ÄSPÖ HARD ROCK LABORATORY

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ABSTRACT

Äspö Hard Rock Laboratory (ÄHRL) has been constructed in virgin bedrock as part of the development of a deep geological repository for spent nuclear fuel in Sweden, the role being to provide input to the performance assessment, to test engineered barrier systems and to develop and refine full scale methods and machines for construction and operation of the real repository. The ÄHRL extends down to 460 m depth with access via both ramp and shaft. Work in the laboratory has been separated into 4 different stage goals:

1. Verification of site investigation methods.
2. Development of detailed investigation methodology.
3. Testing of models for description of the barrier function of the host rock.
4. Demonstration of technology for and function of important parts of the repository system

Stage goals 1 and 2 were in focus during the period 1986-95 and are now completed. Stage goal 1 concerns investigations carried out from ground surface and stage goal 2 investigations carried out underground, in this case during excavation of the ramp. The present work is focused on the two operative stage goals 3 and 4. The activities on barrier function of the host rock comprises primarily in-situ tests with tracer migration in natural fractures and migration of actinides in small samples of rock or bentonite inside a chemical laboratory probe installed in a borehole. The data collected from the tests are used for model development and verification. The demonstration of technology includes studies of engineered barriers and comprises tests of copper stability, bentonite buffer, backfill, plugging and practical development of the main disposal sequences. Up today five full scale deposition holes with buffer and canister, and one full-scale test of backfill and plugging have been installed. The prototype for the deposition machine is in operation.

The work is conducted in an international environment and altogether eight organisations from seven countries besides Sweden take part in the ÄHRL programme.

The paper concludes the results from the stage goals 1 and 2, and presents the projects conducted within the stage goals 3 and 4 as well as conclusions drawn from available results.

INTRODUCTION

Äspö Hard Rock Laboratory (ÄHRL) has been constructed in virgin bedrock as part of the development of a deep geological repository for spent nuclear fuel in Sweden, the role being to provide input to the performance assessment, to test engineered barrier systems and to develop and refine full scale methods and machines for construction and operation of the real repository. It was designed to be a "generic" rock laboratory with the objective of being geo-scientifically representative for a wide range of candidate crystalline rock types in Sweden, and the Äspö area was selected as one location fulfilling this requirement. All siting and construction activities were carried through in a way that provided information on methods and equipment for site investigation and site characterisation that now are being used for planning of the repository site selection activities.

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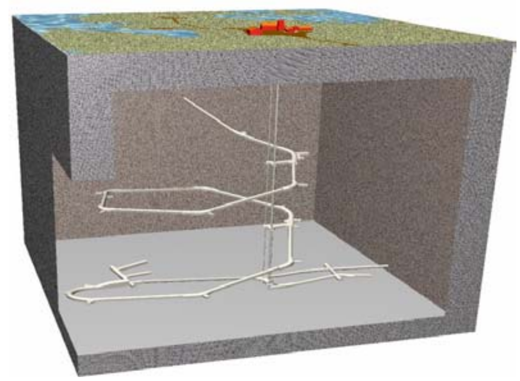

Fig 1. Äspö Hard Rock Laboratory.

STAGE GOAL 1 – VERIFICATION OF SITE INVESTIGATION METHODS

During 1986-1990 geological pre-investigation were made and the ÄHRL located. It started with conventional airborne investigations (aeromagnetic and gravimetric). The aeromagnetic study showed useful, as expected, for interpretation of main lithological units and major structures while the gravimetric study was used for collecting data on the depth of different rock types. Lineament maps in digital form are useful in estimating the density of structures. The thereafter following ground-based geophysical measurements over some of the major lineaments could confirm the width of the airborne measurement results on low magnetic zones due to oxidation. VLF (Very Low Frequency) method and seismic refraction methods supplemented the data information. These data were the basis for the first geological model over an area covering a five times larger geographical area than later was selected for the ÄHRL. In order to successfully carry out a screening process it is essential to analyse the "reliability" of data, which also was used by introducing new definitions for categorisation of properties and comparison of them between the five sites.

When indications pointed towards Äspö detailed investigations were made on the island and eventually three investigation boreholes confirmed the geological hypothesis of a the existence of two different domains, one in the north and one in the south. The southern location is the one finally selected.

A number of main fracture zones exist on the island and along the route from the island to the main land where the ramp was determined to go. One of these zones turned out to represent a problem from a construction point of view, which was outside the present knowledge of grouting technology. This was discovered first when the practical problems arose with high water inflow under high pressure – approx. 200 m of water pillar.

Hydrogeological characterisation may start with traditional fact-finding from meteorological data hydrological features (rivers, peatland etc.) but actual investigation of fractures and fracture zones need drilling and isolation of the feature to study by the use of packers on both sides. In the feature zone the different standard tests are carried out and the result evaluated. In the ÄHRL different lithological units were identified and their hydraulic properties first predicted based on surface investigations and later on studied in detail during the excavation of the ramp. By statistical methods the pattern of fractures were calculated and the flow into different parts of the ramp estimated.

During excavation of the ramp geo-scientific data were continuously collected by means of mapping, rock sampling and analysing, geophysical measurements, core drilling, and sampling and testing in holes drilled in front of the ramp excavation. The hydraulic head was continuously monitored in surface core holes and the volume of inflow in the ramp measured. The latter data were used for comparison of the predicted draw-down. Also new hydrogeological holes were drilled from the ramp and used in the data collection system, later turned into a permanent hydromonitoring system in use also today.

The data collected in the ramp indicated a good agreement between predictions and observations with respect to the mean hydraulic conductivity but not so good with respect to flow into the ramp. The reason is that grouting tightens a zone around the ramp but also the so called "skin zone", which is assumed to decrease the mean hydraulic conductivity around a tunnel periphery. The phenomenon is further addressed below. In general the conclusion is that reliable data can be established by investigations in drillholes from surface. The number and methodology to carry out tests in them will, however, be dependent on the degree of inhomogeneity in the rock block under observation.

The hydrochemical investigations use water sampling and analysing of them in chosen laboratories. It was already possible during the pre-study phase to get a fairly accurate conceptual model of the salinity distribution in the groundwater, and it was possible to predict the composition of the groundwater flowing into the ramp at different locations. One main mistake was made about tritium, which is an indicator of hydraulic connection with ground surface. It was found in most samples and consequently the conceptual model was constructed based on availability of young water, until analysis checks were made by a laboratory, which came to another result and made it clear that the analyses so far had been wrong. That change in conceptual model confused quite a lot of people.

Rock stress measurements were made in drill holes from surface with the main objective to address the question if there would be any risk for rock burst during excavation of the ramp. Hydraulic fracturing and overcoring provided values, which were too low, but still were considered to cause a high risk for rock burst. Even with the higher values determined in the ramp, no problem has been encountered with rock burst in reality. Interesting today is though that overloading of rock has been observed in the bottom part of the ramp close to 460 m level where the ramp direction is parallel to the main principal stress.

A summary of the results from the first 10 years of ÄHRL is presented in (1).

STAGE GOAL 2 – DEVELOPMENT OF DETAILED INVESTIGATION METHODOLOGY

During 1990-1995 comprehensive investigations and experiments were performed in parallel with construction of the laboratory, so called detailed investigations. The main reason was to provide data for the verification of the predictions made. But it was also foreseen that information on different equipment and different investigation methods would be possible to collect.

Investigations were carried through in the following areas:

- Geological borehole investigations
- Geophysical borehole investigations
- Hydrogeological investigations
- Groundwater chemistry
- Rock stress measurements
- Monitoring

Geological borehole investigations tested the SKB-developed core logging system and borehole TV system. The first mentioned system characterises the core and is by far the most accurate method of providing data on the rock along the borehole. But there are drawbacks such as the unreliability of the method over sections with fracture zones, crushed zones and core losses, sections that generally are of large interest to investigate. Another drawback is that the number of fractures seems to be overestimated, one indication being that the number is larger from core logging than from borehole TV. The latter is considered more realistic due to the nature of fracture zones. The borehole TV system works surprisingly good also in muddy water in a borehole, but is no more than a supplement to core logging.

Geophysical borehole investigations are indirect methods for characterisation of geological and hydrogeological properties. A number of well proven methods exist but they came to very limited use at Äspö. During those occasions it was clear that the measurement of rock types is well taken care of by core logging. But more information on fractures and fractured rock would have been valuable. Now surprises were met and the methods provided the expected results. The Swedish borehole radar system provides a powerful tool for examination of the rock around the borehole. The presence of saline water at Äspö showed that the radar method can be used also in such an environment, but the penetration lengths will be shorter than in fresh groundwaters. Fracture zones were successfully detected and positioned with seismic methods but not their properties, except for their extension.

Hydraulic parameters were determined in the traditional way by packing off sections in boreholes. Tests were then done in these sections, e.g. pressure build-up tests and interference tests in addition to the flow logging and groundwater flow measurements. A large number of tests were done. Some difficulties encountered are connected to the installation of packers in holes with both low and high water flow. In the first case was air evacuation the issue while in the second case the issue was the fixing of packers in position. Once packers were in good position the tests were successfully conducted. In general it was observed that grouting in very high permeable features need to be guided with respect to how and when. Interference tests measure the hydraulic head. Accurate measurements need a quiet surrounding with no other activity going on that may affect the groundwater head. The Flow-meter method was also quite frequently used. It gives good indications on water-bearing features intersecting the investigation borehole, but the method tends to mask features with low inflow when conductive features with high inflow are present.

The geochemistry was investigated by sampling and analysing of groundwater. Four different classes were defined for analysis dependent on number of different elements to analyse. The intensity in sampling was increased from earlier work to almost one sample per borehole and day. The earlier mentioned tritium was not part of any of these classes but was an extra and special analysis.

Rock stresses were measured in a few holes (a total of 14) up to the completed construction of the laboratory. Two principles were applied: overcoring and hydraulic fracturing. The wide spread of data has been investigated and the question on whether the results are true or whether they are wrong was answered with “true”, i.e. the heterogeneity of the rock is large. Later investigations of the accuracy in different probes for the two principles of measuring have verified the trust in both methods and concluded that an accuracy of 20% is feasible within the stresses prevailing at 500-700 m depth in Swedish bedrock.

The data and on them based conceptual models of the Äspö rock mass are presented in (2,3,4).

STAGE GOALS 3 – TESTING OF MODELS FOR DESCRIPTION OF THE BARRIER FUNCTION OF THE HOST ROCK

The safety function of a repository is in Sweden separated into three categories:

Isolation, which is the prime function of a repository concept such as the KBS-3 method. Isolation is obtained through the co-function of the natural and engineered barriers. The flow of water to the waste containment largely determines the magnitude at which the corrosion of the canister and the dissolution of the waste form can take place. For a good isolation it is thus necessary to minimise the groundwater flow to the waste containment. Additional conditions that affect the isolation are the chemistry of the groundwater and the mechanical stability of the rock.

Retention of radionuclides is the second most important barrier function of the repository. Retention is provided by physical and chemical processes and will be provided by any system and process that interacts with radionuclides dissolved in the groundwater. Some elements are strongly retarded while others are escaping with the flowing groundwater.

Dilution is the third barrier function. It will take place in the rock volume surrounding the repository. The magnitude of dilution very much depends on the site specific conditions. In the geosphere the dilution is caused by the dispersion in groundwater. No experiment at Äspö is focussing on dilution, although dilution is included in the biosphere safety assessment modelling.

The work is basically organised as an integrated process between conceptual and numerical modellers tools and experiments related to the rock, its properties, and in-situ environmental conditions that support the application and development of these tools, the objective being to evaluate the usefulness and reliability of different models and to develop and test methods for determination of information and parameters required as input to the models.

The main experiments are:

- Redox experiment (Isolation)
- Hydrochemical stability (Isolation)
- Tracer Retention Understanding Experiments (Retention)
- Radionuclide Retention Experiments (Retention)
- Matrix Fluid Chemistry (Retention)

The experiments related to the isolation capability refer to conditions that are affecting the lifetime of the canister. One such condition is whether the environment will be oxidising or reducing. Dissolved oxygen in the groundwater is a theoretical threat as it may activate corrosion of copper. By the redox experiments it has been shown that trapped oxygen in a repository after closure is rather quickly consumed by existing microbes. The results suggest that main effects be achieved already before the repository may be sealed-off. Another issue for long-term function of the copper canister is the composition of the groundwater and the possible changes that may take place in the future. Hydrochemical stability investigates the likelihood for such changes with focus on the increase in salt content coming from deeper waters. But also oxygen may be brought from surface to repository depth in conjunction with a glaciation. Possible changes in the groundwater composition have been modelled and the impact of different scenarios on the isolation function analysed. The bottom line is that the buffering capacity of the rock and favourable chemical conditions can be sustained in the perspective of at least thousands of years.

Tests of models for groundwater flow, radionuclide migration and chemical/microbial processes are one of the top priority issues for the ÄHRL. Studies on retention with tracers, as well as radionuclides, have been conducted in different scales with the aim of increasing the understanding of processes involved. In the ÄHRL experiments with tracers have been conducted in both 5 m and 100 m scale. In the first case were two crossing fractured localised and characterised. Cocktails of tracers were injected in one hole through them and groundwater extracted in another hole approx. 5 m apart in the same fracture. The larger scale has been applied in a 50m x 50m x50m block were several fractures have been characterised and injections made in one fracture and extraction in another so located that the tracer transport distance from the first fracture via one or more fractures to the extraction point becomes up to 100 m. The models have been developed according to the observations on travel times, break-throughs and parts of total injection volumes collected, and are useful and accurate tools for evaluating the retention capability of the rock in the site investigation processes. Part of the understanding is the conceptual composition of a fracture with gauge material and cracks extending from the fracture wall out into the side rock.

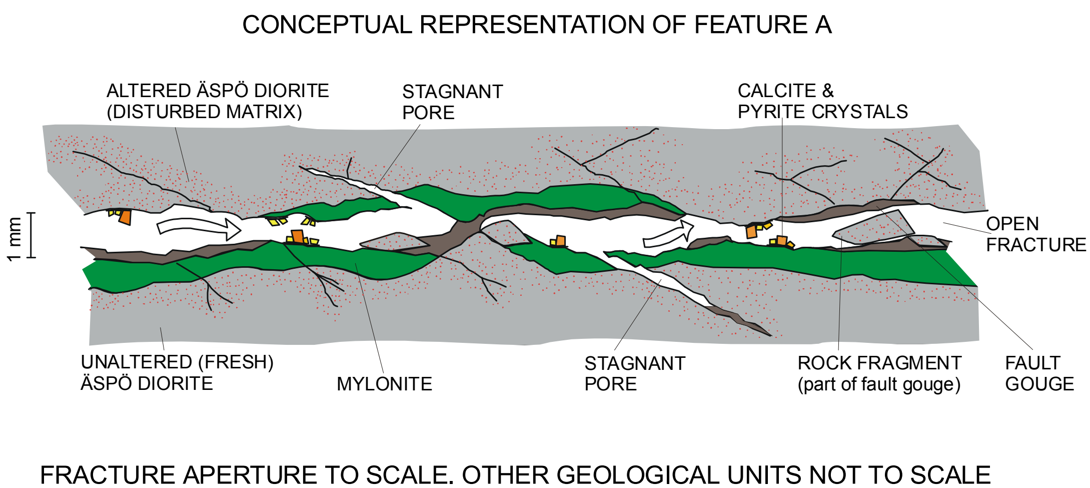

Fig. 2. Conceptualisation of one fracture in the Tracer Retention Understanding Experiment.

Summary of the results obtained, from experiments at Äspö HRL and related analysis performed, within the programme Natural Barriers during the period 1995-2000 is given in (5).

STAGE GOAL 4 – DEMONSTRATION OF TECHNOLOGY FOR AND FUNCTION OF IMPORTANT PARTS OF THE REPOSITORY SYSTEM

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

The main experiments are:

- Prototype Repository.
- Backfill and Plug Test.
- Canister Retrieval Test.

- Long Term Test of Buffer Material.
- Zone of Excavation Disturbance (ZEDEX)

The Canister Retrieval Test, consists of one full-scale canister with heaters and bentonite buffer. Artificial saturation system was designed in order to reach saturation as quickly as possible. It also provides accurate data for the modellers as the hydraulic boundary conditions are known.

One important observation has been made that the bentonite blocks above the canister started to swell much quicker than expected by sucking water from the humid air in the hole. This indicates that the time between installation of the last bentonite block and the backfilling of the tunnel need to be shorter than in present plans unless a temporary plug structure is applied on top of each deposition hole.

Another solution, with a plastic bag covering the bentonite buffer, was tested in the Prototype Repository. This experiment consists of two sections with 4 full-scale deposition holes in an inner section and two holes in an outer one. A concrete plug separates them, and one outer plug separates the experiment from the rest of the laboratory. Each hole has the same design as the hole in the Canister Retrieval Test; one canister with heaters installed in a column of bentonite blocks. No artificial saturation is, however, installed. The plastic bag protected the bentonite from water and humid air until it was removed, which was done when the backfill front approached the edge of the deposition hole.

The ZEDEX experiment (zone of excavation disturbance) compared the disturbance caused by drill and blast with the disturbance caused by mechanical excavation. The two tunnels were excavated at 420 m depth at a distance of 30 meters. Thorough geoscientific investigations indicated a zone with increased fracturing closest to the tunnel and pure elastic response in the rock outside this zone. The drill and blast tunnel, with conventional spacing of the blast holes in the periphery and the application of smooth blasting techniques, had a 300 mm thick affected zone in the tunnel walls and roof, and a 800 mm thick zone in the floor, while the bored tunnel had a 30 mm thick affected zone all around the tunnel. No axial hydraulic connectivity was measured in the walls and roof of the drill and blast tunnel, while indications could be seen in the floor region. This has later been verified in the Backfill and Plug Test that is carried out in that tunnel. When increasing the hydrostatic pressure in the permeable mats placed in the backfill for artificial saturation the piezometric head was immediately raised in all the instrumented holes in the floor region. Also in the old experiment in the Buffer Mass Test in the Stripa Mine in the 80-ies it was concluded that the floor region in a drill and blast tunnel has got axial hydraulic connectivity.

The properties of the disturbed zone in the drill and blast tunnel are complying with expectations and so are the properties in the bored tunnel. But the investigations have revealed new information in details. Although the drill and blast tunnel has a 300 mm thick affected zone, this zone is inhomogeneous around the tunnel. The fracturing is large around the blast hole pipes but non-existing in between the pipes. In the latter part is consequently the radial connectivity different from the axial connectivity in the tunnel wall. The disturbed zone in the bored tunnel is homogeneous all round the periphery. Of concern is the zone around the bored tunnel, or more precisely the zone in the bored deposition holes. If the zone has an increased hydraulic conductivity it will speed up the saturation of the bentonite buffer and also provide water all around for a homogeneous development of the swelling pressure. An increased conductivity with one to two orders of magnitude has been indicated theoretically in the outermost 10 mm from studies of the increased pore volume. In situ measurements are being made in order to verify the real properties.

CONCLUSIONS

The comparison between predictions and data obtained during the ramp excavation has strongly suggested that the methods, instruments and strategy applied may provide predictions in general agreement with observations. No unexpected conditions were encountered, which could have jeopardised the excavation of the ÄHRL.

Experience from Äspö also shows that there is a need for refinement of investigation methods to enhance the quality of collected data, boost efficiency and improve reliability in a demanding underground environment. Furthermore, the detailed characterisation programme needs to be designed so that good co-ordination is obtained between rock investigations and construction activities.

The “generic” development of models and codes for groundwater flow and transport of solutes can be developed very extensively in the ÄHRL environment with international participation and extended “internal” reviews of the results. Part of this work is to verify the accuracy of the results by applying the models and codes to experiments carried through in other underground environments than the ÄHRL. Final refinement of constants and parameter data can only be made at the actual site for the real repository. The conclusion is that the development in the “generic” ÄHRL is accurate enough until the final repository site has been selected in Sweden.

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