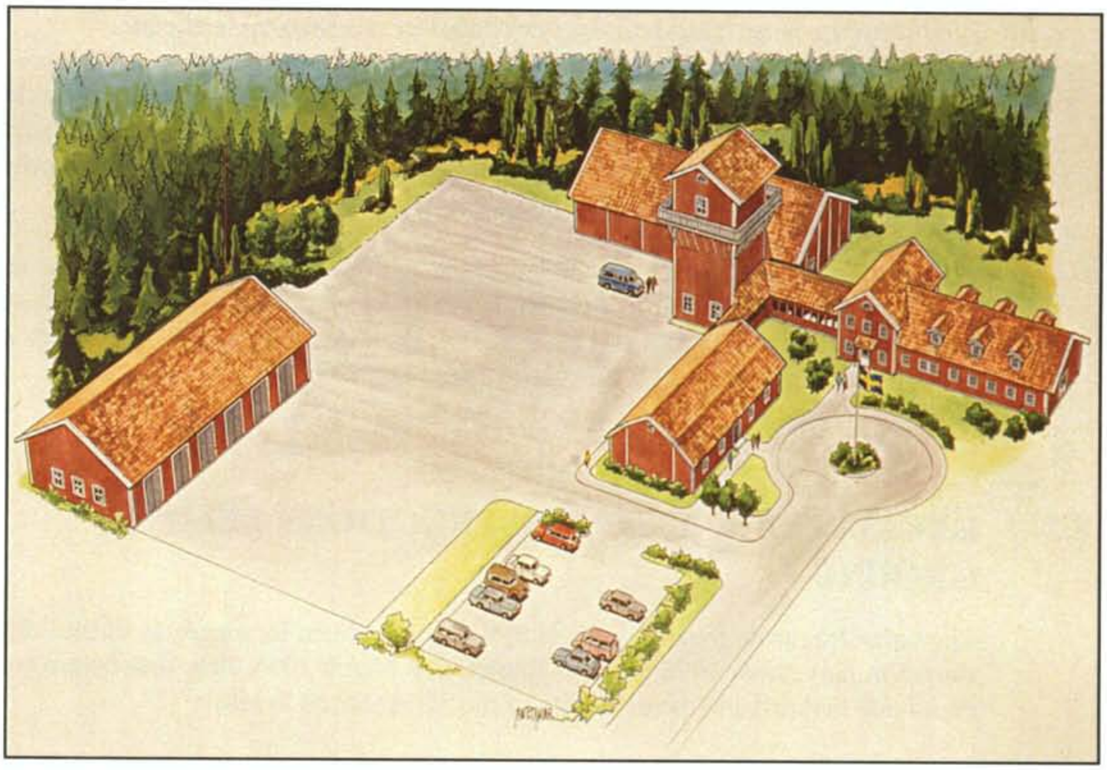

Figure 8-2. *Äspö Research Village.*

The remaining shafts down to 450 m level are now excavated by raise boring in the same manner as the existing shafts from ground level. Pregrouting of the positions for the shafts from 340 m to 450 m has been performed in peripheral holes in the same way as for the level above. The two ventilation shafts have been drilled so far with a good result. The shafts are almost dry and the deviations are within the stipulated limits. The final drilling of the elevator shaft will be performed in January 1995.

8.3 INSTALLATIONS

The hoist machinery with a provisional platform is used for the installation work in the shaft for the hoist. Installation of pipes and cable trays in this shaft is carried out with the same provisional elevator.

The equipment for ventilation of the tunnels and caverns has been installed in the surface building. Functional tests were carried out in May. The total system will not be commissioned until beginning of 1995 when the excavation work is finished.

At levels 220 m and 340 m the permanent drainage system has been installed and functional test have been carried out.

8.4 ÄSPÖ RESEARCH VILLAGE

The construction work for the Äspö Research Village was completed in May 1994. Final inspection was carried out in beginning of June and the research staff moved into the buildings in beginning of August 1994.

An overview of the village is shown in Figure 8-2.

9 INTERNATIONAL COOPERATION

9.1 CURRENT INTERNATIONAL PARTICIPATION IN THE ÄSPÖ HARD ROCK LABORATORY

Eight organizations from seven countries are currently (April 1995) participating in the Äspö Hard Rock Laboratory in addition to SKB.

In each case the cooperation is based on a separate agreement between SKB and the organization in question. Table 9-1 shows the scope of each organizations participation under the agreements.

Most of the organizations are interested in groundwater flow and transport and characterization. This is also reflected in the great interest for 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.

9.2 NEWS RELATED TO THE PARTICIPATING ORGANIZATIONS' WORK

Documentation

The Äspö International Cooperation Report series today consists of twenty reports of which four were produced during 1993 and 16 during 1994. Two of the 1994 reports are still at the printing office. A list of the reports is provided in Appendix B.

Agreements

A prolongation of the agreement with PNC concerning joint studies in the Äspö Hard Rock Laboratory was signed December 19, 1994.

The scope of participation for the different organizations cooperating in the Äspö HRL can be seen in Table 9-1.

Negotiations concerning prolongation of the present agreements are currently performed with CRIEPI and ANDRA.

During autumn 1994 negotiations with Bundesministerium für Forschung und Technologie (BMFT) in Germany has taken place regarding cooperation in the Äspö Hard Rock Laboratory.

Table 9-1. Scope of international cooperation.

ORGANIZATION	SCOPE OF PARTICIPATION
Atomic Energy of Canada Limited, **AECL**, Canada.	General information exchange on site characterization and in-situ experiments at underground facilities.
Teollisuuden Voima Oy, **TVO**, Finland.	Groundwater flow modelling. Measurement of flow in-situ. Hydrogeochemistry.
Agence Nationale pour la Gestion des Dechets Radioactifs, **ANDRA**, France.	Groundwater flow modelling. Characterization of fracture zones. Instrumentation development.
The Power Reactor and Nuclear Fuel Development Co, **PNC**, Japan.	Improved understanding of specific key processes relevant to repository performance. Work on fracture classification and modelling in conjunction with the Tracer Retention Understanding Experiment (TRUE). Disturbed zone effects. Degassing and two-phase flow conditions. Redox experiment in detailed scale. Radionuclide retention.
The Central Research Institute of the Electric Power Industry, **CRIEPI**, Japan.	Improved understanding of specific key processes relevant to repository performance. Validation of specific models for data collection procedures. Optimization of site characterization methods. Numerical modelling of groundwater flow and tracer transport.
United Kingdom Nirex Limited, **NIREX**, Great Britain	Development and validation of flow and transport models. Design of experiments. Development of geotechnical logging procedures.
United States Department of Energy, **USDOE**, USA	Flow and transport characterization in fractured rock. Disturbed zone effects. Geochemical investigations using radiogenic isotope methods. Geochemical modelling. Integration of construction and testing activities.

ORGANIZATION	SCOPE OF PARTICIPATION
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.

9.3 MISCELLANEOUS

During 1994 both CRIEPI and PNC have had one scientist stationed at the Äspö Site Office. The scientists have worked in close cooperation with the project. During spring 1995 CRIEPI has one scientist at the site.

The agreement with NIREX and ANDRA concerning the Zone of Excavation Disturbance Experiment, ZEDEX, in the Äspö HRL was signed March 29, 1994. The Project has been running according to the planned timetable. In-situ tests has been performed in the period May 1994-March 1995. The final report on the project is planned to be ready in March 1996.

ANDRA has during 1994 performed a specific experiment called "Hydromechanical Behaviour of a Joint". The project aim has been the understanding of the response of a fracture in a rock mass to block movements and deformations. The results will later be reported in the Äspö International Cooperation Report series.

10 OTHER MATTERS

10.1 QUALITY ASSURANCE

SKB is required, and recognizes the need, to implement formal Quality Assurance (QA) programs for a number of its areas of management, such as repository site investigations. Quality Management for the Äspö Hard Rock Laboratory project consists of a system of documents that will be developed and refined as the activities of the HRL progress. The system being developed consists of a Quality Assurance Handbook, the Äspö Handbook, Quality Plans, and detailed manuals. The handbooks will be tested, reviewed, and updated based on experience from the HRL project.

The purpose and scope of the Quality Assurance Program is to determine formats for the procedures needed to meet the goals of the HRL. This includes formats for:

- Organizational and administrative procedures, quality system principles.
- Procurement procedures.
- Scheduling and cost control.
- Identification and traceability.
- Changes, non-conformances, and corrective actions.
- Document control.
- Quality audits.

The QA handbook defines in general terms the requirements for the project. The next handbook in the quality system is the Äspö Handbook, which is the instrument of management and describes in greater detail, routines, formats, and responsibilities. The activity process is described in Manuals for the different disciplines and tasks for investigations and rock work, Figure 10-1.

The QA-program is described by the program formats, each of which is described as a procedure in a Manual. The program formats provide a framework for managing all activities and projects for the Äspö HRL that fall under the QA Program. These rules must be complied with, except items specifically defined by the respective project managers and approved by the Director of the Äspö HRL.

The final products of the activities at the Äspö HRL will be various kinds of instruments and techniques as well as documents, including descriptions of techniques, methods, and computer codes. The ultimate goal for the QA program is to minimize the risk of mistakes, achieve proven correctness and traceability of data, and increase confidence in the final products.

10.2 PUBLIC RELATIONS AND INFORMATION ACTIVITIES

The interest for ÄHRL has increased from year to year. During 1994 more than 3 000 persons visited the facility. One of them was the Secretary of Energy from the Department of Energy in the USA.

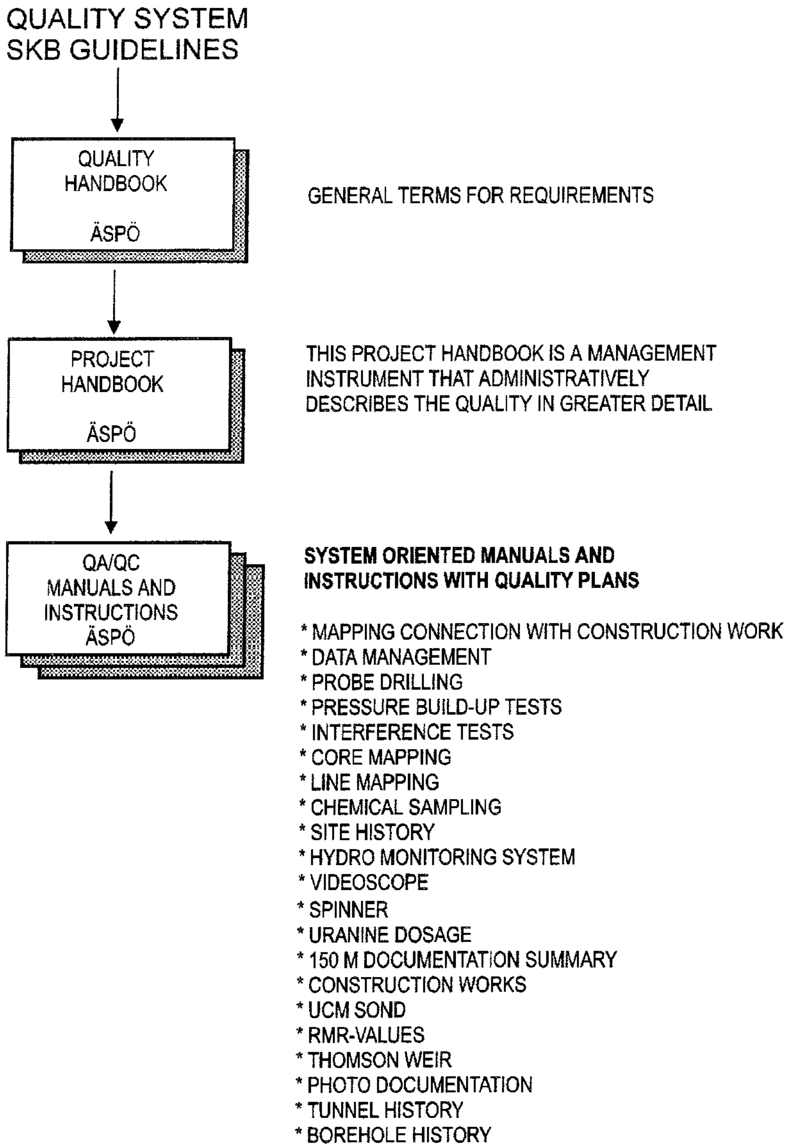

Figure 10-1. *The Quality System of the Äspö Hard Rock Laboratory.*

As previous years, the Äspö Day was held in May. Besides the ÄHRL the visitors were offered a guided trip to CLAB (the central interim storage for spent fuel).

Several national and international newspapers and TV-companies have visited the facility and reported from the work that has been carried out.

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[2] Universidad Politécnica de Cataluña, Departmento de Inginería Química, Barcelona, Spain
[3] MBT Tecnología Ambiental, Cerdanyola, Spain
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Ann-Chatrin Nilsson[3], Christina Skårman[1]
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[2] Conterra AB, Uppsala, Sweden
[3] KTH, Stockholm, Sweden
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Bill Wallin
Geokema AB, Lidingö, Sweden
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