SKB

ÄSPÖLABORATORIET

INTERNATIONAL COOPERATION REPORT

94-10

Äspö Hard Rock Laboratory International workshop on the use of tunnel boring machines for deep repositories Äspö, June 13–14 1994

Göran Bäckblom (ed.)

Swedish Nuclear Fuel and Waste Management Co.

October 1994

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ÄSPÖ HARD ROCK LABORATORY

INTERNATIONAL WORKSHOP ON THE USE OF TUNNEL BORING MACHINES FOR DEEP REPOSITORIES ÄSPÖ, JUNE 13-14 1994

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ÄSPÖ HARD ROCK LABORATORY

INTERNATIONAL WORKSHOP ON THE USE OF TUNNEL BORING MACHINES FOR DEEP REPOSITORIES

ÄSPÖ, JUNE 13-14 1994

Keywords: Design, construction, excavation, characterization, disturbed zone

ABSTRACT

SKB plans to commence final disposal of the spent nuclear fuel in Swedish crystalline bedrock within 15 years.

When the deep repository is built after the turn of the century, Tunnel Boring Machines (TBM) will undoubtedly be the predominant method of rock construction. It is also technically possible to full-face-drill downward-sloping tunnels, which means that the method can also be of interest in conjunction with the detailed characterization that is planned to begin in Sweden in 1999.

SKB has decided to test the TBM technology for parts of the Äspö Hard Rock Laboratory facility. A 5 m diameter Tunnel Boring Machine will excavate 420 m of tunnel from 420 m level down to 450 m. The excavation work started in June 1994 and it is coordinated with several characterization tasks.

SKB invited to a small TBM workshop with 25 participants from Finland, France, Great Britain, Japan, Sweden, Switzerland and USA.

The report includes the presented papers and the discussions.

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PAPER A:

TBM USE AT THE ÄSPÖ HARD ROCK LABORATORY

Göran Bäckblom – Tommy Hedman
Swedish Nuclear Fuel and Waste Management Co

JUNE 1994

1 WHY IS THE ÄSPÖ HARD ROCK LABORATORY BEING BUILT?

SKB plans to commence final disposal of the spent nuclear fuel in Swedish crystalline bedrock within 15 years. There is already about 1,800 tonnes of spent nuclear fuel at the CLAB facility 20 km north of Oskarshamn, where it is being stored for a cooling-off period prior to final disposal.

The safety of the final repository is based on a number of barriers which together ensure very safe containment over very long periods of time (tens of thousands of years). The concrete plans for the deep repository are presented in greater detail in the SKB Research, Development and Demonstration Programme RD&D-92. After thorough scrutiny, the regulatory authorities have expressed their essential support for SKB's planning, which entails that:

- the fuel is encapsulated in a combined steel-copper canister. The encapsulation station is situated at CLAB
- the deep repository is sited somewhere in Sweden, with the consent of and in collaboration with the concerned municipality
- licensing of the site is preceded by exhaustive studies and investigations.

An important part of these studies is ascertaining the technical characteristics of the site at repository depth. The work is proceeding in stages. At present the prospects for siting a deep repository in the municipalities of Storuman and Malå are being investigated in *feasibility studies*. SKB's intention is to carry out a limited number of feasibility studies (5). Where conditions are found to be most suitable, *site investigations* will be carried out on two sites. After the necessary permits have been obtained (under, for example, the Natural Resources Act, the Planning and Building Act and the Environmental Act), *detailed characterization* will be commenced in connection with construction of a tunnel or shaft down to the depth of the planned repository (400 to 800 metres). The investigations of the rock will yield data that will be used to design and construct the facility, but above all to assess the safety of the repository. Deposition of fuel will commence in 2008, after a licence has been obtained under the Act on Nuclear Activities.

SKB's overall purpose with the Äspö HRL is to test and develop the technology that will be used in connection with the construction of the Swedish deep repository.

2 THE DEEP REPOSITORY — AN INTERESTING ROCK FACILITY

The deep repository will include the following underground works:

- tunnel (shaft) to repository depth 400—800 m
- 40,000 m tunnel
- several connecting shafts between the ground surface and the repository

- about 4,500 holes with a diameter of about 1 m and a depth of 7 m drilled from deposition tunnels. These holes will be used for deposition of the encapsulated fuel.
- backfilling of buffer around canisters
- backfilling of tunnels/shafts

Execution will take place under carefully controlled conditions. One important aspect is that the construction of the repository will be coordinated with investigations of the bedrock.

3 WHY TBM AT THE ÄSPÖ HRL?

When the deep repository is built after the turn of the century, TBM will undoubtedly be the predominant method of rock construction. It is also technically possible to full-face-drill downward-sloping tunnels, which means that the method can also be of interest in conjunction with the detailed characterization that is planned to begin in 1999. It is therefore of urgent importance to begin testing the method of coordinating tunnelling by means of TBM with rock investigations in the same way as is being done for the drill-and-blast tunnel down to a depth of about 430 m. The TBM-bored tunnel can then be used to demonstrate and test methods for the deep repository. The possibility of building an (inactive) prototype of a deep repository on Äspö Island is currently being investigated. This planning includes a 100 m TBM-bored tunnel.

4 OVERVIEW OF OF THE ÄSPÖ FACILITIES

The Äspö HRL facility comprises several construction parts and phases (Figure 4-1). A tunnel ramp has been excavated from the Simpevarp peninsula 1500 m out under the Äspö island. The tunnel reaches Äspö at a depth of 200 m. The tunnel then continues in a hexagonal spiral under Äspö. The first turn of the spiral was completed in the summer of 1993. The tunnelling of this part was done by means of conventional drill and blast technique.

The first part of the second spiral will follow a hexagonal shape and also be done by drill and blast. A rock cavern will be excavated at the end of this part for assembly of the TBM. For the final part of the second spiral (from 420 to 450 m level), fullface boring with a Tunnel Boring Machine, TBM, will be tested. The tunnel will then go down to the 450 m level close to the shafts and continue horizontally westward. The TBM tunnel simulates both downward boring and boring on a slight uphill gradient, both of which can be expected to be necessary in conjunction with detailed characterization if the TBM technique is chosen for a deep repository.

Three shafts are being built for communication and supply to the experimental levels. Two shafts are being built for ventilation, one for fresh air and one for exhaust air.

Office and storage buildings for the future research work are being constructed at Äspö over the tunnel-spiral. These buildings as well as buildings for ventilation equipment and machinery for the hoist buildings form the "Äspö Research Village", which is designed to resemble other small villages in the surrounding archipelago.

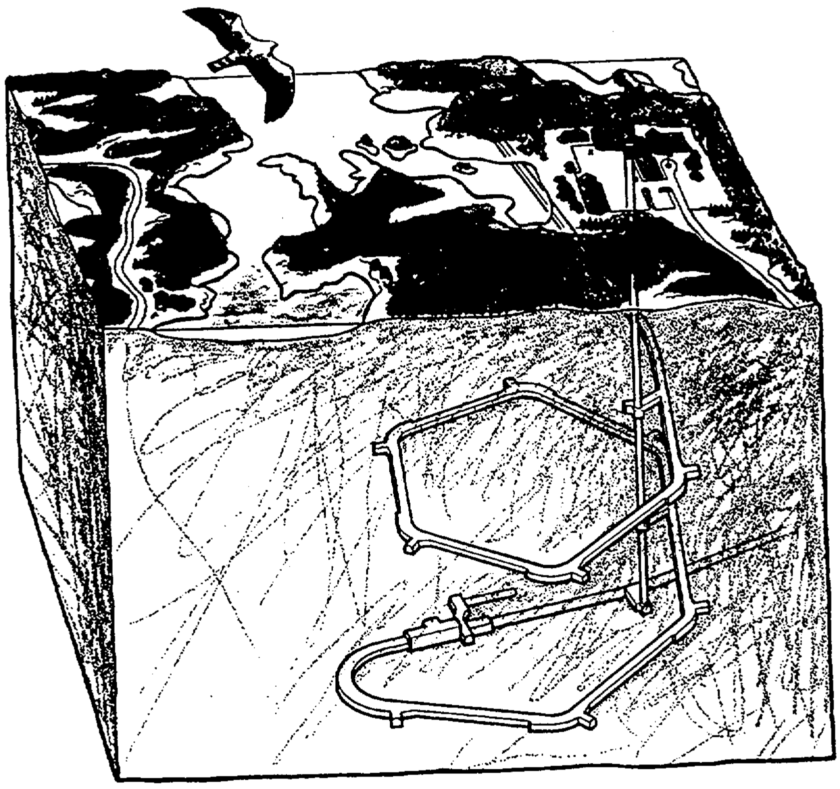

Figure 4-1 Overwiev of the tunnel and shafts

During September 1993 the first phase of the tunnelling work was finalized. Contractor for this work was Siab. Excavation of the tunnel excavation Phase 2 started at section 2600 m on level -340m in the end of October 1993 with the contractor SKANSKA who was awarded the new contract. In the contract for the second phase tunnel boring with a TBM is included. The total length of the TBM tunnel is planned to be 420m. The tunnel diameter is 5 m. TBM boring is being commenced in June 1994. SKB's contractor, SKANSKA, has chosen to bore with a new Atlas Copco Jarva Mk 15.

5 DESIGN WORK FOR THE TBM

5.1 LAYOUT OF THE TBM TUNNEL

In the beginning of 1993 an invitation to tender for the second construction phase was issued by SKB to four civil contractors. The base for the invitation to tender was a tunnel spiral with 150 m diameter making a full turn from the position of the shafts on level -340m down to - 450m (Figure 5-2). This thus implied a continuous horisontal curve together with a decline of around 13%. These requirements were set after discussions with TBM manufacturers. From the viewpoint of TBM, this is a difficult layout

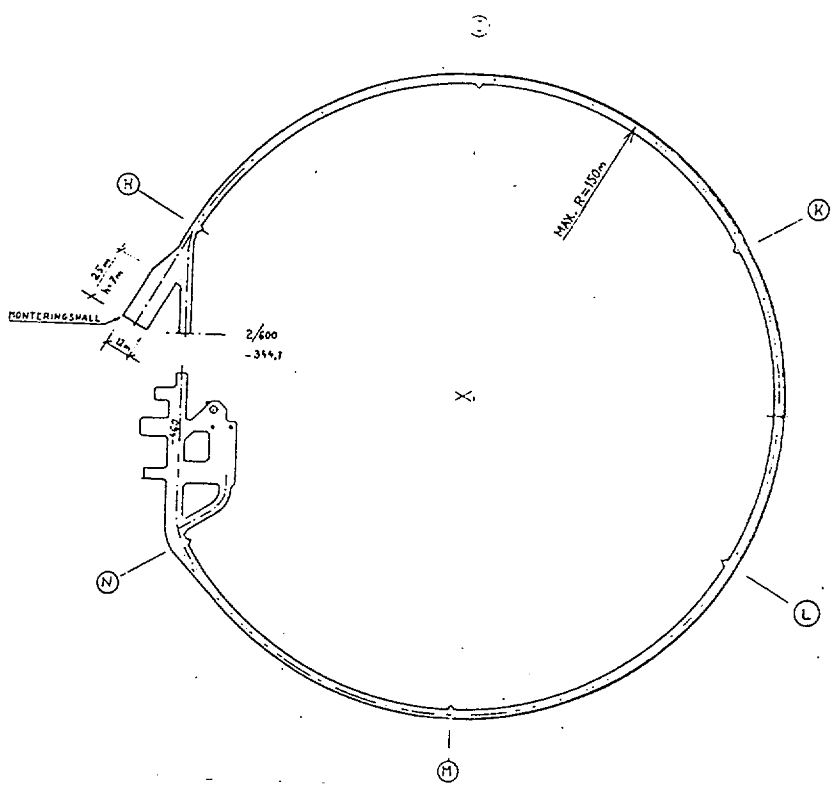

Figure 5-2 Layout as presented in the invitation to tender

The dimension of the tunnel section was open to proposal but it was stated that it should not be less than 4,5m to accomodate the transports forseen during the Operational Phase of the Äspö HRL, (Figure5-3). The minimum dimensione was set to 3,0 m in width, 3,5 m in height and 8 m in length.

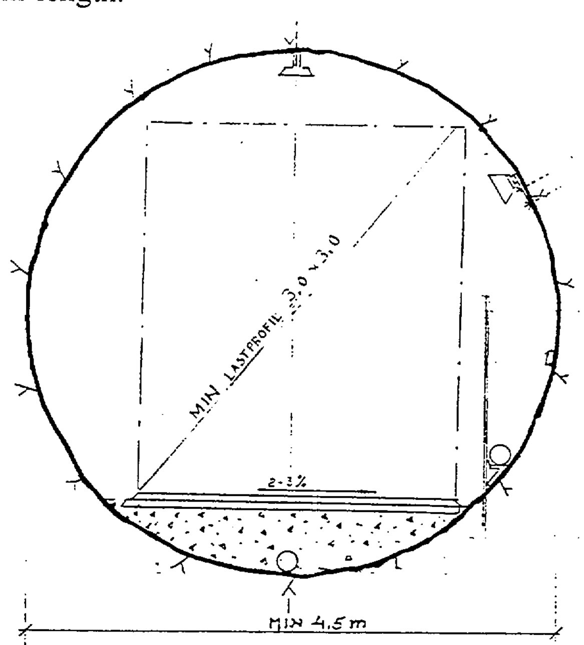

Figure 5-3 Minimum dimensions of the TBM tunnel

A rock cavern for assembly of the TBM was planned to be excavated at the end of the first turn close to the shafts. The dimensions of this cavern was not specified by SKB but for the initial layout work it was anticipated to be around 25m in length, 12m in width and height of 7 m (Figure 5-2).

None of the tenders did fully conform with the specified requirements in the invitation. They pointed out the the difficulty and risk associated with drilling in a continuous horisontal radius of 150m. If it proves impossible to maintain the curve radius this will have severe consequences, since the tunnel would then enter the extremely complex and highly water-bearing zone NE-1. This zone was crossed at the access ramp and another crossing should be avoided due to the extent of grouting that was needed for a safe passage.

In conjunction with the evaluation of tenders, alternative layouts were studied in order to explore every possible way to minimize the risk.

An interesting layout proposal was presented by SKANSKA in their tender. Their proposal was to start the TBM tunnel half way down at a point in the eastern region of the spiral and drill in a moderate horisontal radius down to the final level (Figure 5-4). This way the the zone NE-1 is easily avoided. The TBM is as well driven in an angle more or less perpendicular to some minor very water conducting NNW-oriented minor fracture zones.

The layout now chosen is a successful compromise between the demands of research and a rational execution. The tunnel avoids large zones. The major water conductors located in the north-northwesterly direction are intersected at a right angle. This improves the chances of effective sealing.

The dimension of the tunnel was proposed to be 5,0 m giving a good margin for the minimum.

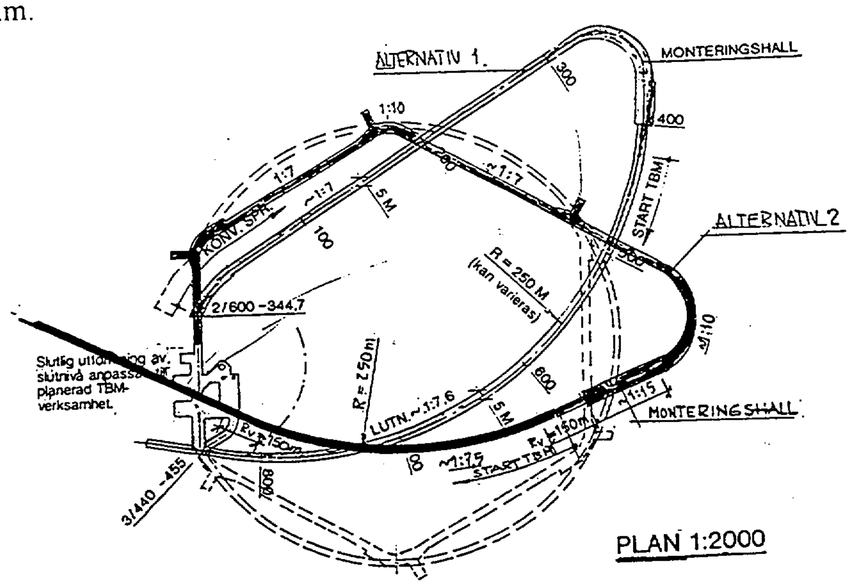

Figure 5-4 Layout proposal by SKANSKA

The contract for the TBM tunnelling is now based on a flexible design with the following rquirements for the layout of the tunnel.

- Security distance to the zone NE 1 is 50m.
- Minimun radius for curves is 150m vertically and 200m horisontaly.
- The lowest point of the tunnel is -450m.
- The vertical inclination shall be minimum 0,5% upwards after passage of the lowest point

The tunnel beyond the position of the shafts into an area suitable for longterm experiments (Figure 5-5).

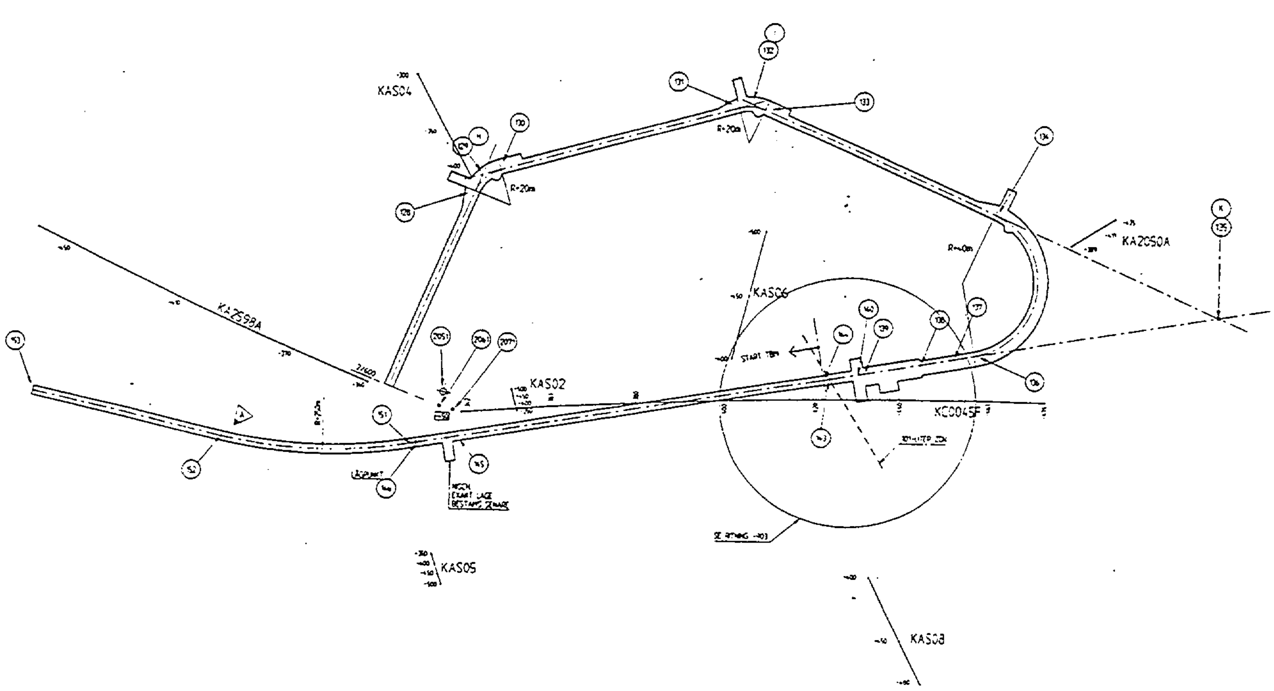

Figure 5-5 Final layout of the TBM tunnel

5.3 OTHER DESIGN REQUIREMENTS

The water inflow shall be measured in the same way as for the blasted tunnel parts. Dams with overflows for measuring have therefore to be provided for the the round section of the TBM drilled tunnel (Figure 5-6).

The water pressure is up to 45 bar, which requires special measures in conjunction with probe drilling and grouting.

In the downward-sloping part of the tunnel it is necessary that the tunnel be relatively dry. Grouting is less flexible with TBM than with conventional driving. This entails a greater risk that the grouting cement will spread to the "wrong" rock volume and disturb planned experiments there. To ensure that probing and grouting are effective, it was an important requirement from SKB that drilling be possible through the cutter head if necessary.

Supplementary investigations in a central cored hole in ther tunnel decline has been conducted prior to TBM boring to reduce surprises.

6 COORDINATION BETWEEN RESEARCHERS AND BUILDER

A large quantity of data has been collected in conjunction with the drill&blast tunnelling work. There are more than 170 measurement points in boreholes around the tunnel. Here pressure changes are recorded on-line. Mapping was carried out in the tunnel during one hour after each blasting round. After every fourth round, pressure build-up tests were conducted in two 20 m long probe holes to get a measure of the permeability of the rock. The data are used for a systematic comparison with the hundreds of predictions of the bedrock made before the blasting began in October 1990. Comparisons between predictions and outcome are made regularly. The overall evaluation of the comparisons will be presented during 1995. The evaluation is important for being able to plan and execute reliable site investigations.

The TBM driving work influences the planning of the continued work. Different working methods will be tried to find a rational and safe methodology for both the researchers and the builder. These procedures are described by Stanfors, Rhen (ibid).

7 STUDIES IN CONJUNCTION WITH TBM DRIVING

SKB plans to conduct different types of studies at the Äspö HRL as a basis for its choice of drill-and-blast or TBM for the Swedish deep repository. One of these studies — ZEDEX (Zone of Excavation Disturbance EXperiment) — aims at comparing the mechanical changes in the rock between a drill-and-blasted and a bored tunnel. This study is being conducted in cooperation with ANDRA of France and UK NIREX. This study is described more in deatil by Olsson (ibid).

8 CONCLUSION

TBM boring at the Äspö HRL will yield valuable experience that will be applied within 15 years when SKB builds the Swedish deep repository and commences deposition of the spent nuclear fuel.

PAPER B:

FEATURES OF THE TBM-MACHINE TO BE USED AT THE ÄSPÖ HARD ROCK LABORATORY

Stig Eriksson
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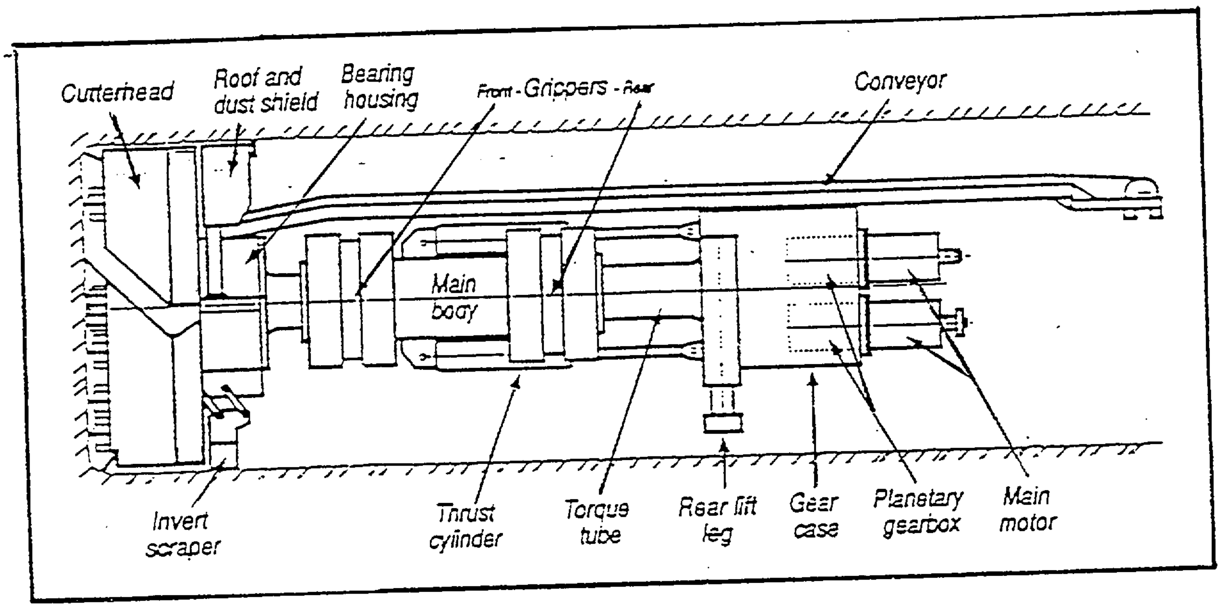
JUNE 1994

1 GENERAL MACHINE DESCRIPTION

Jarva type Tunnel Boring Machines (TBM) are of so called *open design* and primarily intended for work in medium hard to hard, competent rock. They consist of two main assemblies:

- an anchoring or stationary section.
- a working or moving section.



The TBM to be used in Äspö is a Jarva MK 15 with a diameter of 5.030 mm.

The anchoring section consists of a main frame and four grippers attached to the front and rear of the main body in the horizontal plane.

Adjustable bronze slide bearings – with an automatic greasing system – support the working section in – and transmit the torque reaction to – the main body.

The grippers are individually controlled and the gripper pads are mounted by means of a ball joint, so that they will automatically seat uniformly against the tunnel wall, thus eliminating point loading which could cause tunnel wall rock failure.

The working section consists of the cutterhead, bearing housing, torque (reaction) tube, the drive train, the rear lift legs and the muck conveyor. The torque reaction tube is a rigid structural member which is supported by the main body and connects the bearing housing to the gear case.

Cutterhead rotational torque is developed by electric motors located at the rear of the machine. The MK 15 is equipped with 3 motors, rated at 560 kW each.

Cutterhead thrust is developed by the thrust cylinders. They transmit this thrust from the main body through the gear case and the torque tube. This is accomplished by retracting the cylinders which have the cylinder ends pinned to the main body and the piston rods to the gear case housing at the rear end of the TBM.

The cutterhead is divided into a centre section, carried by the main bearing of the TBM, and four detachable spokes.

Scraper blades are located on the spokes to scoop the muck into the buckets mounted at the rear of the cutterhead, and a rock breaker is provided for crushing large chunks of rock before they are loaded into the buckets and then onto the conveyor.

The cutterhead is dressed with 34 disc cutters of different types: two twin-disc centre cutters, eight cutters in the gauge area and a number of face cutters in between.

2 BACK-UP SYSTEM

The back-up system to the TBM is a Fosdalen back-up rig type FI-500 ES. It is an extra short version and consists of 6 decks which houses the following equipment:

- operators cabin
- hydraulic power packs
- high voltage switch 10 kV
- electrical transformers 2 x 1250 kVA + 630 kVA
- frequency converters
- electrical cabinets for TBM and back-up
- ventilation duct magazine
- ventilation system with dust filters
- air compressor
- emergency generator
- water supply system for cooling of motors and sprinkling at face
- pumping system
- grouting equipment
- work shop area.

3 BORING CYCLE

With reference to the figure on the next page, a normal boring cycle can be described as consisting of the following steps.

1 At the beginning of the cycle, the anchoring section has been brought forward (ie reset) in relation to the working section and is gripped in.

The invert scraper is in floating contact with the rock in the invert and the rear support legs have been pulled up from the invert.

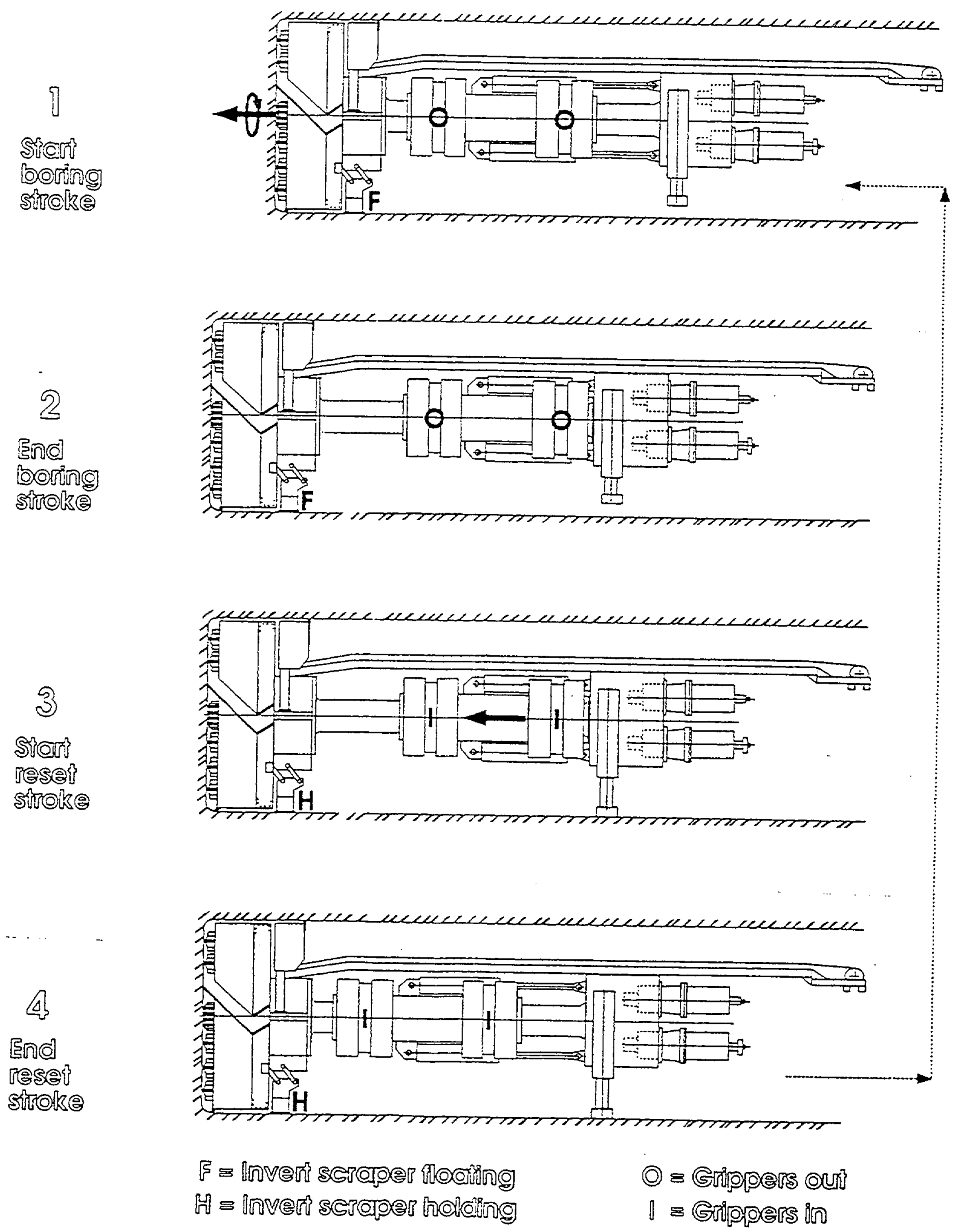
2 With the head rotating, the thrust cylinders are activated to retract and they now stroke the working section forward over a distance of 1.5 m.

3 At the end of the forward stroke, preparations are made for the reset stroke: cutter-head rotation is stopped, the rear lift legs are lowered against the invert and the invert scraper is brought from the floating mode - which is the normal one for boring - to the supporting mode, to carry the weight of the front end of the machine.

4 With the TBM thus supported at both ends, the grippers are retracted, so that the anchoring section becomes free for resetting which is done by reversing the thrust cylinders.

When these are fully extended once more, the invert scraper is brought to the floating mode again.

Steering is accomplished with the use of the rear grippers and the rear lift legs to position the TBM on the desired line and grade. Once the anchoring section is gripped into the bore, the cutterhead will not change course during the boring stroke, but advance in a straight line, guided by the torque tube sliding through the main body. The machine, therefore, will bore a curve as a series of chords, each of which has the same length as one boring stroke and steering is only done when the anchoring section is reset.



A complete boring cycle – step by step

4 SPECIAL FEATURES

The TBM and the back–up has been modified with the following special features for the Äspö project:

- extra short back–up of 6 decks instead of normally 11 decks by placing the equip–ment on both sides of the back–up with a 1 meter free passage in the centerposition.

- the operators cabin is tiltable for the various inclinations and is also designed to accomodate 4 persons in case of fire.

- for probe hole, drainage and injection drilling, two Atlas Copco BMH 1310 feeds with rock drill of type COP 1238 are mounted on top of the anchoring section on a circular shaped frame.
  Holes can be drilled in a number of positions at the perimeter of the tunnel at an angle of 7° out from the tunnel alignment. It is also possible to drill through the cutterhead in 8 positions (4 straight ahead and 4 inclined towards the tunnelcenter).

- the emergency power unit is designed to manage the pumping system required for the Äspö project.

- the water supply system is designed to reuse the water to maximum content and hence reduce the spillage of water.

- the filters for the dust control is of sintered plastics which have shown to be efficient both in dry and humid enviroment.

- the TBM is equipped with frequency converters and each electric drive motor is powered from its own, separate frequency converter. This implies, that if a mal–function occurs in an electric motor of frequency converter, the other drive units are not affected and the machine can be keept going – albeit at reduced power.
  The possibility of varying the rotation of the cutterhead will simplify the correct positioning prior to probedrilling through the cutterhead.

- The BORE system will continously monitor data from both the TBM boring and the probedrilling for various parameters.

5 ASSEMBLING

The TBM was assembled and tested during February - April in Götaverken, Gothenburg. At Äspö an assembly hall, 30 m long with a cross section of 90 m2, has been excavated some 3.200 m from the portal at 420 m below the sea level.

A portal crane with a capacity of 50 tons has been installed in the assembly hall to fascilitate the assembling of the TBM.

Prior to starting of the assembly a detailed planning has taken place and especielly the sequence of the works was carefully studied.

The heaviest parts, the center section and the main body, were transported directly from Götaverken to the assembly hall using a special short trailer.

The trailer was also used to transport many of the other TBM items from above ground to the assembly hall underground.

The decks of the back-up were put together to maximum extent above ground and later carefully brought down to the assembly hall.

Underground the final assembling of hydraulics, electricals and controls has been done for the TBM and the back-up and testing of all functions have been carried out and the machine is now ready for production.

TBM JARVA Mk 15

Diam 5.00 m (5.03 m with new cutters)

Power	1680 kW
RPM	10.1
Torque	1588 kNm
Thrust force	8300 kN
No of cutters	34 no
Cutter force	245 kN, max
Stroke	1.525 m
Gripper force	25 000 kN, tot
Length	approx 17 m

PARAMETERS (logged every second, average for 5 min stored)

- Time and date
- Thrust force
- Stroke, penetration
- Torque
- RPM
- Activity performed

Relative position in tunnel must be measured.

PROBE- AND GROUT DRILLNG
(logged and stored every 2 seconds)

- Penetration
- Percussion pressure
- Rotation pressure
- Feeding pressure

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PAPER C:

METHODOLOGY FOR ROCK CHARACTERIZATION IN CONNNECTION WITH TBM-EXCAVATION AND SOME PRELIMINARY RESULTS FROM THE CORED BOREHOLE PARALLEL WITH TBM TUNNEL

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Roy Stanfors, Roy Stanfors Consulting
Leif Stenberg, Swedish Nuclear Fuel and Waste Management Co

JUNE 1994

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1 BACKGROUND

1.1 ÄSPÖ HARD ROCK LABORATORY

In order to prepare for the siting and licensing of a spent fuel repository SKB has decided to construct a new underground research laboratory.

In the autumn of 1990, SKB began the construction of the Äspö Hard Rock Laboratory (Äspö HRL) near Oskarshamn in the south-eastern part of Sweden, *see Figure 1-1*. A 3.5 km long tunnel is now excavated in crystalline rock down to a depth of approximately 460 m, *see Figure 1-1*. The laboratory is expected to start operating in 1995, and research concerning the disposal of nuclear waste in crystalline rock can then be carried out.

The pre-investigations for the Äspö HRL started in late 1986. The pre-investigation phase involved extensive field measurements from ground level as well as from boreholes, aimed at characterizing the rock formation with regard to geology, geohydrology, hydrochemistry and rock mechanics. Intermediate reports on the investigations were published in */Gustafson G et al, 1988, Gustafson et al, 1989, Wikberg P et al, 1991, Stanfors et al, 1991, and Almén K-E and Zellman O, 1991/*.

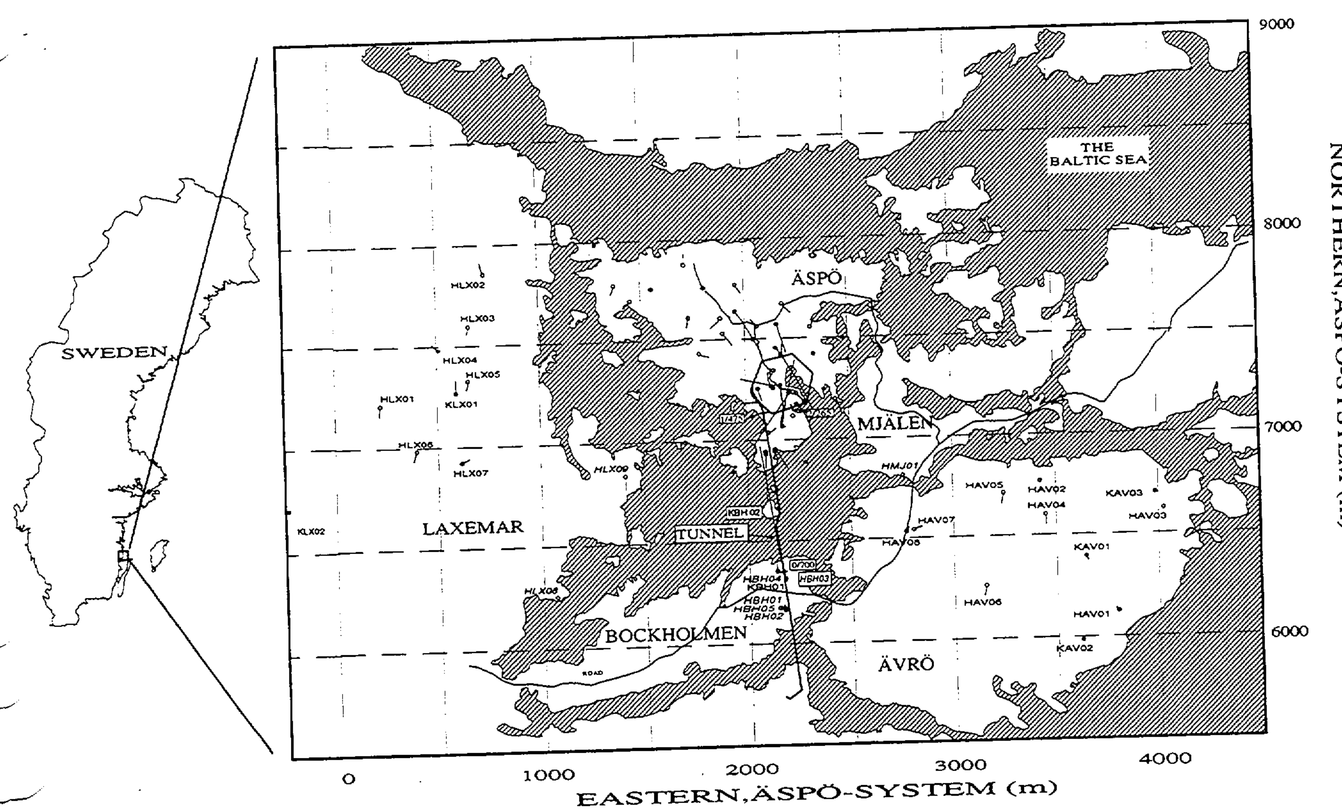

Figure 1-1. *Boreholes on Äspö, Ävrö, Hålö, Mjälen and Laxemar. Filled circle = corehole, hollow circle = percussion hole.*

1.2 TBM-TUNNEL

As possibly fullface boring of tunnels with a Tunnel Boring Machine (TBM) will be used at the future deep repository for spent fuel, it was decided 1993 by SKB that it would be suitable to get some experience of the TBM technique by using this technique for the final part of the tunnels for Äspö HRL. In *Figure 1-2* the TBM-tunnel is shown. The drilling will start at level -418 m and the deepest point will be -450 m, close to the elevator shaft.

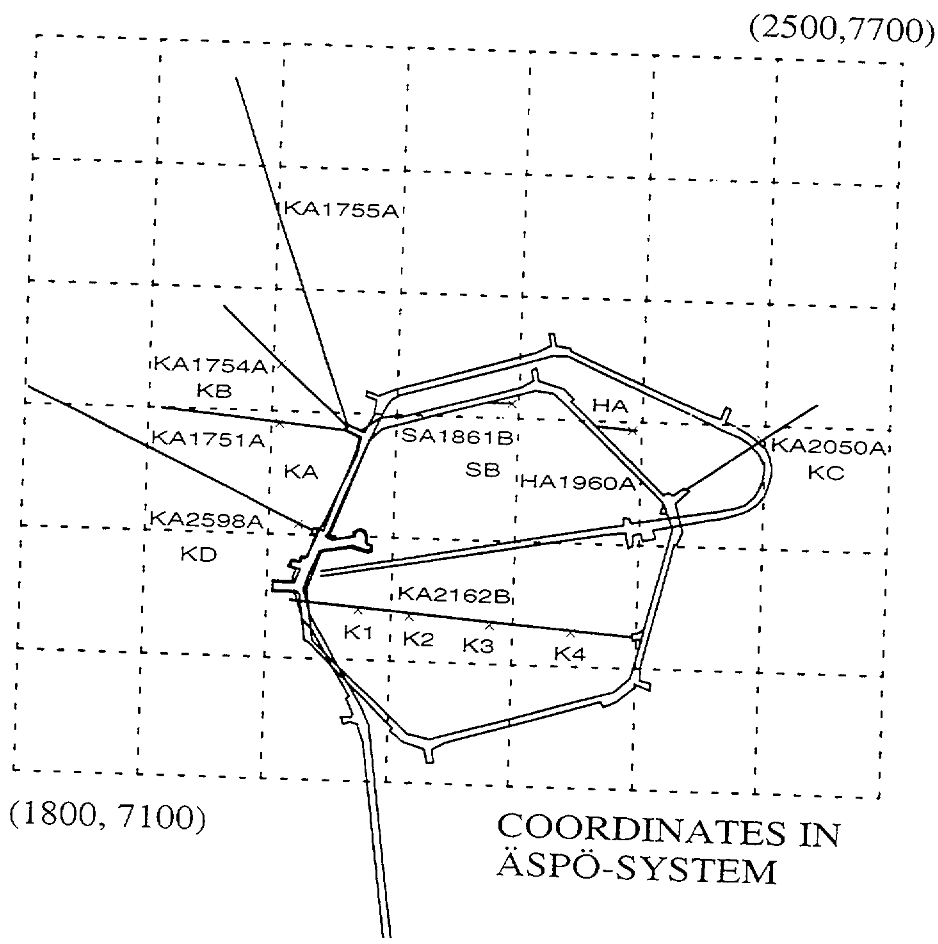

Figure 1-2. *Tunnel layout. Äspö HRL planned TBM-tunnel in black.*

2 GEOLOGICAL CHARACTERIZATION OF TUNNEL AT ÄSPÖ HRL

2.1 DRILL AND BLASTED TUNNEL

The geological characterization of the tunnel was mainly based on the follow-up mapping during the construction.

The aim of the follow-up work was primarily to collect sufficient data to validate the predictions made on the basis of the pre-investigations. Data collection was done within the disciplines **geology**, **rock mechanics**, **geohydrology** and **hydrochemistry**.

The daily mapping work has been performed by a special characterization group at the site according to "Manual for field work in the tunnel" */Christansson and Stenberg, 1991/.*

2.1.1 Continuous geological mapping and data collection

The general geological mapping of the tunnel was carried out continuously in direct connection with each new round excavated. The mapping comprises:

- Rock type distribution.
- Structures like folds, and fracture zones.
- Fracture mapping, where fractures longer than about 1.0 m were documented.
- Fracture fill materials.

Photographing in colour of each working face and the walls exposed by the last round.

The general routine mapping was complemented by line mapping for documenting of the 50 m blocks. The line mapping provides more detailed information concerning

- Fracture frequency data (fractures >0.3 m) along the whole tunnel from which, for instance, the RQD and other data can be calculated for both the total number of fractures and component figures.
- Differences in the fracture frequency distribution in different types of rock.
- Data for comparison with any core boreholes close to the tunnel.
- Detailed description of a fracture zone and its immediate surroundings.

2.1.2 Continuous rock mechanical mapping and data collection

Mapping of conditions which are important for the rock mechanical characterisation and evaluation of bedrock stability was carried out after each new round excavated. The following conditions were estimated and documented:

- Rock strength for the dominating rock type.
- Joint spacing.
- Fracture frequency data, RQD.
- Fracture surface conditions.
- Water conditions.
- Relation between tunnel axis and geological dip and strike.
- Installed rock reinforcement, type and frequency.

Complementary investigations

To be able to evaluate the general stress conditions in the rock mass, rock stress measurements were performed. The measurements were carried out in selected coreholes dominantly located in the 50 m rock blocks. Between one and three measurements were performed in each of the 50 m rock blocks, where each measurement comprised three individual readings.

Core samples of Greenstone, Fine-grained granite, Småland granite and Äspö diorite were collected for laboratory testing of rock mechanical characteristics and fracture surface properties.

2.1.3 Geological documentation during drilling of probe holes

Two 57 mm probing holes - 20 m long - were drilled every 16th metre on each side of the working face (every 4th round). The probing holes were directed 20° out from the tunnel wall and parallel to the bottom of the tunnel, i.e. point downwards slightly. (*See Figure 2-1.*)

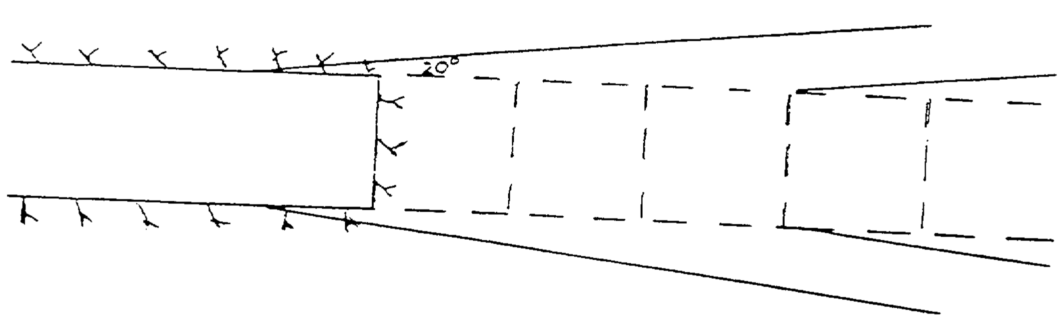

Figure 2-1. Probe drilling.

The geological documentation in conjunction with the drilling of probing holes consisted of assessing the rock type variations by means of continual observation of variations in the colour of the flushing water and the rate of penetration of the drilling.

2.1.4 Databas and data handling

Data produced are mainly stored in SKB's database GEOTAB or at the site office in the CAD computer. An overview of the geology and the reinforcement is always presented on plots covering approximately 150 m of the tunnel, *see Figures 2-2 and 2-3.*

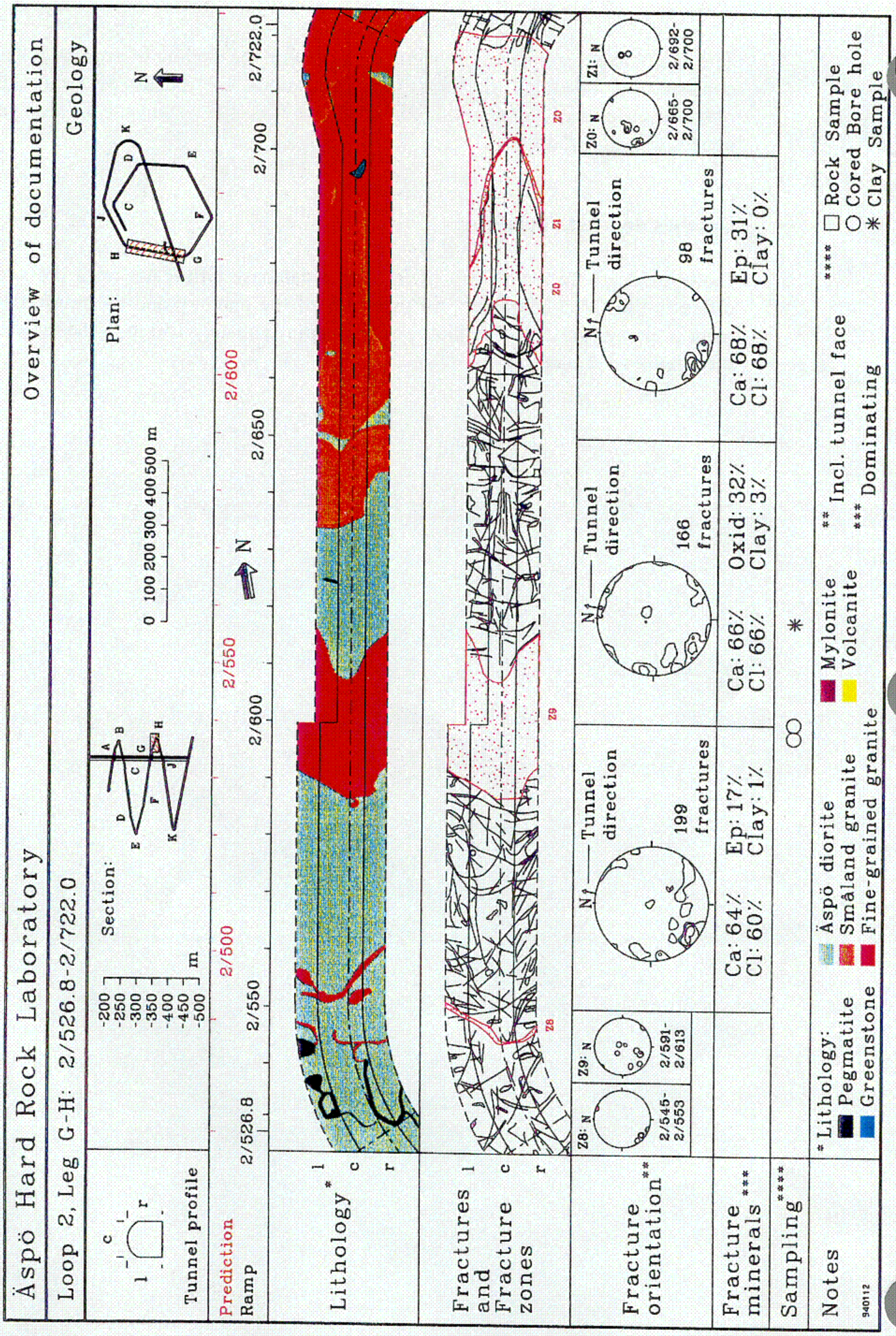

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Figure 2-2. Geology, tunnel section 2526-2722 m.

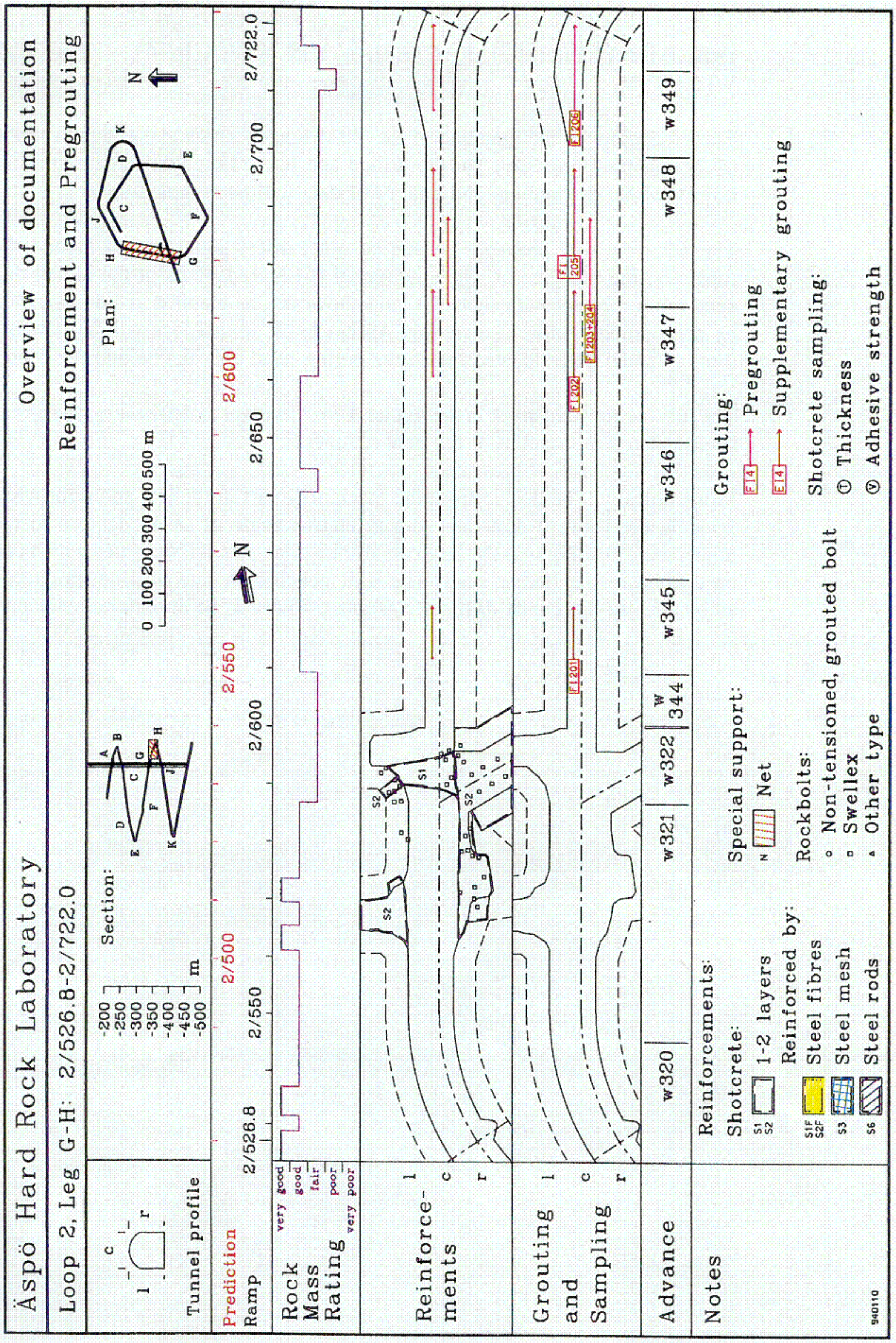

Figure 2-3. *Reinforcement and pregrouting, tunnel section 2526-2722 m.*

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2.2 DOCUMENTATION/CHARACTERIZATION WORK IN CONJUNCTION WITH TBM

The procedure for the mapping of the TBM tunnel is to some extent different to the mapping procedure for the drilled and blasted tunnel. The ambition is, however, that the amount and quality of data will be comparable.

The mapping will probably be carried out earliest about 100 m behind the tunnel boring machine or when the tunnel is finished. Parts of the tunnel that need reinforcement with shotcrete, must however, be mapped and documented by photography before shotcreting. Access to the tunnel face will be possible through small gates located inside the boring head and just behind the head.

The manual for field work in the tunnel */Christiansson and Stenberg, 1991/* has been updated on account of the new routines.

Probe holes will be drilled from the machinery part in the left and right walls 20 m in the forward direction with a relative angle of seven degrees to the tunnel axis. Drilling into the face can also be done through the gates which can be opened in the boring head. The drill penetration rate will be monitored automatically. Colour of drill cuttings must, however, be monitored manually.

3 GEOHYDROLOGICAL CHARACTERIZATION OF TUNNEL AT ÄSPÖ HRL

3.1 DRILL AND BLASTED TUNNEL

During excavation of the tunnel documentation is prepared and measurements made to obtain data for a comparison between the prediction and outcome. The documentation and measurements are also used to update the geological, geohydrological and groundwater chemical models.

The geohydrological testing and documentation comprises:

- Probe drilling and pressure build-up tests at the tunnel face.
- Mapping of water conducting fractures and estimating the fractures inflow rate and inflow characteristics.
- Monitoring of pressure in boreholes from the surface and from the tunnel.
- Measurements of the water flow into the tunnel with dams along the tunnel (approximately every 150 m).
- Dilution and salinity measurement in boreholes.

The documentation and measurements are described briefly in *Rhén et al /1994/*. Below only probing and pressure build-up test are described.

3.1.1 Probing and pressure build-up tests

Approximately every fourth round two 20-m long probe holes are drilled about 4 m from the tunnel face, one on the left wall and one on the right wall. The main purpose of the probe holes is to estimate the hydraulic properties of the rock. Generally the borehole direction is 20° from the tunnel line and with a dip of approximately 10°. During drilling the inflow of water (flow rate and position in the borehole) and the rock composition are estimated. Groundwater samples are also taken, *see Wikberg et al /1994/*.

After drilling, a pressure build-up test is performed. Generally the packer is installed 5 m into the borehole (*see Figure 3-1*). The flow and pressure build-up periods are approximately 30 + 30 min. The transmissivity of the tested section is evaluated from the pressure build-up test. The type of rock in the tested section is estimated from the probing and mapping of the tunnel wall.

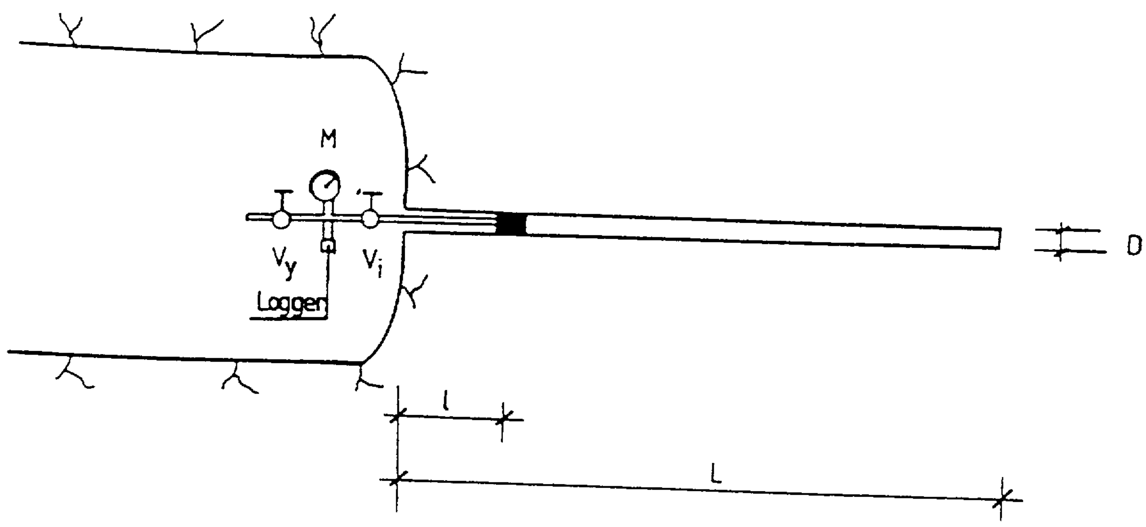

Figure 3-1. *The equipment used during a pressure build-up test.*
L = length of sounding borehole
l = distance between packer and the rock surface
D = borehole diameter
M = Precision pressure gauge for manual readings
V = Valves (outer and inner)

The method of using probe holes close to the tunnel face and pressure build-up tests was chosen for the following reasons:

1 To estimate the hydraulic properties of the undisturbed rock. The properties are probably more undisturbed behind of the tunnel face than in front of, at least if short boreholes are tested.

2 The pressure build-up test is a simple and robust method.

3 The probe holes drilled ahead of the tunnel face provide the builder and contractor with information about the rock properties and water problems.

The transmissivity is estimated from the pressure build-up test in a probe hole, which is a single-hole test. The flow regime is also studied, and it has been found that in most cases radial flow seems to dominate the latter part of the test. Thus, evaluating transmissivity seems to be a reasonable course. A few interference tests have also been performed and from some of these tests it has also been possible to evaluate the storage coefficient in some cases.

The predictions of the hydraulic properties were given as the hydraulic conductivity for the tunnel section 700 - 1475 m, 1475 - 2265 m, 2265 - 3064 m and 3064 - 3854 m. The hydraulic conductivity is estimated as the transmissivity divided by the estimated length of the test section, which is estimated as the distance from the bottom of the borehole to the packer.

The hydraulic conductivity predictions in *Gustafson et al /1991/* were given in the 20 m scale (20 m = test section). The predictions were based on injection tests with a packer interval of 3 m. The predicted values of point estimates etc. were scaled up to the 20 m scale according to the empirical relationship shown in *Wikberg et al /1991/*. In *Rhén et al /1994/* the hydraulic conductivity predictions in *Gustafson et al /1991/* were rescaled to 14 m which is the geometric mean of probe hole test section lengths.

The transmissivities evaluated from the probe holes that penetrated the most intensive parts of the mapped fracture zones have been used for estimating the fracture zone transmissivities.

3.1.2 Data base and data handling

Data produced are mainly stored in SKB's database GEOTAB or at the site office in the CAD computer. An overview of the geohydrology and ground-water chemistry is always presented on plots covering approximately 150 m of the tunnel, *see Figure 3-8*.

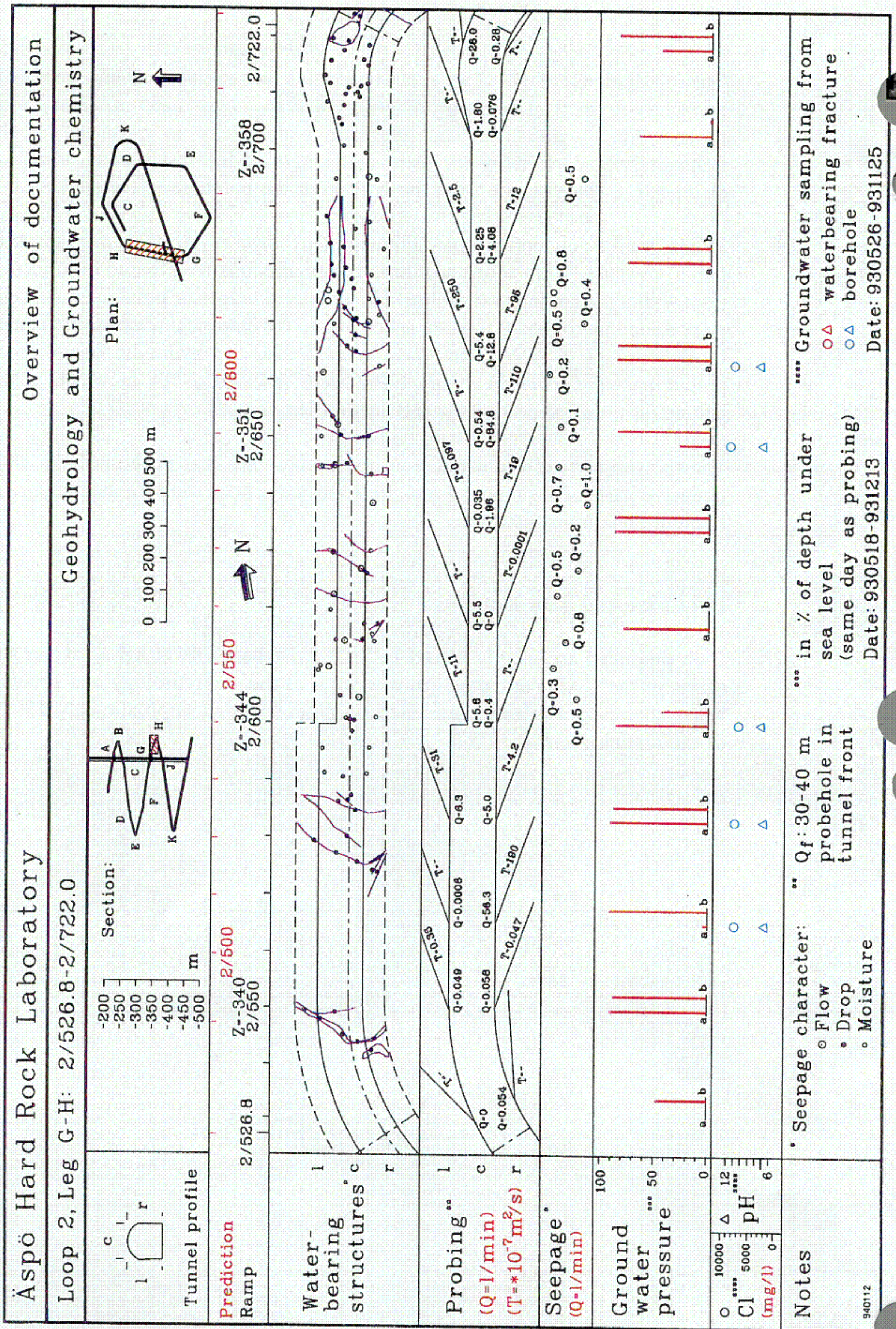

Figure 3-2. Geohydrology and groundwater chemistry, tunnel section 2526-2722 m.

C-03

3.2 TBM-TUNNEL

As described in *Chapter 3.1* some of the more important documentations and testings are performed close to the tunnel face in the drill and blasted tunnel. When now the excavation will be made by a TBM the pre-requisites for documentation and testing the rock mass have changed quite a bit compared to the drill and blasted tunnel. In the planning for the TBM excavation it has been discussed how to perform investigations with the same objectives and the same ambition as in the drill and blasted tunnel. Below the investigation strategy is outlined.

3.2.1 Hydraulic characterization of the undisturbed rock mass in front of the TBM

Two concepts are tested:

- Cored borehole along the TBM- tunnel
- Probe drilling at tunnel face from the TBM

The hydraulic tests performed in the corehole are:

- Documentations of flow rates into the borehole during drilling and borehole depth as function of real time.

- Hydraulic head (pressure) observations during drilling in selected boreholes with the hydromonitoring system (HMS) and data loggers.

- Flowmeter logging and pressure build-up test after 100 m and full drill depth (210 m).

- Pressure build-up test, during drilling, of the last drilled 15 m, if these last 15 m has to be grouted.

- Pressure build-up tests, after drilling, with double packer system with 15 m test section in sections not previously tested.

The concept with a corehole and the investigation program as above (compare also with *Chapter 2*) is more ambitious than the ordinary documentation with the probe holes in the drilled and blasted tunnel. However, there are some practical matters:

- Suitable drill position and time must be available if the rock ahead of the TBM is to be investigated.

- As the cored hole must be close to the TBM-tunnel, either it has to be grouted because of rock mechanical or excavation conditions, or it will be grouted during the excavation. The last remark indicates that installed packer for pressure monitoring might get struck in the hole.

The other way to characterize the rock is to use similar technique as in the drill and blasted tunnel - that is to drill probe holes from the TBM. In *Figure 3-3* two alternatives for drilling are shown.

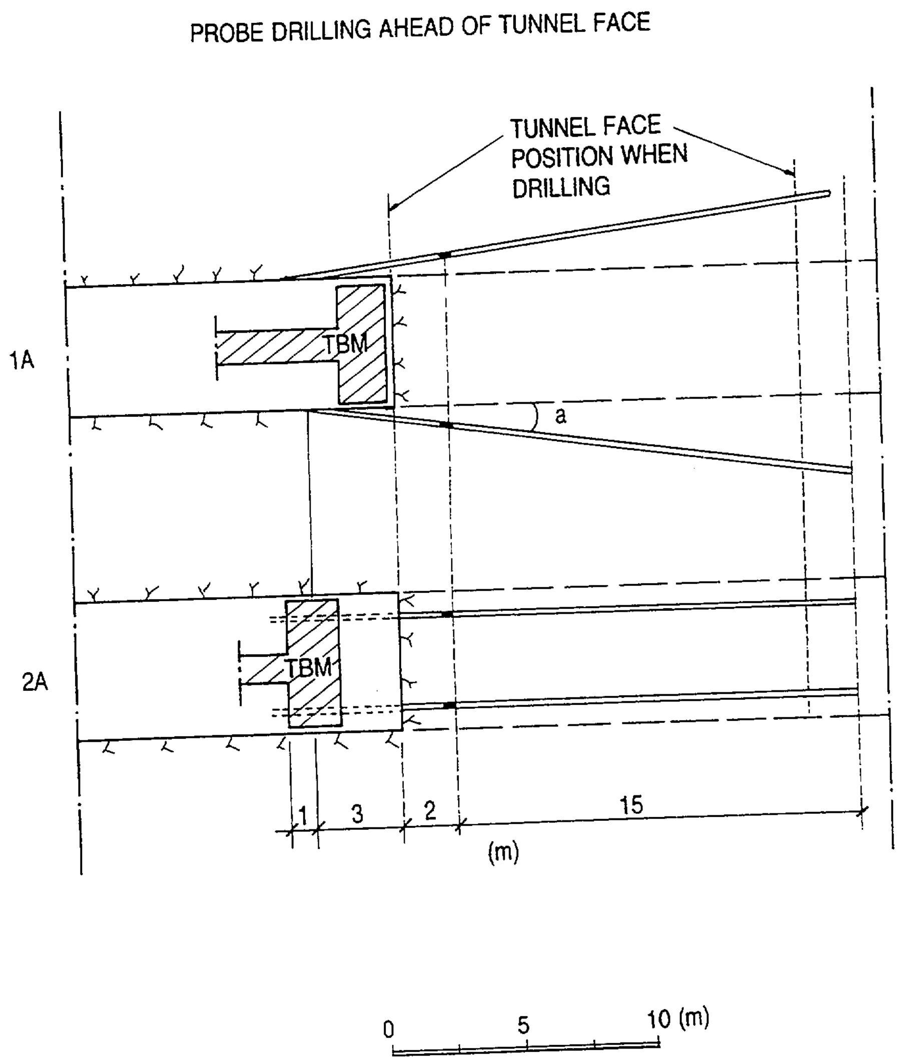

Figure 3-3. Probe drilling from the TBM.

There are two possibilities to drill from the TBM (used at Äspö HRL):

1A: drill behind the TBM drill-head
1B: drill through the TBM drill-head

The documentation and hydraulic testing can in principle be performed as in the drill and blasted tunnel. However, there are several difficulties, which are outlined below.

A general problem with testing and documentation close to the TBM head is the limited working area compared to the drill and blasted tunnel.

During drilling the inflow of water (flow rate and position in the borehole) and the rock composition are to be estimated. This may be quite difficult to perform in alternative 2A. It is sofar unclear what can be documented, during drilling according to alternative 2A. Probable two people, instead of one, are needed and the quality of the documentation will probably be less compared to drill and blasted tunnel.

The maximum borehole deviation from the tunnel centre line is a = 7°, *see Figure 3-3*. This means that the probe hole will be close to the tunnel and the risk that the borehole will be filled with grout is great, if grouting is needed. This means that installing packers for pressure measurements in the probehole would probably not be successful, if the angle is around 5-10°. Another problem with starting pressure monitoring just after drilling the probehole is that the outer part of the borehole has to be reamed in order to get the outer part of the packer system (valves etc) outside the tunnel periphery, so that the grippers doesn't damage the packer system.

Alternative 2A is somewhat better than 1A just considering installing packers for pressure build-up tests, but the contractor prefers alternative 1A because the cutters might be damaged if the packer equipment get stuck in the boreholes.

According to preliminary decisions alternative 1A will be tested in the TBM tunnel west of the shafts. During the spring and summer 1994 a modified packer system is developed for this alternative. The idea is to use the drillriggs on the TBM for installing the packers for pressure build-up tests. No pressure monitoring will be done in these holes - new boreholes will be drilled, *see below*.

3.2.2 Pressure monitoring around the tunnel

In the drilled and blasted tunnel the pressure monitoring is made in the probeholes which were drilled at the tunnel face. As discussed above the design of the TBM at Äspö is not able to drill probeholes suitable for pressure monitoring. The alternative is to drill new boreholes with an ordinary drillrigg some distance behind the TBM. The disadvantage is that you have to drill new borehole (cost) and that it is not possible to start the monitoring immediately. The advantage is that the boreholes can be better designed for the pressure measurements. In *Figure 3-4* pressure monitoring in the drill and blasted tunnel and 3 alternatives in the TBM tunnel are shown.

According to decision made alternative 1B or 2B will be chosen. Mechanical trippel packers are being developed during spring and summer 1994.

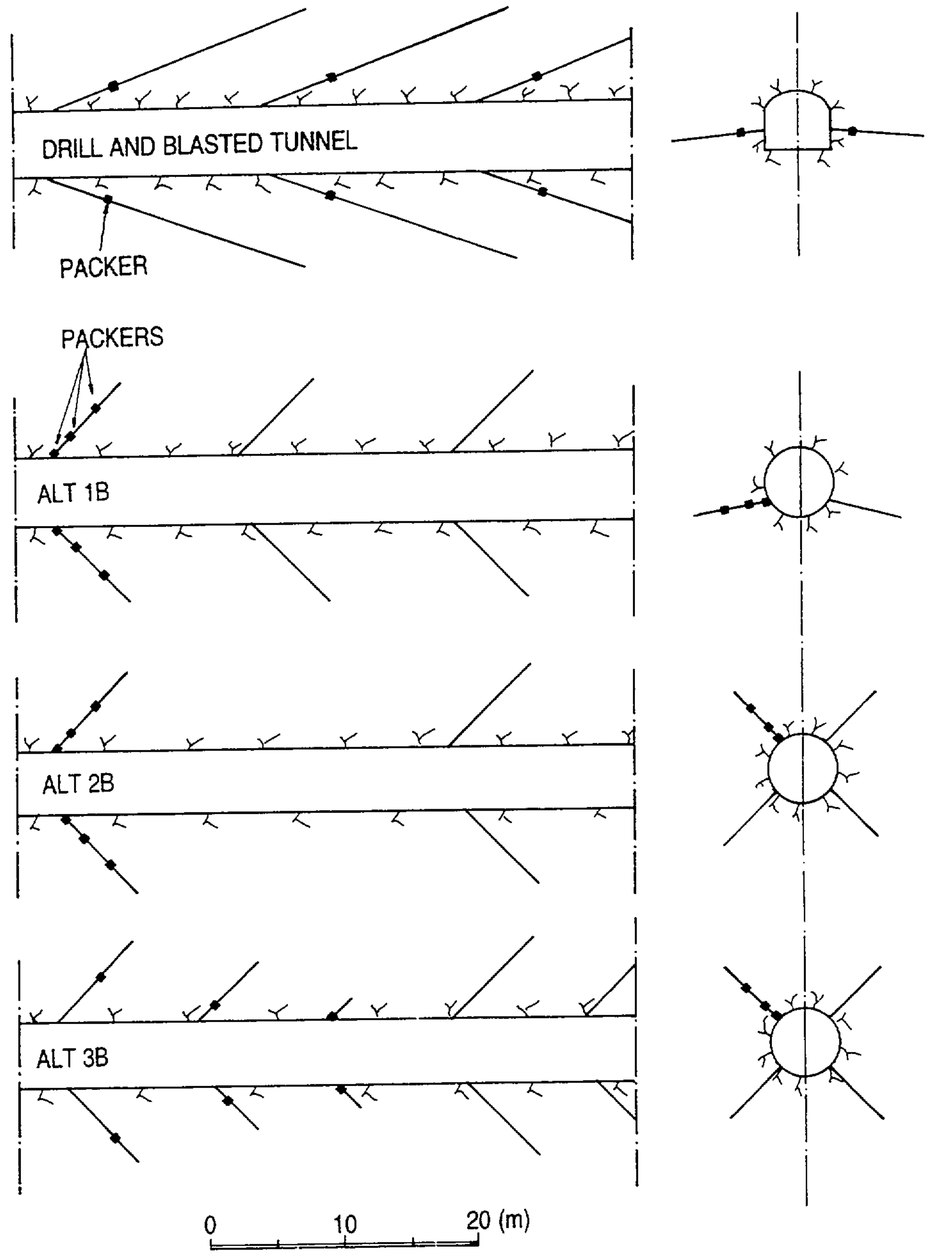

Figure 3-4. Pressure monitoring around the tunnel.

4 PRELIMINARY RESULTS FROM THE CORED BOREHOLE PARALLEL TO THE TBM TUNNEL

4.1 OBJECTIVE WITH THE CORED BOREHOLE

The borehole KA3191F is drilled from the TBM assembly hall in the centre line of the TBM tunnel down to the lowest position of the excavation at a depth of 450 metres below ground surface in the vicinity of the shafts, *see Figure 4-1*. The borehole is 210 m long. The objective of this borehole is to:

- provide data in advance of the TBM-tunnel for characterization of the rock properties and fracture zones which can give completing information of value in advance of the TBM boring.

- provide completing data for geological, geohydrological and groundwater 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.

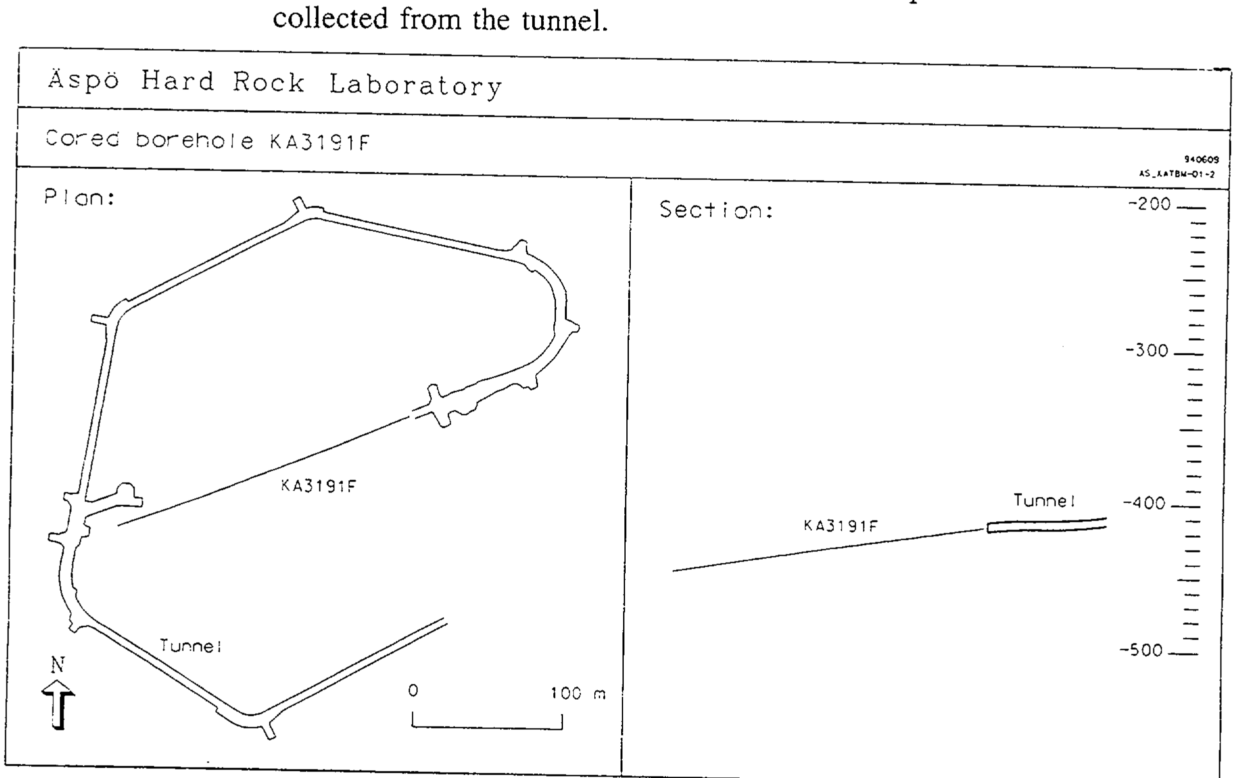

***Figure 4-1.** Overview of the cored borehole KA3191F.*

4.2 GEOLOGY AND GEOPHYSICS

4.2.1 Drill core mapping

The drill cores have been mapped according to the Petrocore system.

The colour plot for the cored borehole KA3191F for the cored borehole KA3191F presents lithology, alteration, fracture infillings, fracture surface character, fracture alteration, crush zones, veins and fracture frequency.

As can be seen from *Figure 4-2*, Äspö diorite is the dominating rock type making up more than 95 % of the core. Fine-grained granite, mylonite and greenstone occur in some 1-2 m wide sections and minor veins.

The fracture frequency in the major part of the core is two-three fractures/m.

Alteration in the core is concentrated to some sections with increased fracturing at approximately 40-50 m, 175 m and 190 m.

Less than 1 metre wide crushed sections are mapped at approximately 40 m, 110 m and 125 m.

Dominating fracture minerals are chlorite and calcite.

RQD >75 (very good rock quality, is calculated for approximately 90 % of the core.)

4.2.2 Borehole radar measurements

Borehole radar measurement using directional antenna has been performed in the cored borehole KA3191F with the objective to find the orientation and extent of minor fracture zones, and to study rock structures in the vicinity of the borehole. Measurement with directional antenna was made with the RAMAC system.

Reflectors have been identified in bandpass-filtered data.. The angle of intersection relative to the borehole and the magnetic azimuth have been determined for most reflectors. This gives the orientation of the reflectors relative to the borehole. Based on these data the orientation relative the magnetic north was used.

The reflectors identified from the radar measurement in borehole KA3191F are listed in *Table 4-1* and tabled in *Figure 4-4*.

The depth of intersection in the borehole is given relative to the steel-plate at casing. Accuracy is ±1 m.

Magnitude is a relative (subjective) measure on the strength of the reflectors on a scale from 1-3. 1 signifies a weak reflector and 3 a strong reflector.

Dip and strike of oriented reflectors are given relative to magnetic north. The interpretation was performed with the help of a computer program called CROSHOLE. CROSHOLE uses a right-hand coordinate system. Dip angles are in the interval 0 to 90 degrees, while strike directions are in the range 0 to 360 degrees. A strike of 0 degrees implies a dip to the east while a strike of 180 degrees implies a dip to the west. Strike angle is positive clockwise from the north.

Table 4-1. Reflectors identified from directional antenna measurement in borehole KA3191F. Dip and strike are relative to magnetic north. (Depth are given relative to steel plate at casing, which is 0.345 m from rock surface).

Reflector ID	Depth of intersection (m) (m)	Angle of intersection (degrees) (degrees)	Magnetic azimuth T(0)=0 (degrees)	Dip (deg.)	Strike (deg.)	Magnitude 1=weak 2=medium 3=strong U=uncertain
1	13	7	80	79	255	2
2	17	49	260	90	19	2
3	42	47	210	62	182	2
4	84	35	290	69	35	2
5	86	36	80	77	284	2
6	89	41	120	74	116	2
7	95	38	140	60	123	U
8	114	32	340	30	15	2
9	126	59	270	82	111	2

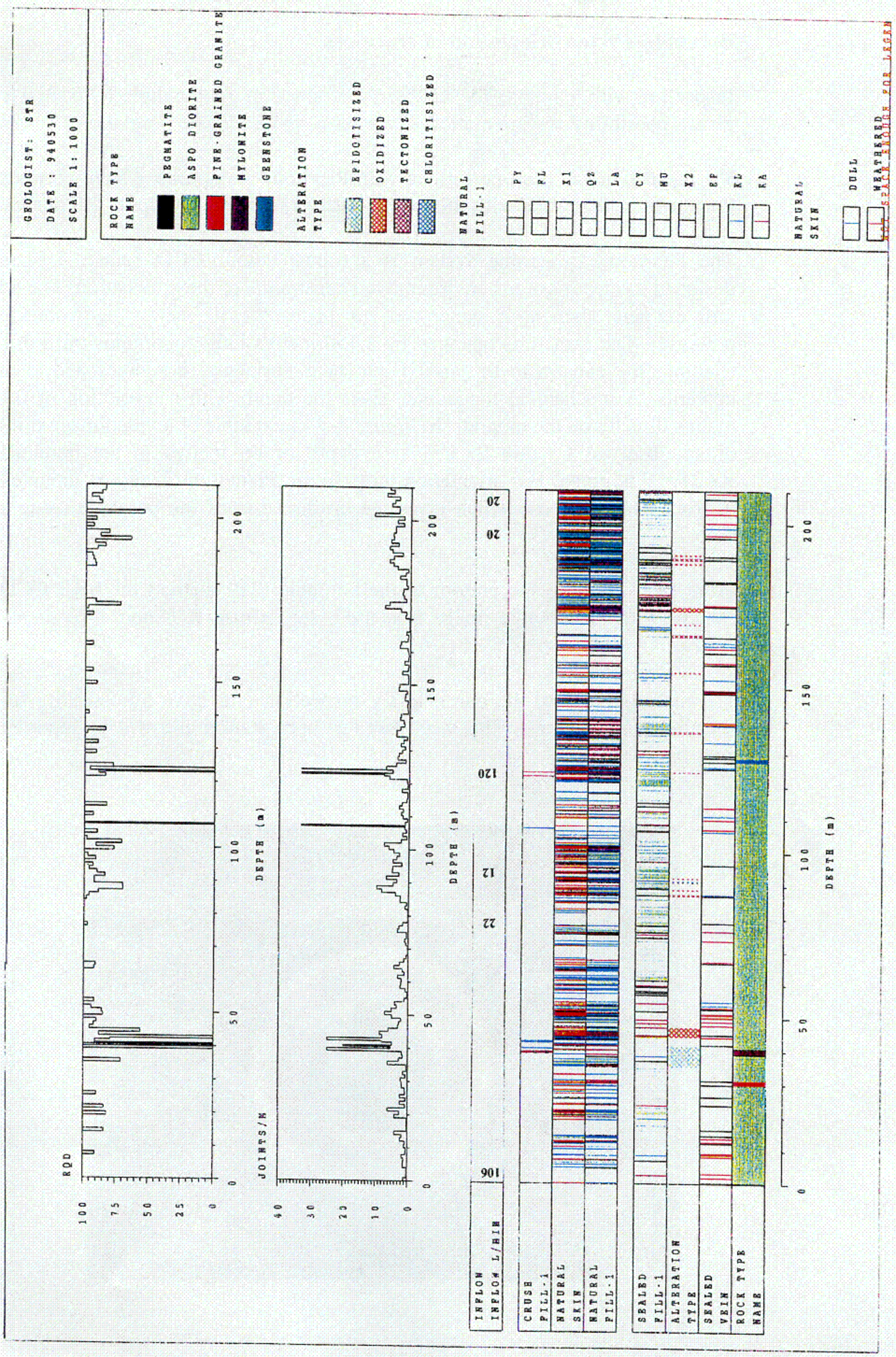

Figure 4-2. *Borehole KA3191F. Lithology and RQD.*

C-04

4.2.3 Borehole-TV for orientation of fractures

Inspection with borehole-TV has been performed in the borehole KA3191F to give a possibility for orientation of fractures visible in the borehole.

TV-inspection has been performed with Pearpoint flexiprobe system between 0 up to 145 metres and with SKB CCD-camera between 140 up to 210 metres.

The Pearpoint flexiprobe system is a robust colour CCD camera system designed to meet rigorous environmental constraints of the application. The 44 mm diameter camera is waterproof to 11 bars (110 metres hydrostatical pressure). The camera is operated by a 150 metres long continuous push rod, enabling the camera to be pushed into near horizontal boreholes and even upwards. A mechanical rodcounter gives the depth with a resolution of 0.1 metres directly on the monitor. In *Figure 4-3* an example of a videoimage print of an observed fracture located at a depth of 46 metres in the borehole KA3191F is given. For orientation purpose an orientation device is mounted in front of the camera which gives the up direction of the borehole using a bulb.

From 145 metres to the bottom of the borehole (210 metres) the SKB CCD camera with black/withe image was used, see */Almén K-E and Zellman O, 1991/.*

The main purpose of the borehole-TV inspection is to give a possibility for orientation of fractures. This work has just been started and will be reported later on.

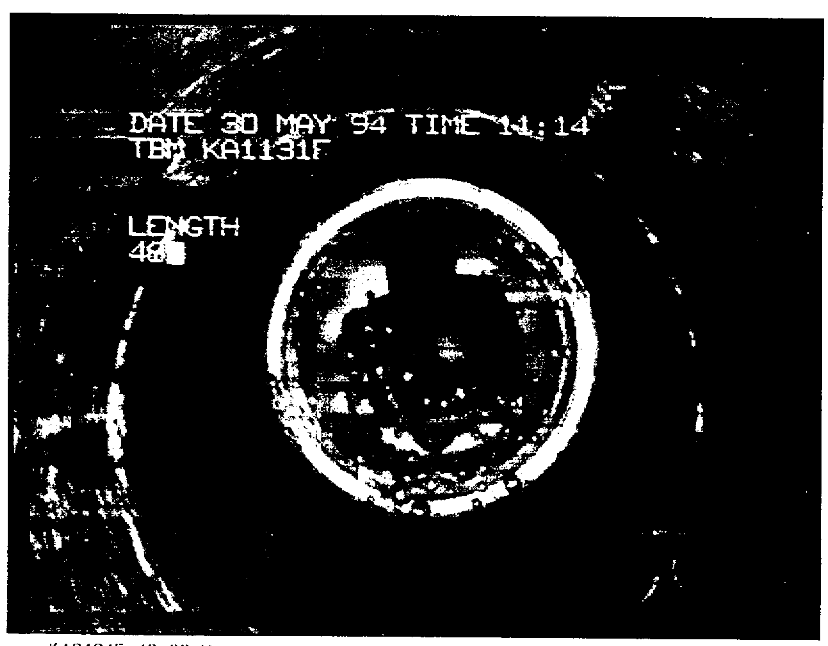

Figure 4-3. *Colour image from TV-inspection with Pearpoint Flexiprobe system from the depth of 46 metres in KA3191F.*

4.2.4 Geophysical borehole logging

In order to investigate lithological, fracture and tectonical conditions at Äspö Hard Rock Laboratory, geophysical logging has been performed in the cored borehole KA3191F.

Equipment used in this project was Malå GeoScience Wellmac logging system designed primarily for slimhole logging. Each probe in the Wellmac system is a stand-alone unit, where probes can be combined virtually without restriction.

In this case the resistivity and gamma probe was measured at the same run. Density and susceptibility in a another run. Sonic is not a standard Wellmac probe and cant be combined with Wellmac probes and must therefore be measured in a separate run.

The following logging methods have been used in the KA3191F.

- Gamma
- Density
- Susceptibility
- Single Point Resistivity
- Normal 1.6
- Normal 0.4
- Lateral 1.6/0.1
- Sonic (DT)

Detailed information of these methods is found in MALÅ GeoScience Wellmac technical documentation.

Since the gamma and density measured effect has a statistical influence, the presented logs has been filtered by a weighted average over three measurement stations (station interval 0.1 metres). The filtered value that is obtained is given at the depth that corresponds to the midpoint of the filter at the step in question.

All loggings are presented together with the lithology in *Figure 4-4*. The length along the borehole is given relative to rock surface. The results will be reported later on in a technical note.

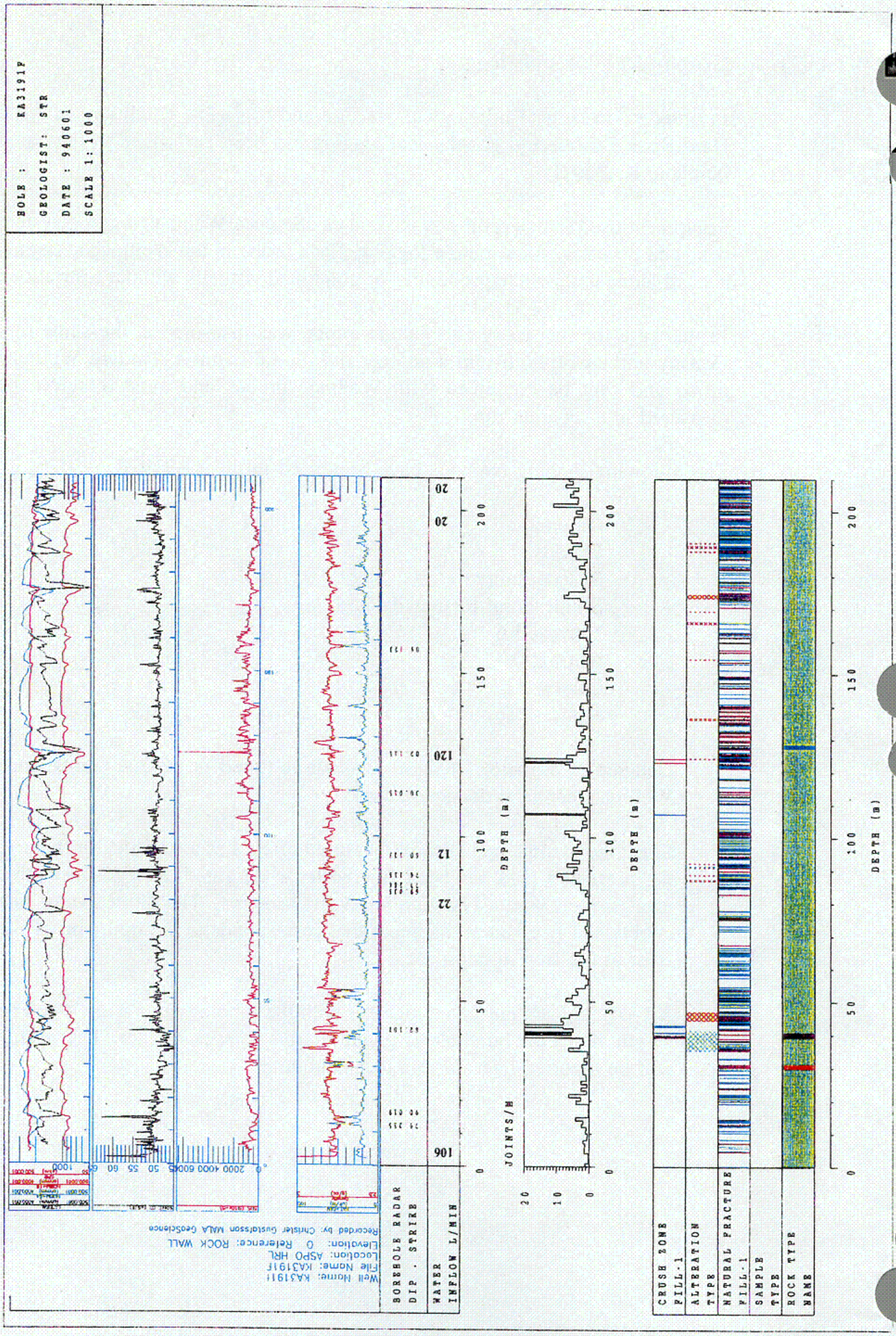

Figure 4-4. *Borehole KA3191F. Lithology and geophysics.* C-05

4.3 GEOHYDROLOGY

The objectives with the geohydrological investigations are 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.

In this article only the transmissivity distribution is presented. The results are presented in *Figure 4-5* and *4-6*.

In *Chapter 3.2.1* the test methodology was outlined. It was not possible to follow the methodology completely during the drilling. The intension was that every 15 m section of the bore was to be tested before any grouting. For section 90 - 135 m the drilling continued until it was decided that it was necessary to grout. Before grouting a pressure build-up test was made in borehole section 90 - 135 m with injection packer equipment. This test failed and therefore the transmissivity for this section is based on specific capacity for the test section and the estimated relation between the specific capacity and transmissivity based on pressure build-up tests in the tunnel section 1475 - 2874 m - *see Figure 4-7*. Possibly the transmissivity in section 90-135 m is in the interval 10^{-5} to 10^{-4} m²/s, which means that the structure can be very transmissive.

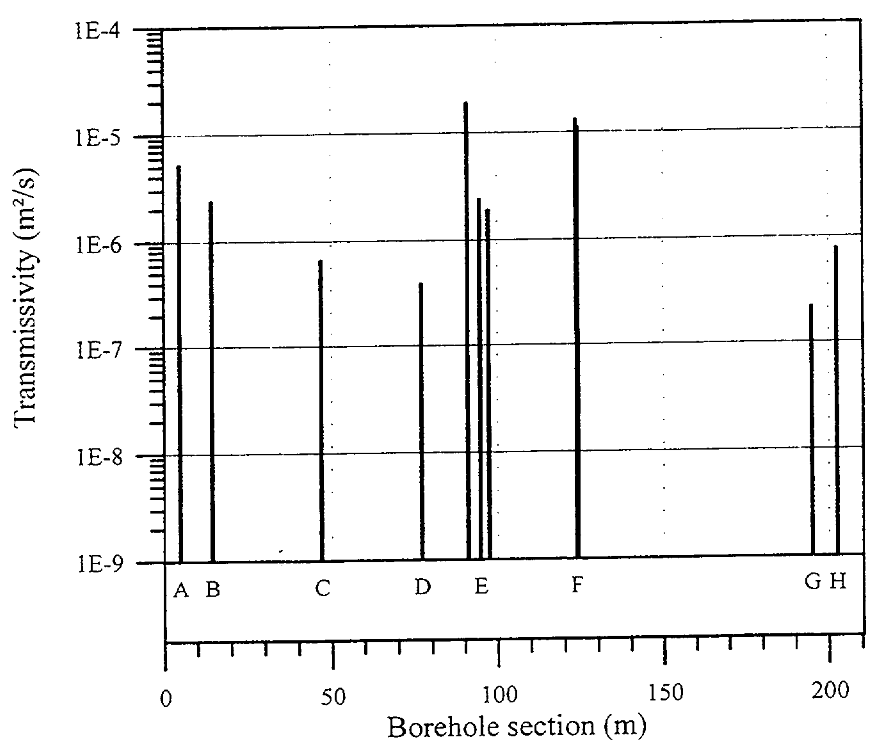

Figure 4-5. *Transmissivity distribution in KA3191F according to flowmeter survey, drilling records and large scale pressure build-up tests. (A, B etc are identified conductors.)*

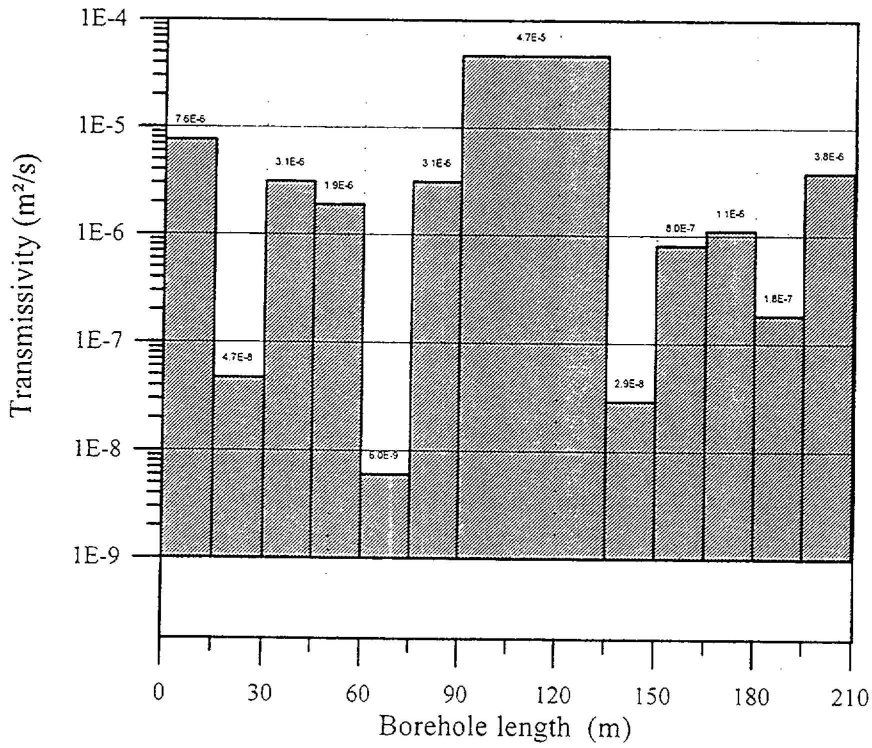

Figure 4-6. *Transmissivity distribution in KA3191F according to pressure build-up tests with test section lengths = 15 m, except for section 90 - 135 m with test section length = 45 m.*

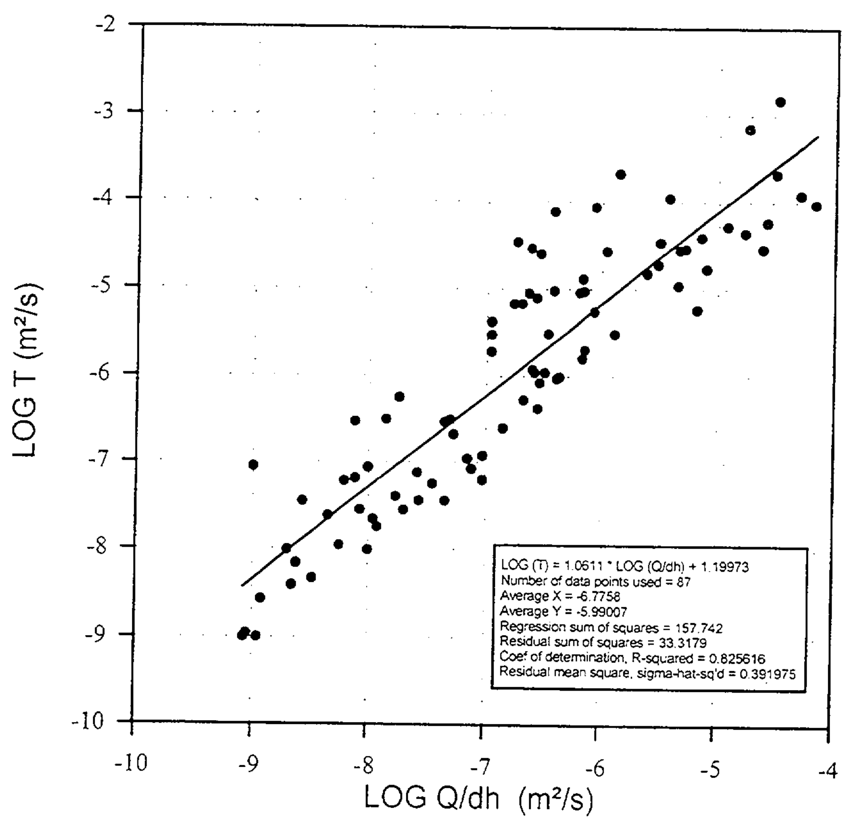

Figure 4-7. *The relation between transmissivity and specific capacity based on data from probeholes in tunnel section 1475 - 2874 m.*

5 FINAL REMARKS

* Characterization work in conjunction with the TBM excavation is planned to have the same ambition as for the drill and blast tunnel. The main difference is that the mapping will probably be carried out in one campaign when the tunnel is finished.

* Investigations in the cored borehole parallel to the planned TBM-tunnel indicate one dominating rock type (Äspö diorite), rather low fracture frequency - except in a few sections - and high RQD (>75) in most of the cores. Water inflows are recorded in same sections. The most conductive parts in the cored borehole are 0-15 m, 90-135, and 195-210 m. The results from the test in section 90-135 m are uncertain but the structure can possibly be very conductive.

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PAPER D:

ZEDEX –
A STUDY OF THE EXCAVATION DISTURBED ZONE FOR TBM AND DRILL & BLAST EXCAVATION

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JUNE 1994

ABSTRACT (English)

A study of the excavation disturbed zone (EDZ) for different excavation techniques will be executed at the Äspö HRL. The study is organized as a joint venture by ANDRA, UK Nirex, and SKB and is named the ZEDEX Project. The main objective is to study the mechanical behavior of the EDZ with respect to its origin, character, magnitude of property change, extent, and its dependance of excavation method. The project will also provide a test of equipment and methodology for quantifying the EDZ. The ZEDEX Project includes tests of "normal" excavation by drill and blast, a smooth blasting procedure based on low shock explosives, and excavation by tunnel boring.

The extent and properties of the EDZ will be quantified by measurements of acceleration, displacement, seismic velocities, natural and induced fracturing, temperature, acoustic energy release, and state of stress. Measurements will be performed before and after excavation in boreholes drilled along the planned excavations. In addition, measurements will be made after excavation in radial boreholes drilled from the two test tunnels. The experiment is expected to improve understanding of the extent and character of the EDZ and its dependance on the method of excavation used.

1 INTRODUCTION

The excavation of a tunnel will cause a disturbance to the rock surrounding the tunnel. The character and the magnitude of the disturbance is due to the existence of the air filled void represented by the tunnel and the method of excavation used to construct the tunnel. The properties of the disturbed zone around excavations is of importance to repository performance in that it may provide a preferential pathway for radionuclide transport or may affect the efficiency of plugs placed to seal drifts. The character and magnitude of the Excavation Disturbed Zone (EDZ) is due to:

- the air filled void represented by the tunnel,
- the method of excavation,
- the value of certain in-situ parameters such as frequency and orientation of discontinuities, rock mass properties, and stress.

To obtain a better understanding of the properties of the disturbed zone and its dependance 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 change in method of excavation used for the Äspö HRL spiral from drill and blast to tunnel boring (TBM) that will take place in June 1994 provides an opportunity to study the effects of different excavation methods on the rock surrounding the tunnel.

The properties of the disturbed zone must be considered in the design of a repository and in the assessment of its long-term safety. In addition, the data collected in drifts will be used for detailed characterization of the repository and hence used in performance assessment. For these reasons it is important to understand how the method of excavation affects the properties and extent of the disturbed zone and the ability to characterize the rock. This knowledge is essential in deciding what excavation method or combination of methods to use for a future repository. The ultimate aim in constructing vaults for the emplacement of radioactive waste is to do it in a manner that ensures that the EDZ does not have a significant impact upon repository performance.

This paper presents a summary of the Test Plan for the ZEDEX Project. The Test Plan is published in the Äspö ICR Report series (SKB, 1994). Field work commenced in May 1994 and results are not yet available.

2 OBJECTIVES

The objectives of the ZEDEX project are:

- to understand the mechanical behavior of the Excavation Disturbed Zone (EDZ) with respect to its origin, character, magnitude of property change, extent, and its dependance 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.

In addition to the objectives, the following success criteria have been defined to qualify the extent to which the objectives will be met

- On time - final report March 1996 or earlier
- On budget - less than 12 MSEK
- We understand the EDZ
- Minimum 3 papers published in scientific journals
- No accidents on-site
- Strengthened relations between the parties of the project

3 EXPERIMENTAL CONCEPTS

3.1 LOCALIZATION OF EXPERIMENT

The test site for a comparative study of excavation disturbance has to be located at the beginning of the planned TBM drift as this is the only place where TBM excavation can be performed at a reasonable costs. This implies that the experimental drifts will be located adjacent to the TBM Assembly Hall (Figure 3-1).

There will be two test drifts, one excavated by drill and blast and one excavated by tunnel boring. The test drifts will be parallel and located approximately 25 m apart. The intention is that the test drifts should be located in relatively homogeneous Äspö diorite so that the geological conditions at the two drifts are similar to facilitate a meaningful comparison. The test drifts will be located at an approximate depth of 420 m below ground surface and the orientation of the drifts will be roughly perpendicular to the main horizontal stress direction.

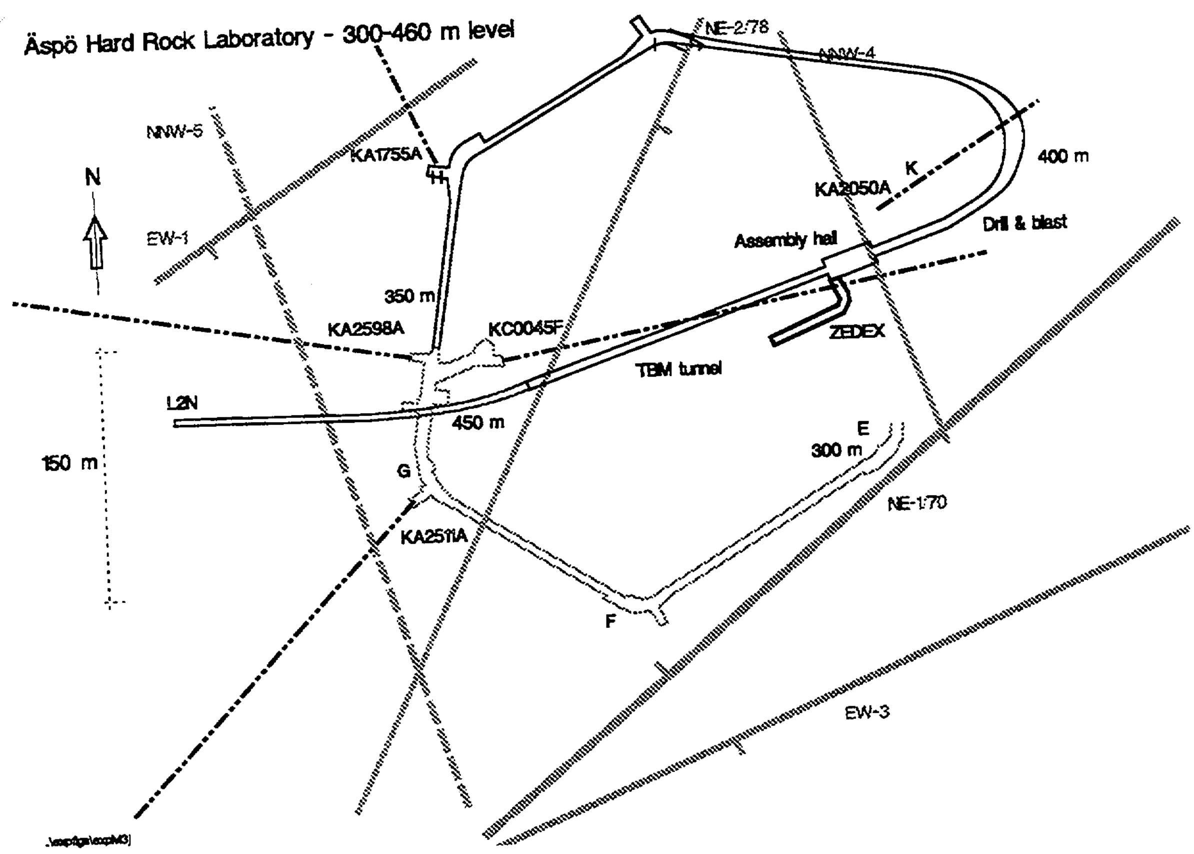

Figure 3-1 The test drifts are located adjacent to the TBM Assembly hall of the Äspö HRL tunnel.

3.2 TESTED HYPOTHESIS

It is assumed that the disturbance to the rock depends on 1) the excavation method used and 2) the combined effects of the existence of a void and the geological and rock mechanical properties of the excavated rock (excavation method independent disturbances). The hypothesis is that near field (< 2 m) disturbance can be reduced by application of an appropriate excavation method (smooth blasting or tunnel boring). It is hoped the test will confirm that smooth blasting limits the extension of the damaged zone without affecting the blast productivity. The hypothesis is that far field disturbance (> 2 m) will be essentially independent of excavation method as it is caused by stress redistributions, discontinuity geometry, and mechanical properties of the rock.

The ZEDEX Project will include tests of the following excavation techniques:

- "normal" blasting, similar to that used for excavation of the Äspö HRL tunnel to a depth of approximately 420 m,

- smooth blasting based on the application of low shock explosives and an optimized drilling pattern, and
- tunnel boring.

The test should determine displacements, micro-crack movements, and geophysical profiles in an EDZ during mine-by, which can then be related to hydraulic conductivity changes.

3.3 CONFIGURATION

The TBM test drift will constitute a part of the main access tunnel of the Äspö HRL and will be located shortly after the TBM Assembly hall. The Drill & Blast test drift will be parallel and located approximately 25 m to the south of the TBM tunnel as shown in Figure 3-2. An access drift (12 in Figure 3-2) will be excavated from the end of the Assembly hall to access the Drill & Blast test drift. The purpose of the first round in the Drill & Blast test drift is to reduce the effects of the anomalous stress field caused by the drilling niches. The next four rounds will be used for testing of a smooth blasting technique based on low-shock explosives, and the following five rounds will be used to study effects of normal blasting.

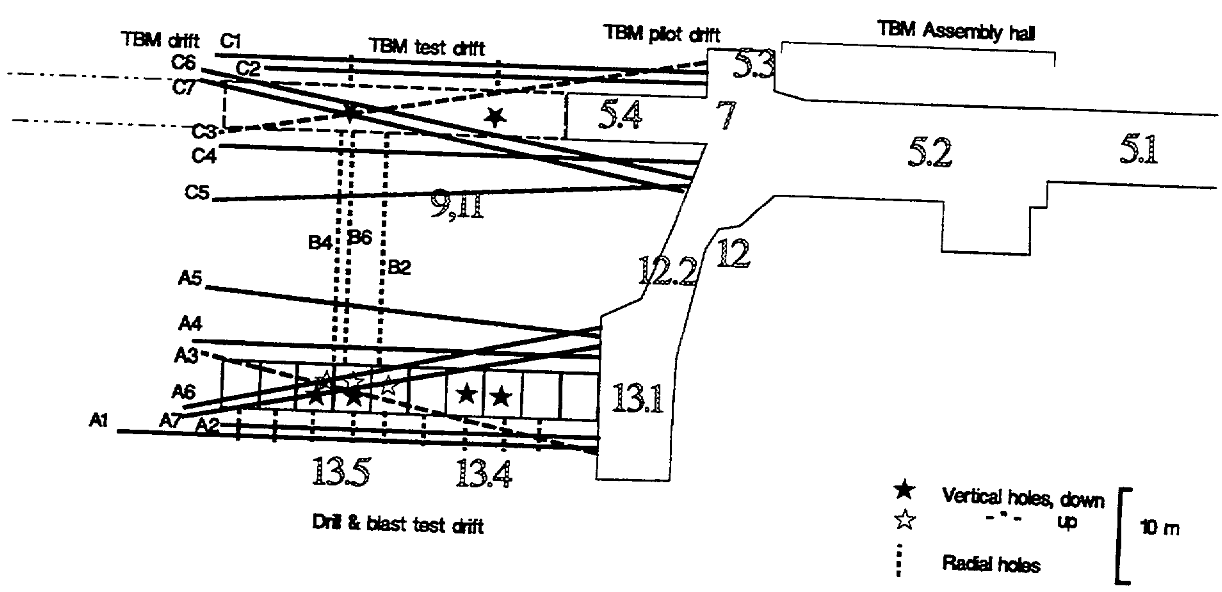

Figure 3-2 Proposed experimental configuration for the ZEDEX project.

The shape of the blasted drift should be rounded (circular with a flat floor) and the diameter of the blasted drift should be about the same as for the TBM drift, i.e. 5 m.

There will a number of boreholes drilled axially and radially relative to the test drifts to assess the properties and extent of the EDZ. The location of the boreholes in plan and vertical section is shown in Figures 3-2 and 3-3, respectively. A borehole for accelerometer measurements (diameter 86 mm) will be drilled parallel to and at a distance of 3 m from each test drift (boreholes A1 and C1, respectively). At each drift, six boreholes (three to the side, one above and two directed below the drift, boreholes A2-7 and C2-7, respectively) with a length of 40-50 m will be drilled to facilitate acoustic emission, directional radar, seismic tomography, and hydraulic conductivity measurements before and after excavation of the drifts.

After excavation of the drifts a number of short (3 m) radial boreholes will be drilled in each drift to assess the extent of the disturbed zone in the near field. There will also be a set of longer boreholes extending radially from the center of the blasted test drift to investigate properties of the disturbed zone at a larger distance from the wall. Three of these holes will drilled from the TBM drift towards the Drill & Blast drift and will be used to measure displacements and changes in rock properties at the Drill & Blast drift before and after excavation.

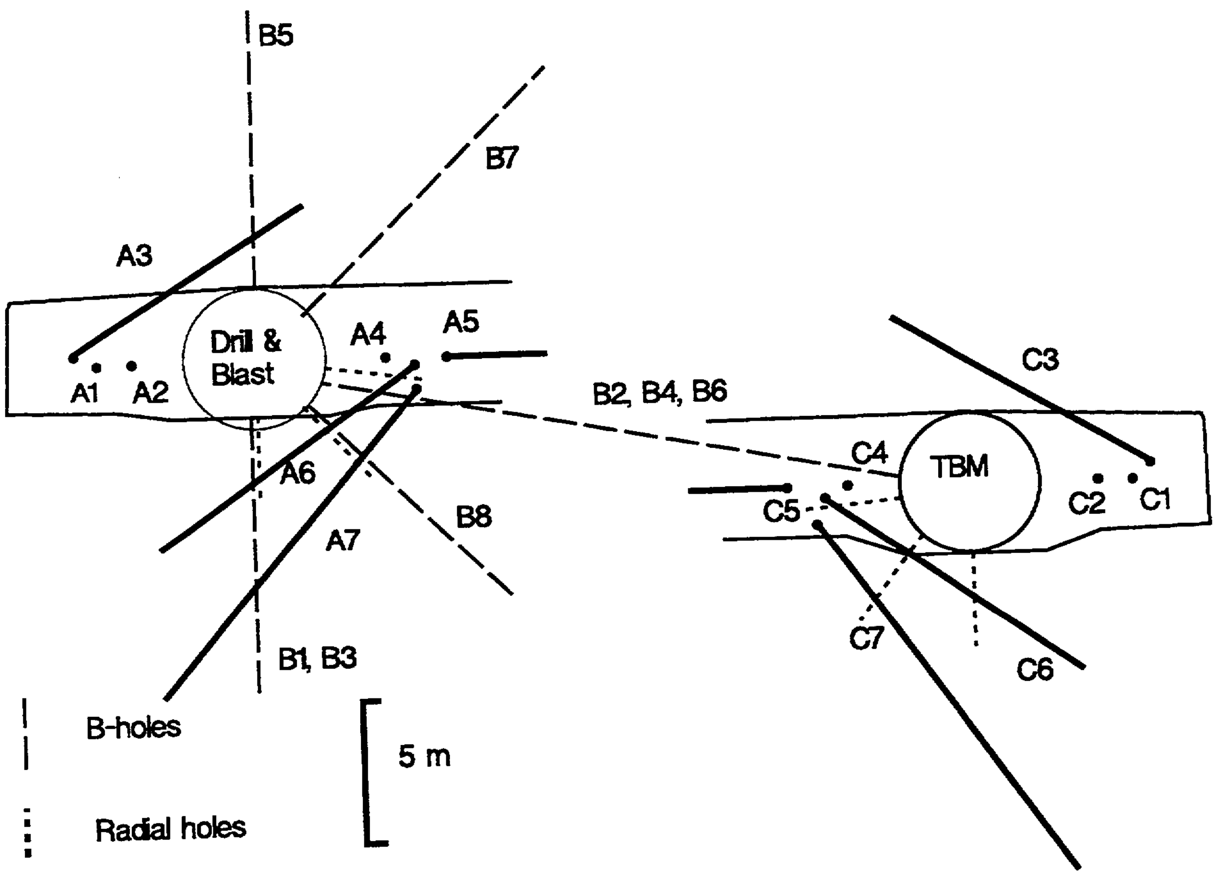

Figure 3-3 Vertical section showing location of boreholes in relation to the test drifts.

3.4 PARAMETERS QUANTIFIED

Excavation disturbance has to be expressed in terms of measurable quantities where "disturbance" is defined as a change in properties from the natural state before excavation. The ZEDEX Project will include quantifying the following parameters:

- acceleration
- displacement
- P-wave velocity
- hydraulic conductivity
- natural and induced fracturing
- temperature
- acoustic energy release
- stress state

The following remote sensing techniques will be applied for characterization of the EDZ:

i) P wave seismic velocity tomography and its variation across the EDZ. Variations of seismic velocity with the direction of wave propagation relates to the preferential directions of open joints.

ii) The attenuation of seismic waves obtained by tomographic techniques for estimating the general effects of stiffness of the joints and/or their aperture, conductive length, and frequency.

iii) Acoustic emission monitoring to detect the location of micro-crack events. This should provide information on the extent of the zone where joint movements occur.

iv) The velocity of electro-magnetic waves (radar) obtained from reflection measurements in the tunnel and boreholes along the tunnel yielding information on the presence and orientation of fractures and on the average water content of a given rock volume.

v) Measurements of acceleration during excavation to estimate the magnitude of force applied to the rock.

Table 3-1 gives a summary of the methods applied within the project, where and when they are applied in relation to excavation of the drifts.

Table 3-1 ZEDEX Project - Investigation summary.

Parameter	Drill & Blast				TBM				When			
	Axial	Long radial	Short radial	Drift	Axial	Long radial	Short radial	Drift	Before	During	After	Dis-tance
Acceleration	A1				C1					X		N
P-wave velocity, acoustic impedance			X				X				X	N
Hydraulic conductivity												
- 3.5 m/1 m sections	A4-5	B2, B4			C4-5	B2,4			X		X	I
- 50 mm sections			X				X				X	N
Displacement												
- MPBX		B5-8				B6			D&B	D&B	D&B	N,I,F
- Convergence pins				X				X		d&b	X	I,N
Fracturing, core and walls												
- natural	A1-7	B1-6			C1-7				X			I,(N)
- induced	x	x	X	X	x	x	X	X	x		X	N
Temperature	A1				C1					X		I
Remote sensing												
- Seismics axial	A4-7				C4-7				X		X	I,F
- Seismics radial		B1-4				B1-4			D&B		X	N,I
- Acoustic emission	A2-4,6				C2-4,6				X	X	X	N,I
- Directional radar	A2,3,6				C2,3,6				X			I,F
- Tunnel radar				X				X			X	I,N
Stress									X			F

X=both drifts or all holes
D&B, TBM=data from specified drift only
(lower case indicates limited data obtained)

N=near drift wall
I=intermediate distance from drift wall
F=far from drift wall

3.5 EXPECTED OUTCOME OF EXPERIMENT

The experiment is expected to improve understanding of the extent and character of the EDZ and its dependance on the method of excavation used. Specifically, the experiment is expected to provide information on the following items:

- Mechanical damage to the rock for the excavation methods used, this includes crushing of rock (at blast holes or at TBM grippers) and induced fracturing, both on macro and micro scale.
- The magnitude of force (vibrations) applied to the rock mass during excavation.
- Comparison of quality and information content obtained from geological mapping (number of fractures, fracture characteristics) for the two excavation methods.
- Magnitude of excavation disturbance as a function of distance from drift perimeter measured in terms of fracture frequency (induced fractures), micro fracturing, acoustic emissions, radar and seismic velocities, temperature changes, and hydraulic conductivity.
- Character of tunnel inflow for the two excavation methods (channeling etc.).
- A test of a system for measuring the total extent of the EDZ by using geophysical techniques and rock mechanics assessment in order to quantify parameters on the configuration of the damaged zone required for safety assessment.
- A basis for selection of optimized methods of excavation.

4 PROJECT ORGANIZATION AND SCHEDULE

4.1 PROJECT ORGANIZATION

The project is controlled by a Steering Committee with one member from each participating organization. The members of the Steering Committee are:

- Andre Cournut, ANDRA

- David Mellor, UK Nirex
- Göran Bäckblom, SKB

The project is run by a Project Manager who reports to the Steering Committee. The Project Manager is Olle Olsson.

The Project Manager is assisted by technical experts from ANDRA (Karim Ben Slimane) and UK Nirex (Nick Davies) who are responsible the technical contributions by their respective organizations.

Gunnar Ramqvist acts as On-Site Coordinator with responsibility to coordinate on-site activities.

Mats Ohlsson acts as Data Manager with responsibility to file data collected in the Äspö HRL Project database.

4.2 TIME SCHEDULE

The in-situ tests should according to current schedule for excavation take place during the period May 1994-March 1995. Test in the TBM test drift are expected to be completed in October 1994. Tests in the Drill & Blast test drift are expected to begin early November 1994.

Integrated analysis of results will commence in September 1994 and is expected to be completed in December 1995.

The final report will be completed in March 1996.

REFERENCES

SKB, 1994. Test plan for ZEDEX - Zone of Excavation Disturbance Experiment, Release 1.0. Äspö ICR 94-02, SKB, Stockholm, Sweden.

PAPER E:

THE YUCCA MOUNTAIN EXPLORATORY STUDIES FACILITY TESTING IN CONJUNCTION WITH TUNNEL BORING MACHINE OPERATIONS

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JUNE 1994

ABSTRACT

A general description from the testing perspective of the Yucca Mountain underground Exploratory Studies Facility (ESF) being constructed in Nevada as a part of the United States High-Level Nuclear Waste Repository Site Characterization Program is presented. The facility construction sequence using Tunnel Boring Machine (TBM) excavators is being optimized to allow site characterization of the potential repository block for a Site Suitability determination and possibly a License Application. The test program that is fielded in conjunction with TBM operations will also collect site characterization and geotechnical information which may be used for construction, facility design and long-term monitoring.

Key Words: ESF Testing, Yucca Mountain, Tunnel Boring Machine, Exploratory Studies Facility

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TITLE: THE YUCCA MOUNTAIN EXPLORATORY STUDIES FACILITY TESTING IN CONJUNCTION WITH TUNNEL BORING MACHINE OPERATIONS

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SUMMARY

The design, construction, and site characterization strategies for the underground facility to be constructed at the United States potential High-Level Nuclear Waste Repository Site have evolved significantly during the last fifteen years. The site is located in southern Nevada in volcanic tuff under a ridge called Yucca Mountain. The design of the underground ESF facility is being developed in segments (packages) allowing flexibility to respond to conditions discovered as construction proceeds and to optimize the facility's ability to support testing activities. The prime construction methodology is based on the use of Tunnel Boring Machine (TBM) excavators. The testing program being implemented as construction proceeds includes efforts to collect information related to the site geology and characteristics, specific information related to site geohydrology and geochemistry, and the thermal and mechanical rock properties of the site that may change as a result of facility construction at potential repository operations. Geotechnical information to aid the design/construction team in their selection of the type of ground support necessary to provide the required worker safety and tunnel stability is collected as a part of testing field work.

1. INTRODUCTION

The Exploratory Studies Facility (ESF) is intended to provide underground access to the potential repository horizon (the Topopah Spring Welded Tuff formation) and a lower level, the nonwelded bedded tuffs of the Calico Hills. An "underground laboratory" will be developed in which a wide variety of tests will be performed. During facility construction, a subset of construction phase tests will be implemented to collect data that support site suitability determination and establish a baseline data set for the underground facility, and potential repository system.

2. FACILITY DESCRIPTION

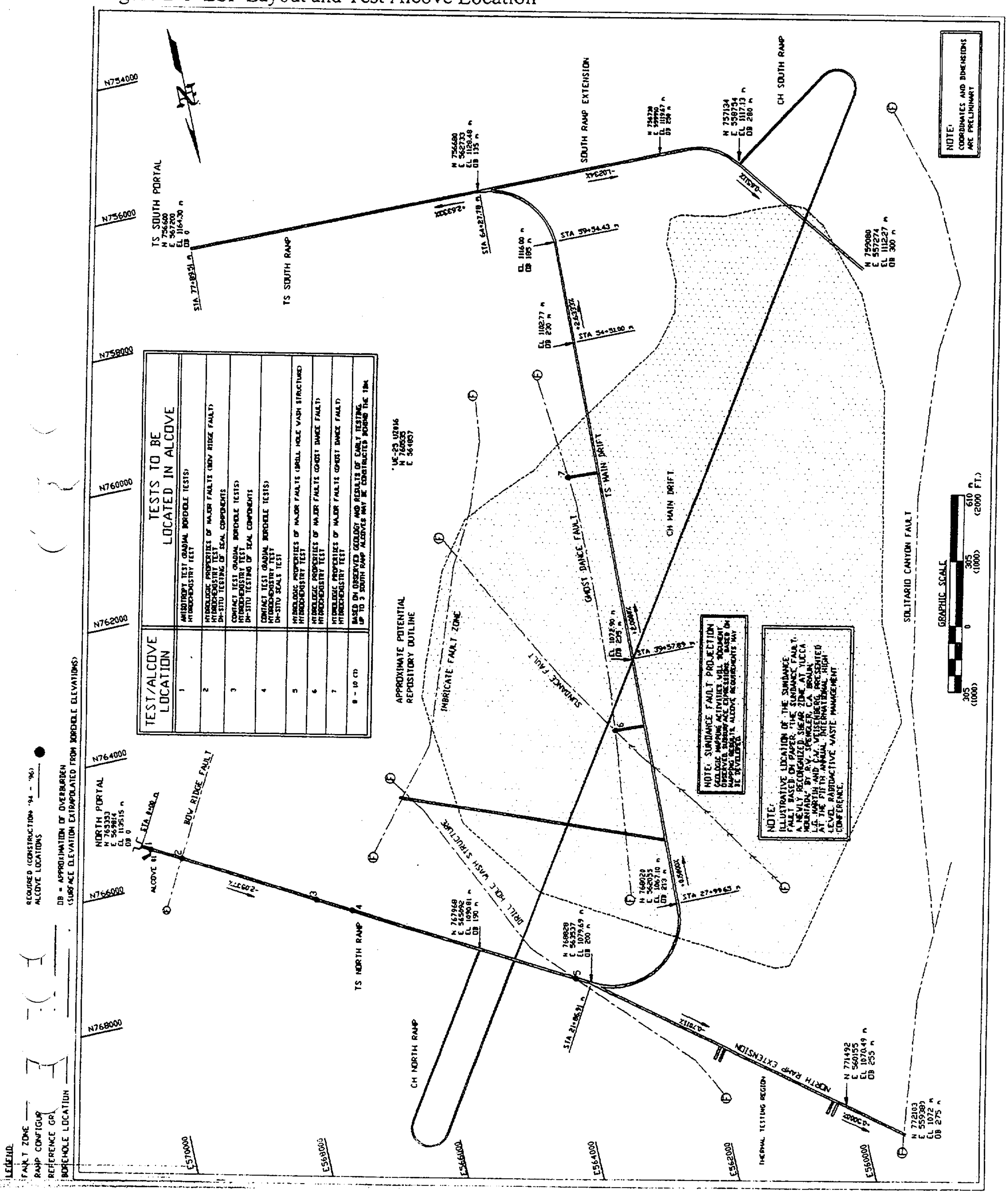
The facility will consist of two main access ramps from the surface ("North" and "South") at either end of a 3.2 kilometers (2 miles) long main tunnel running roughly north-south in the potential repository level, the Topopah Spring level (TSL). Two additional smaller diameter ramps are planned to extend from the main ramps to either end of a second generally north-south tunnel in a lower level, the Calico Hills level (CHL). Various side drifts will be driven to provide access to fault zones and other potential areas of interest. Twenty-five thousand six hundred (25,600) meters (84,000 feet) of tunnel will be excavated, resulting in approximately 1,910,000 tonnes (2,100,000 tons) of excavated rock. The general layout of the facility is shown in Figure 2-1.

Mechanical excavation methods will be used whenever possible with conventional (drill & blast) excavation being used only when necessary. In the upper level, the rock is fairly hard; 155 megapascals (mPa) (22,500 pounds per square inch [psi]) compressive strength (For comparison, normal concrete is about 28 mPa [4,000 psi]). A 7.6 meter (25 ft.) diameter tunnel boring machine (TBM) will be employed to excavate this material in the main ramps and drifts. Side tunnels on the upper level will likely be excavated by a second smaller diameter TBM. The Calico Hills level rock is much softer, and can be mechanically excavated by several different types of machines. Alcoves and refuge chambers off the ramps, main, and ramp extension drifts can be excavated using either conventional (drill & blast) or mechanical excavation methods.

Surface facilities will be built in three primary areas. The north portal area will consist of a 4.9 hectare (12 acre) pad with the primary office/warehouse complex, data acquisition system building, visitor center, portal control building, and electrical substation. The south portal will have a 2 hectare (five acre) pad with the primary ventilation fan installation and several smaller structures. The optional shaft area, if constructed, will consist of a one hectare (two acre) pad, hoist and headframe, and minimal administrative/maintenance buildings.

The total construction time from the start of site preparation to the completion of all excavation is currently expected to be seven years. This time span is based on current anticipated funding levels and assumes that all currently planned basic and optional facilities are built.

Figure 2-1 ESF Layout and Test Alcove Location



3. CONSTRUCTION SEQUENCE/EXCAVATED VOLUMES (PLANNED)

Tunneling has begun at the North Portal and will proceed down the North Ramp to the Topopah Spring level, along the main Topopah Spring level drift, and up the South Ramp, breaking out on the surface at the South Portal. This first effort, called "the loop":

- Covers a distance of approximately eight kilometers.
- Will provide a good first look at the Topopah Spring level (potential repository horizon).
- Will provide two separate paths of access to the underground facility.

Upon completion of the loop, excavation will begin on the ramp extension drifts, and the lateral tunneling on the Topopah Spring level . Under current plans, when all excavation is complete on the Topopah Spring level, the South Ramp to the Calico Hills level will be started. Similar to the Topopah Spring level loop, this excavation will proceed down the South Ramp, along the Calico Hills level main drift, and up the Calico Hills North Ramp, connecting into the Topopah Spring North Ramp. Side tunneling in the Calico Hills level will be completed after the Calico Hills loop is completed.

Scientific testing will be performed on a limited basis from the start of tunneling operations, and will expand after the completion of the initial loop and ramp extensions. Table 3-1 summarizes the estimated lengths and volumes of planned Exploratory Studies Facility drifting.

TABLE 3-1

COMPONENT	LENGTH (METERS)	GRADIENT (%)	VOLUME (CUBIC METERS)	DRIFT CONFIGURATION (METERS)
NORTH RAMP, SURFACE TO TSL	2,800	-2.05	127,693	7.62 ROUND
SOUTH RAMP, SURFACE TO TSL	1,835	-2.63	83,685	7.62 ROUND
NORTH RAMP TO CALICO HILLS	2,295	-10/-6	54,257	5.49 ROUND
SOUTH RAMP TO CALICO HILLS	1,805	-10/-6	42,673	5.49 ROUND
TSL MAIN DRIFT	3,155	+0.5/+2.0/+2.63	143,883	7.62 ROUND
TSL NORTH RAMP EXTENSION	1,615	-1.0/+0.5	73,652	7.62 ROUND
TSL SOUTH RAMP EXTENSION	2,005	-0.89/-0.77	91,438	7.62 ROUND
TSL IMBRICATE DRIFT	1,275	N/A	30,143	5.49 ROUND
TSL GHOST DANCE DRIFTS (2)	420	+0.5	9,365	3.7 x 6.1
MAIN TEST AREA	2,865	N/A	63,882	3.7 x 6.1
CH MAIN DRIFT	3,415	+3.8	80,736	5.49 ROUND
CH EAST GHOST DANCE DRIFT	465	+0.5	6,221	2.7 x 4.9
CH WEST GHOST DANCE DRIFT	330	+0.5	4,415	2.7 x 4.9
CH IMBRICATE DRIFT	655	+0.5	8,763	2.7 x 4.9
CH SOLITARIO DRIFT	670	+8.75/0	8,964	2.7 x 4.9
TOTALS	25,605	N/A	829,770	N/A

4. CONSTRUCTION PHASE TESTS AND SAMPLING PROGRAM

The testing program being implemented as construction proceeds includes efforts to collect information related to the site general rock type and geologic characteristics, specific information related to site geohydrology and geochemistry, and the thermal and mechanical rock properties of the site that may change as a result of facility construction and potential repository operations. Four test activities are implemented in conjunction with the TBM advance (Geologic Mapping, Perched Water Testing, Consolidated Sampling, and Construction Monitoring). Other tests identified in Table 4-1 are implemented as alcoves are constructed behind the TBM trailing gear.

TABLE 4-1

TEST/ALCOVE LOCATION	TESTS TO BE LOCATED IN ALCOVE
1	ANISOTROPY TEST (RADIAL BOREHOLE TESTS) HYDROCHEMISTRY TEST
2	HYDROLOGIC PROPERTIES OF MAJOR FAULTS (BOW RIDGE FAULT) HYDROCHEMISTRY TEST IN-SITU TESTING OF SEAL COMPONENTS
3	CONTACT TEST (RADIAL BOREHOLE TESTS) HYDROCHEMISTRY TEST IN-SITU SEALS TEST
4	CONTACT TEST (RADIAL BOREHOLE TESTS) HYDROCHEMISTRY TEST IN-SITU SEALS TEST
5	HYDROLOGIC PROPERTIES OF MAJOR FAULTS (DRILL HOLE WASH FAULT) HYDROCHEMISTRY TEST
6	HYDROLOGIC PROPERTIES OF MAJOR FAULTS (GHOST DANCE FAULT) HYDROCHEMISTRY TEST
7	HYDROLOGIC PROPERTIES OF MAJOR FAULTS (GHOST DANCE FAULT) HYDROCHEMISTRY TEST
8 - 10	BASED ON OBSERVED GEOLOGY AND RESULTS OF EARLY TESTING, UP TO 3 SOUTH RAMP ALCOVES MAY BE CONSTRUCTED BEHIND THE TBM.

4.1 GEOLOGIC MAPPING (ROCK CHARACTERIZATION PROGRAM)

Geologic mapping and photogrammetry are used to document lithologic and fracture variability throughout the vertical and horizontal extent of all ramps, drifts and alcoves, to investigate structural features, and to provide siting data to confirm (or modify) planned test locations. Activities are conducted from a mapping gantry deployed as a part of the TBM trailing gear during the daily TBM maintenance shift. Data sets include stereo photogrammetry, line surveys, and geologic assessments.

4.2 CONSOLIDATED SAMPLING/PERCHED WATER (GEOHYDROLOGY AND GEOCHEMISTRY PROGRAM)

Rock samples for analyses will be collected from all ramps, drifts, and alcoves by USGS/USBR geologic mappers under their consolidated sampling role in support of other site characterization efforts. Sampling activities are conducted from the mapping gantry and behind the trailing gear based on criteria provided by other researchers.

If perched water or zones of saturation are detected, measurements will be made to delineate the lateral and vertical extent of perched water zones, to identify perching mechanism(s), and to sample perched water for chemical analyses. Because there is significant uncertainty regarding the likelihood of encountering perched water, this test is categorized as a "contingency test."

4.3 CONSTRUCTION MONITORING (THERMAL AND MECHANICAL ROCK PROPERTIES PROGRAM)

This test consists of three activities, evaluation of mining methods (to monitor and evaluate excavation methods and rock responses), monitoring of ground support systems (to develop recommendations for repository ground support systems in drifts), and monitoring drift stability (to monitor drift convergence using multi-point borehole extensometers and borehole pressure cells). The thermal rock properties program is not a construction phase activity and not addressed in this paper.

5. CONSTRUCTION-RELATED GEOLOGICAL/GEOTECHNICAL DATA COLLECTION

As the TBM excavation proceeds, data is collected by members of the Site Characterization scientific team during each shift at the TBM tail shield and supplemental ground support installation deck for evaluation by the facility Constructor/Designer to allow selection of the rock support system. The data also provides a mechanism for the Constructor/Designer to verify that the installation specifications have been met. Instrumentation is installed and monitored to evaluate the excavation and tunnel support systems performance, and establish the necessary maintenance schedule. The "As-Built" geotechnical data and information allows the Constructor/Designer to prepare permanent records on the geotechnical conditions and rock support system to meet potential repository access design requirements.

6. CONCLUSIONS

A mixture of TBM mechanical excavation and, when necessary, drill & blast excavation will allow the development of an "Underground Laboratory" at the Yucca Mountain Site Characterization Project ESF that meets site characterization testing requirements. Test results that are of use to the constructor and designer of the facility are shared real time as construction proceeds. The phased approach to facility design has advantages in that information gained during construction, both by the constructor and the testing organizations, feeds the next design phase to maintain maximum flexibility and construction efficiency.

The ESF test program provides three key objectives:

- Initial site characterization supporting a suitability determination of the Yucca Mountain site as a high-level nuclear waste repository.
- An extensive, engineering-oriented test program to support potential repository design and regulatory license application, if the site is deemed suitable.
- An ongoing, real time geotechnical data base provided to ESF designers and constructors to enhance facility operability/constructability and support phased facility design.

7. ACKNOWLEDGMENTS

This paper was prepared by the Exploratory Studies Facility Test Coordination Office Staff in support of the Swedish/United States International Agreement and the Yucca Mountain Site Characterization Office as a part of the Civilian Radioactive Waste Management Program.

PAPER F:

BORING OF FULL-SCALE DEPOSITION HOLES IN THE TVO-RESEARCH TUNNEL

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JUNE 1994

ABSTRACT

The excavation of deposition holes has been one of the key topics for repository technology development. A project was set up by TVO (Teollisuuden Voima OY) and SKB (Svensk Kärnbränslehantering AB) in co-operation to carry out an boring experiment to study the feasibility of the fullface blind boring technique to produce a better basis for the future development and performance evaluation. The novel boring technique chosen for the boring the full-scale deposition holes was based on rotary crushing of rock and removal of muck by vacuum flushing through the drill string. During the boring certain testing procedures were carried out in order to find out the effect of changes in operating parameters to the performance of the boring machine and the quality of the hole.

The research, reporting and analysis of the results of the study is still in progress but some preliminary results can be presented. The study proved that deposition holes can be bored effectively using a boring machine which is based on full face rotary crushing and removal of muck by direct air vacuum suction from the bottom of the hole.

Comprehensive characterization of the rock around the holes started before the boring of the full-scale deposition holes and will continue further on. One aim of the characterization study is to evaluate the suitability of existing investigation methods for the characterization of the near field. Another aim is to study both mechanical and hydrological impact on the nearfield caused by the boring of the hole. The results indicate among other things that there appears to be a distinct skin over the mantle of the Research Tunnel and no such more conductive disturbed zone below the tunnel floor as assumed in the TVO-92 safety analysis has been revealed so far.

Keywords: Shaft boring, rotary boring, full face boring, rock characterization

1 INTRODUCTION

According to the preliminary design for the final repository for the spent fuel from the Olkiluoto nuclear power plant, the repository is excavated at a depth of 300-800 m in the bedrock and the encapsulated spent fuel is emplaced in 1200 holes in the tunnel floor

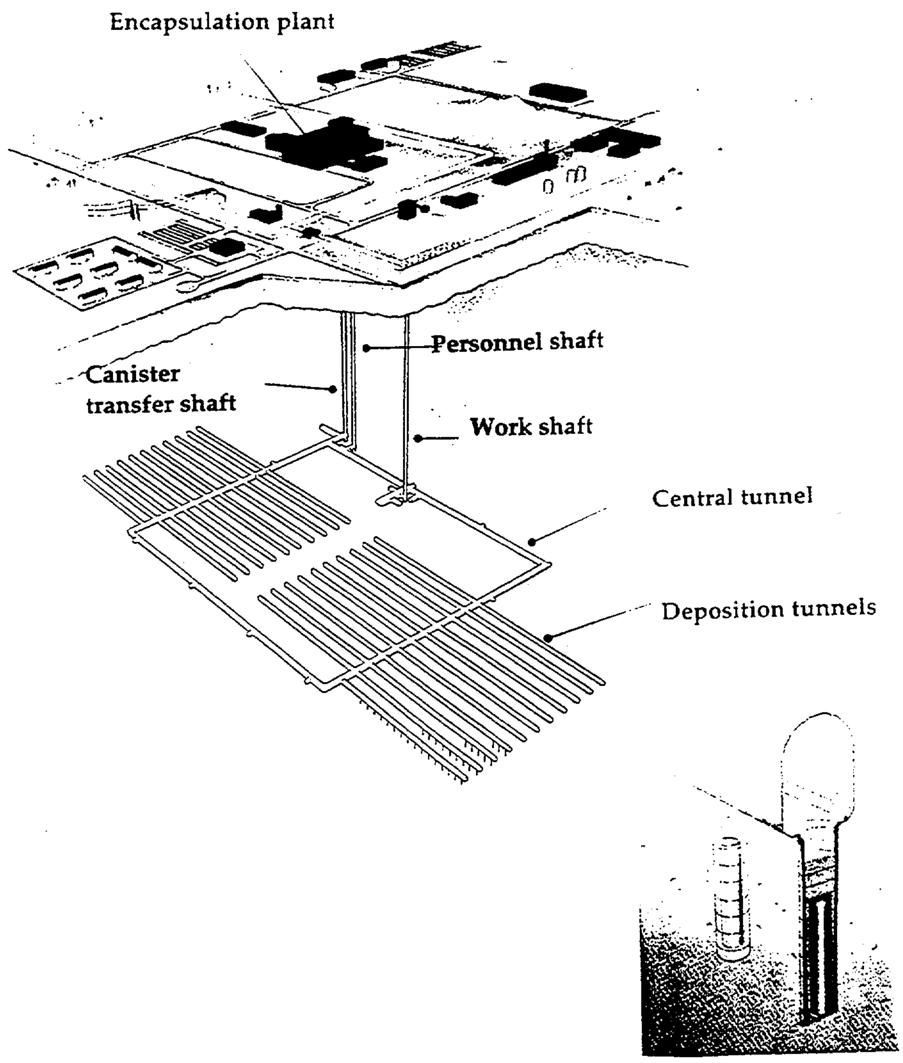

Figure 1-1. TVO preliminary design for the final repository for the spent nuclear fuel.

The excavation of deposition holes has been one of the key topics for repository technology development. The quality of the hole has an impact on the long term safety of the disposal and the excavation of large number of holes from a small tunnel at a considerable depth in very sensitive and remote tunnel system is a very challenging work in technical sense.

There are alternative ways to make such 1.5 m wide and 7.5 m deep deposition holes of which the fullface boring technique was assessed to be most potential method. After a preliminary study and a review with different manufacturers and contractors a conclusion was drawn that a boring machine suitable for boring and based principally on existing proven technique could be developed and constructed.

A project was set up by TVO (Teollisuuden Voima OY) and SKB (Svensk Kärnbränslehantering AB) in co-operation to carry out an boring experiment to study the feasibility of the full face blind boring technique to produce a better basis for the future development and performance evaluation. Drillcon Contracting AB was chosen to carry out the boring work in practise.

The boring experiment was carried out in VLJ-repository which was built for the final disposal of operating waste produced by Teollisuuden Voima OY. It was taken into operation in 1992 at Olkiluoto commune in municipality of Eurajoki, near Pori on the southwest coast of Finland. The repository is located in nuclear power plant area 60 meters deep in the crystalline bedrock. The TVO-Research Tunnel is located in the repository at 60 m level.

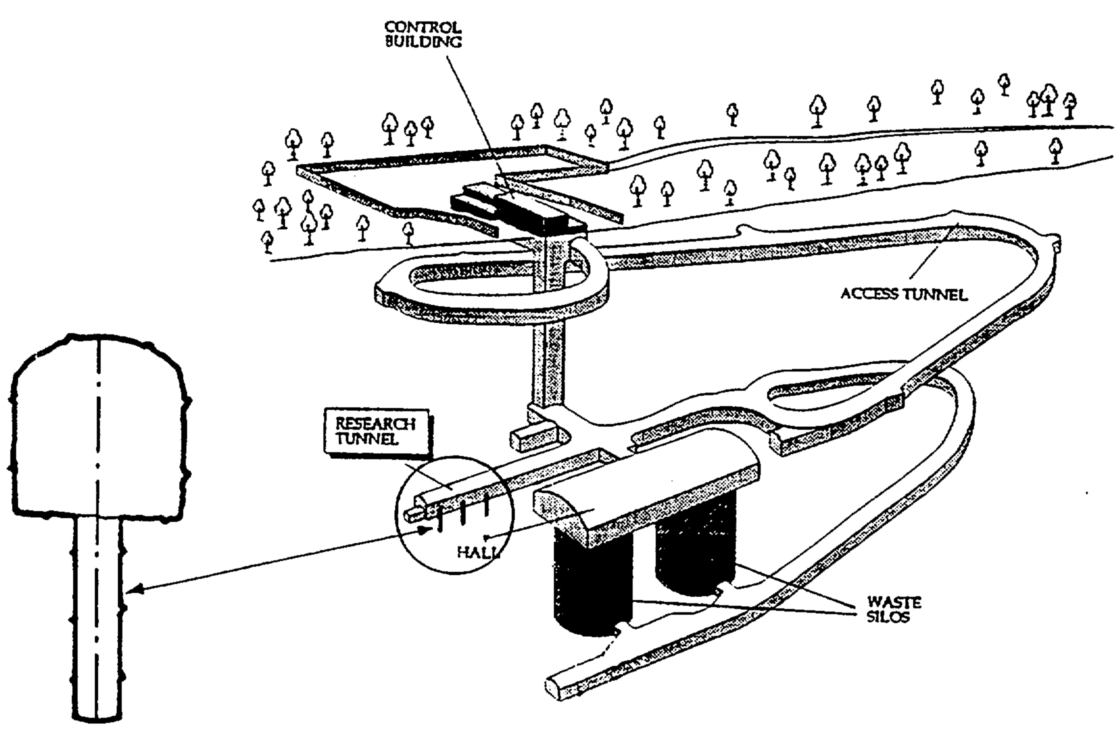

Figure 1-2. The VLJ-repository and TVO- Research Tunnel.

2 GEOLOGY OF THE RESEARCH TUNNEL

The VLJ repository has been excavated in an east-west striking tonalite formation surrounded by mica gneiss. The rock types found in the Research Tunnel are gneissic tonalite and pegmatite. Tonalite is usually slightly foliated, medium grained, massive and sparsely fractured. Besides gneissic tonalite, a fine grained, isotropic tonalite variant is met. Pegmatite is non-foliated, coarse grained, massive and sparsely fractured.

Several structural zones of different types were discovered during field investigations. The main structures are a 5-8 meters thick pegmatite vein (structure RE), which cuts the Research Tunnel, another pegmatite vein (structure RF) situated under the tunnel, and a fracture set called RV1.

The average DRI-value which describes the drillability of the rock is 53 for tonalite, which is the main rock type and 49.5 for pegmatite.

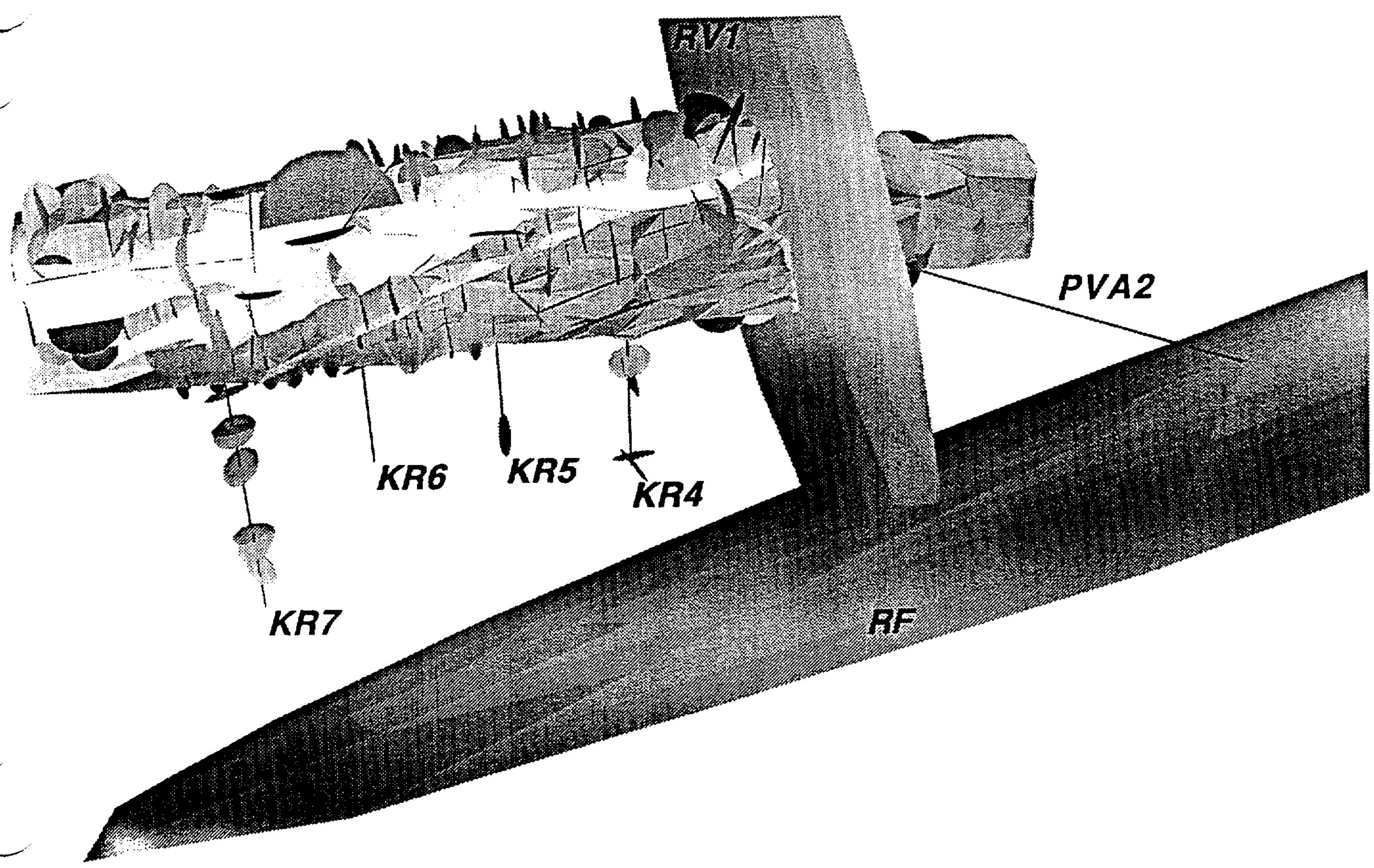

Figure 2-1. 3-D model of the TVO-Research Tunnel.

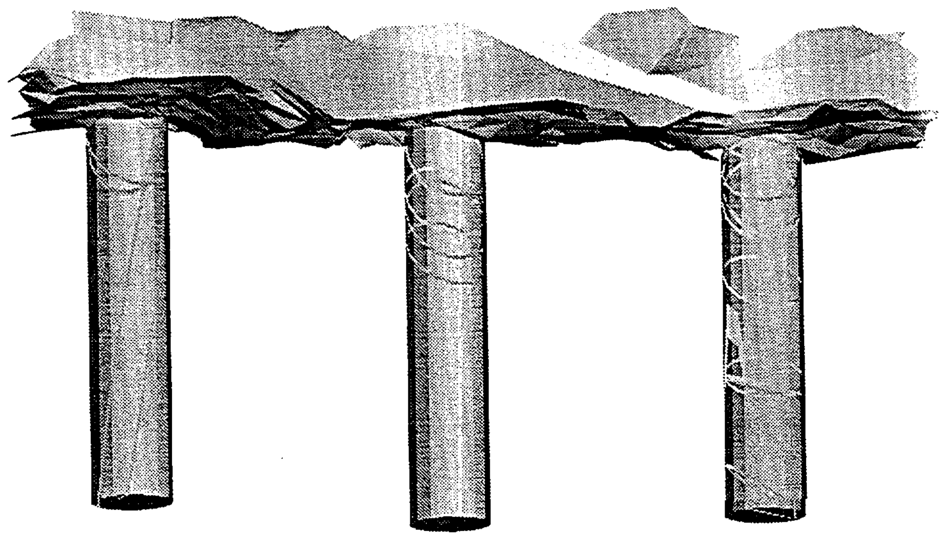

Figure 2-1. Model of the large holes showing the fractures.

The samples of anisotropic tonalite show clearly lower values of Young's modulus and strength values than those of isotropic tonalite. The average Young's modulus of anisotropic tonalite is 57 GPa and for isotropic tonalite 66 GPa and the average compressive strength is 75 MPa and 112 MPa, respectively. The average tensile strength of anisotropic tonalite is 7.1 MPa, whereas the tensile strength of anisotropic tonalite is 10.1 MPa.

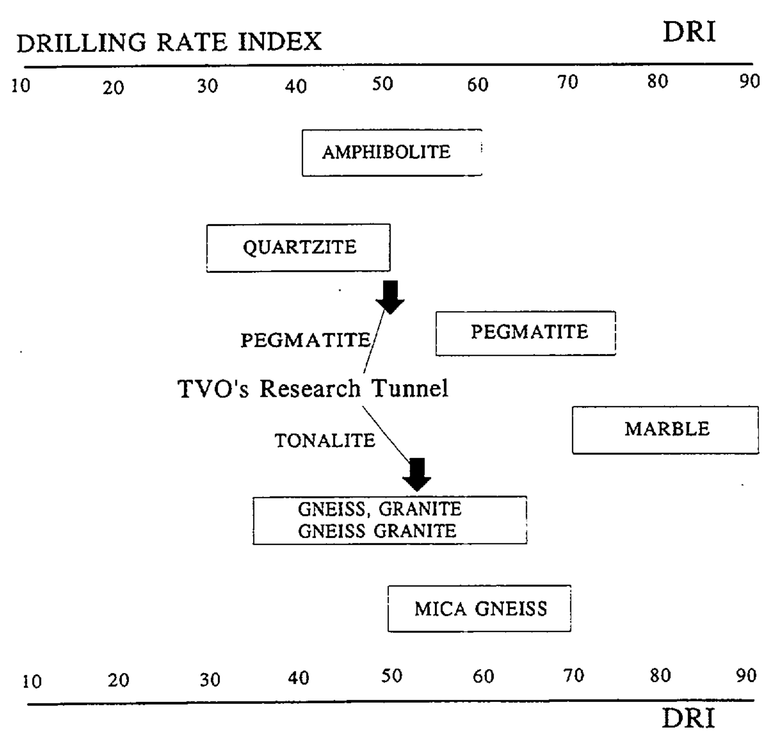

Figure 2-2. DRI-values for drillability.

3 DEPOSITION HOLE BORING TECHNIQUE

The boring technique for boring the full-scale deposition holes was based on rotary crushing of rock and removal of muck by vacuum flushing through the drillstring. The boring equipment was composed of a raiseboring machine, frame, drillstring, cutterhead and vacuumsuction system.

The raiseboring machine which was used to create the torque and thrust necessary for the cutting was an old smaller size standard machine with a maximum thrust of 50-60 tonnes. The machine was lifted on a frame so that it was possible to lift up the cutterhead for inspection, maintenance and transfer.

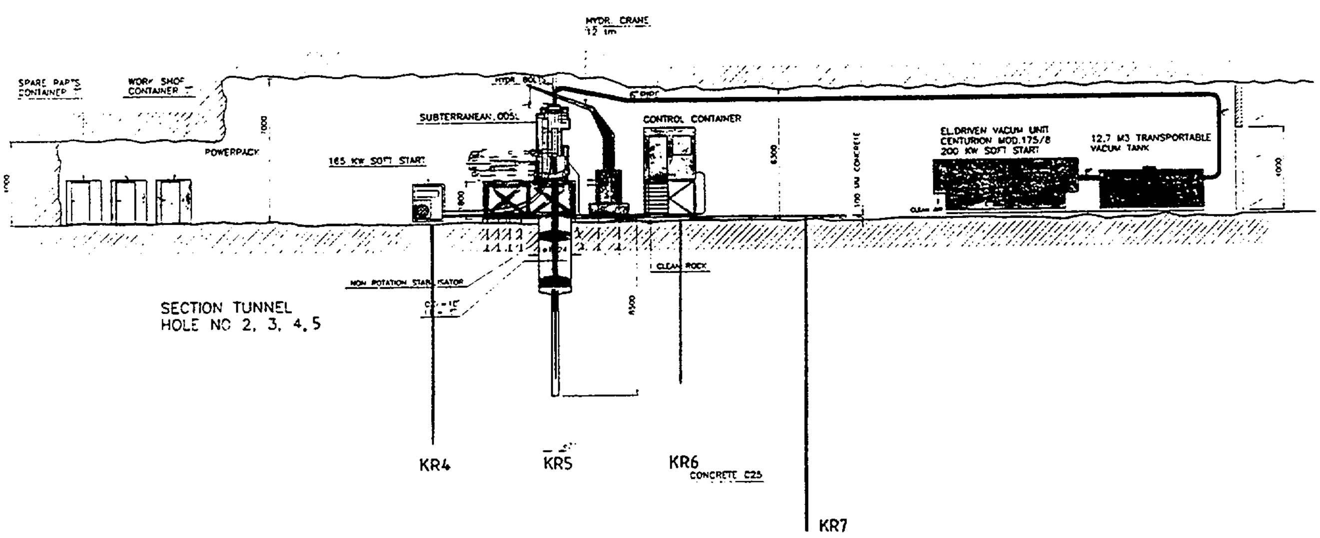

Figure 3-1. The deposition hole boring equipment.

The cutterhead was a used Sandvik CBH-5 blind hole head designed for boxhole boring with a hole diameter of 1524 mm. The head was furnished with 8 roller button cutters of type Sandvik CMR and 4 gauge rollers. A combination of both 5 and 6 row cutters and 4 and 5 row cutters was used. A Sandvik Coromant roller pilot bit with a diameter of 311 mm was used for drilling a pilot hole and for quiding the cutter head.

Two nozzles, which were located in the cutter head between the cutters, were used to suck up the muck. The muck was sucked through the cutterhead and drillstring to the suction line which was composed of transport pipes, muck tank and vacuum unit. An extra sampling arrangement was added occasionally for taking muck samples.

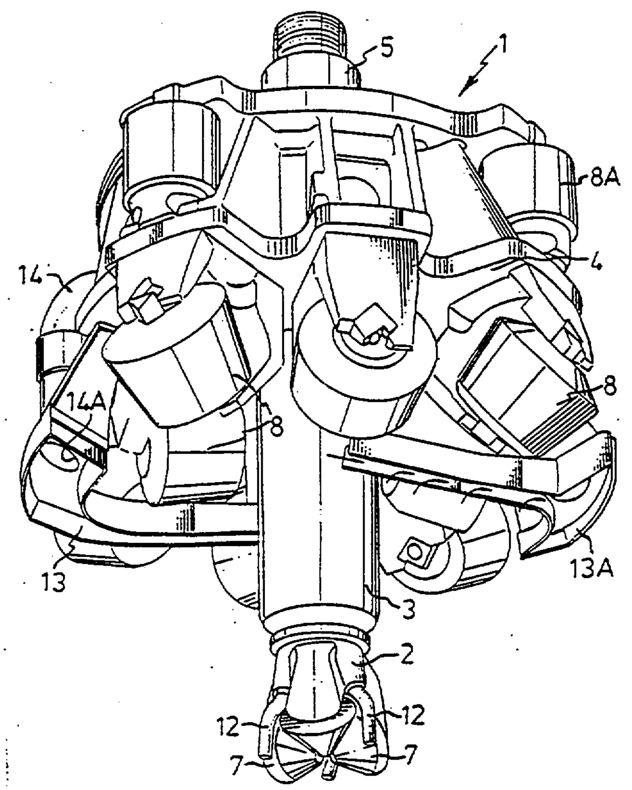

Figure 3-2. The cutterhead.

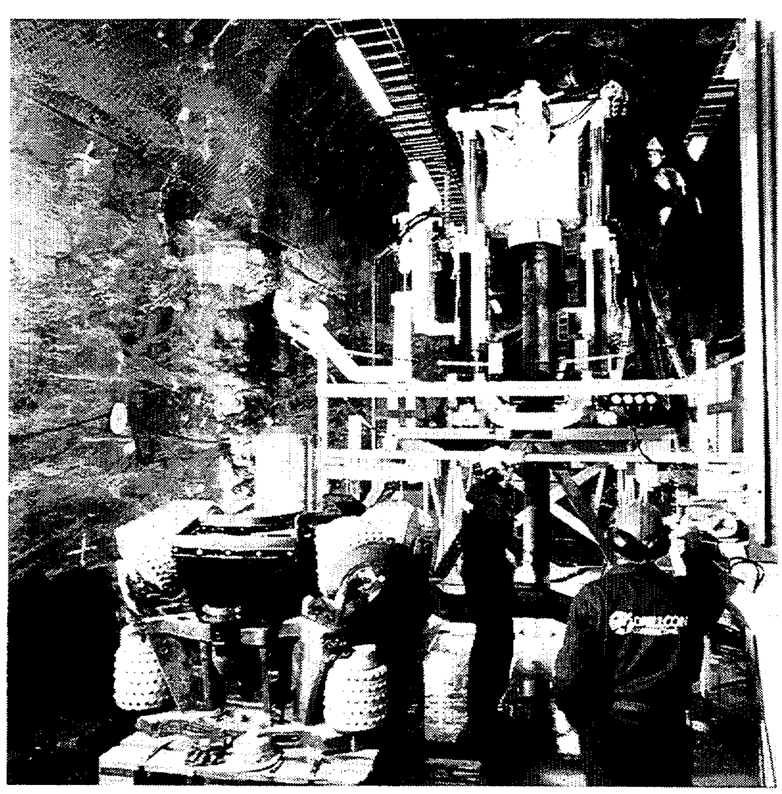

Figure 3-3. The set up of the deposition hole boring machine.

4 TEST PROGRAM

The work included boring of three holes of depth 7.5 m and the exact diameter of the hole was adjusted to the size of the available cutterhead being 1524 mm. During the boring certain testing procedures were carried out in order to find out the effect of changes in operating parameters to the performance of the boring machine and the quality of the hole. The main interest in the technical performance was focused on the penetration rate and efficiency of the vacuum suction system. The main interest in the quality of the hole was focused on the surface roughness of the hole and the mechanical "excavation damage" disturbance meaning increased microfracturing and porosity in a zone next to the surface.

The thrust force and rotation speed of the boring machine was varied to find out the characteristic penetration curve for the set up. Typically the thrust force was increased five steps while the rotation speed was kept constant, and vice versa, the rotation speed was changed three steps while the thrust force was kept constant.

Figure 4-1. The cutterhead in a hole which is almost ready.

Boring without a pilot hole was tested so that one section of the hole was bored without a separate pilot hole using the same cutter head set up as normally. Muck samples were taken during the boring to find out the effect of different thrust forces and rotation speeds on the quality of muck. The temperature of the cutters was monitored as well as the noise level, the dust content and temperature of the inside air in the tunnel.

5 RESULTS

The research, reporting and analysis of the results are still in progress but some preliminary results can be presented.

The study proved that deposition holes can be bored effectively by using a boring machine which is based on fullface rotary crushing and removal of muck from the bottom of the hole by direct air vacuum suction. The test boring without a separate pilot hole succeeded well and from the technical point of view the hole can be made as well without it if necessary.

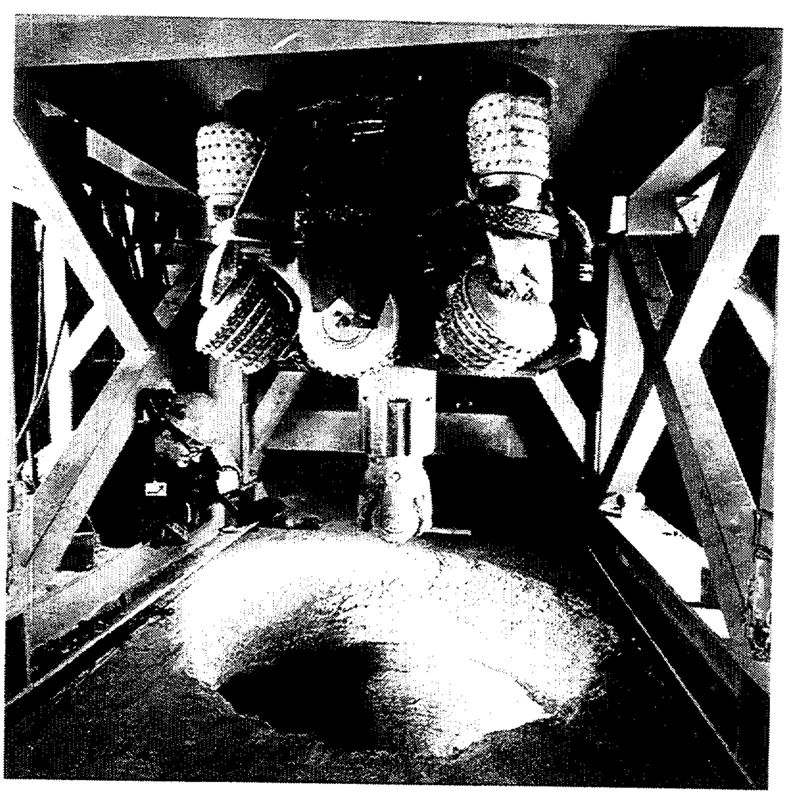

Figure 5-1. The cutterhead on the top of the hole.

The highest rate of penetration (ROP) which was achieved during the boring was about 1 m/h with a total maximum thrust of 73 tonnes and rotation speed of 8 rpm. When testing with different rotation speeds it was noted that the depth of cut per rotation becomes smaller when the rotation speed is raised. It was concluded that the speed of about 8 rpm was optimal and used normally, although a higher ROP could have been achieved with higher rotation speed. The result means that as a consequence of increased speed the vacuum suction system is not cleaning the surface well causing regrinding of the muck, low efficiency and high wear. As a consequence the suction system and especially the nozzles have to be developed to meet the requirements of higher rotation speed.

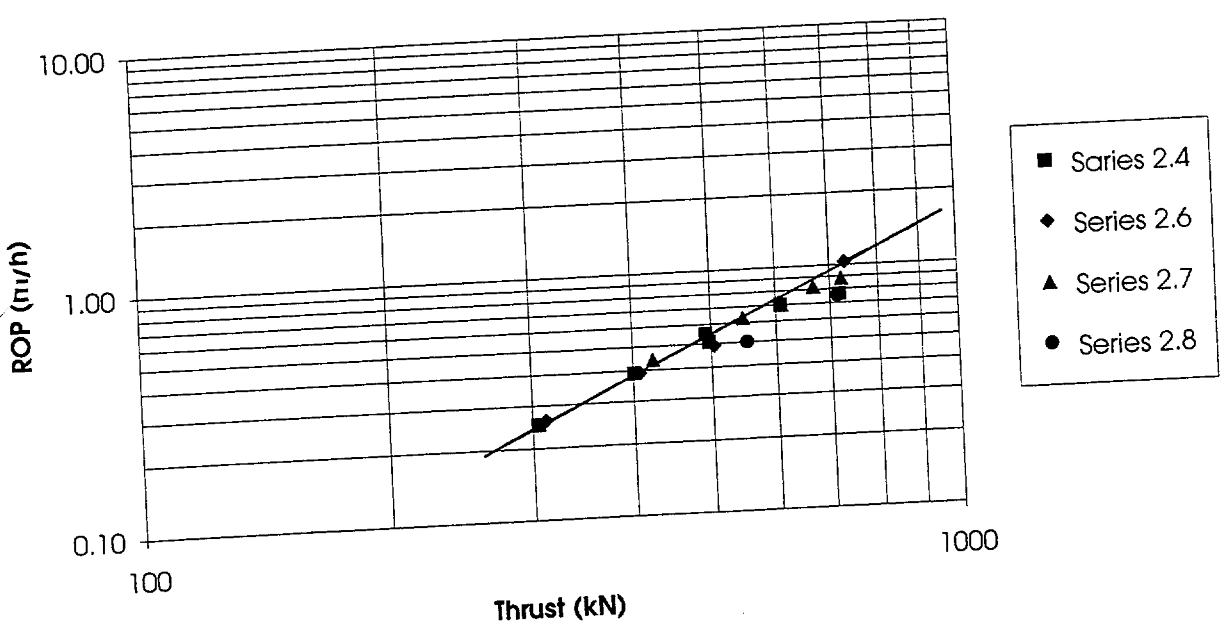

Figure 5-2. Rate of penetration as function of thrust. Four different tests.

The measured correlation between the ROP and thrust was linear in the same manner as can be shown theoretically, which proves that the measured characteristic curve can be used to estimate the performance of a similar type but more powerful boring machine. The estimated rate of penetration of this type of machine with higher thrust and torque capacity is over 3 m/h for similar type of rock as in the research tunnel.

The working environment in the tunnel was good which was also indicated by the fact that the boring didn't cause any interruptions to the operation of the VLJ-repository.

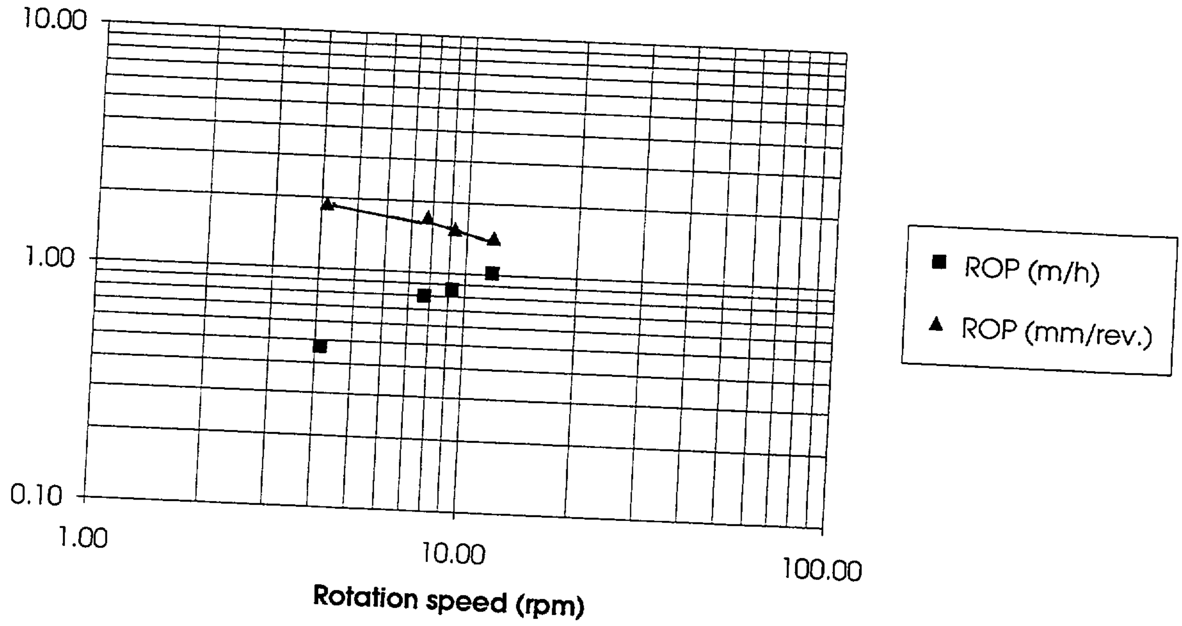

Figure 5-3. Rate of penetration as a function of rotation speed.

6 CHARACTERIZATION OF THE HOLES AND TRACER TESTS

Comprehensive characterization of the rock around the holes started before the boring of the full-scale deposition holes and will continue further on. One aim of the characterization study is to evaluate the suitability of existing investigation methods for the characterization of the near field. Another aim is to study both mechanical and hydrological impact caused by the boring of the hole on the nearfield.

The activities in the research program can be grouped under following categories: a) geometrical and geological mapping of the hole, b) characterization of the excavation damage, c) hydrological characterization and d) geophysical characterization which include among other things hydrological measurements and tracer tests.

The characterization and test in the holes are in progress. So far the investigations have revealed that fracturing and other small-scale properties of rock can be characterized in a certain extent a priori by means of small-diameter (56 mm) coreholes, high frequency seismic survey and tunnel radar survey. Great care should be paid to interpreting results from coresamples, as simple as it seems and the same applies in a much more pronounced way to interpretation of geophysical measurements.

The inflow rates of water to the large holes 1, 2 and 3 were correspondingly 18 l/h, 0.05 l/h and 6 l/h. The middle hole no. 2 was almost dry as expected. The inflow rate to the hole no. 1 was same as to the 56 mm core hole. Visual inspection of the inflow and tracer test give strong indications of flow in sparse and narrow channels. The observed non-fickian dispersion is thought to be caused by the velocity differences over the channel width or by diffusion into stagnant pools in the fracture filling.

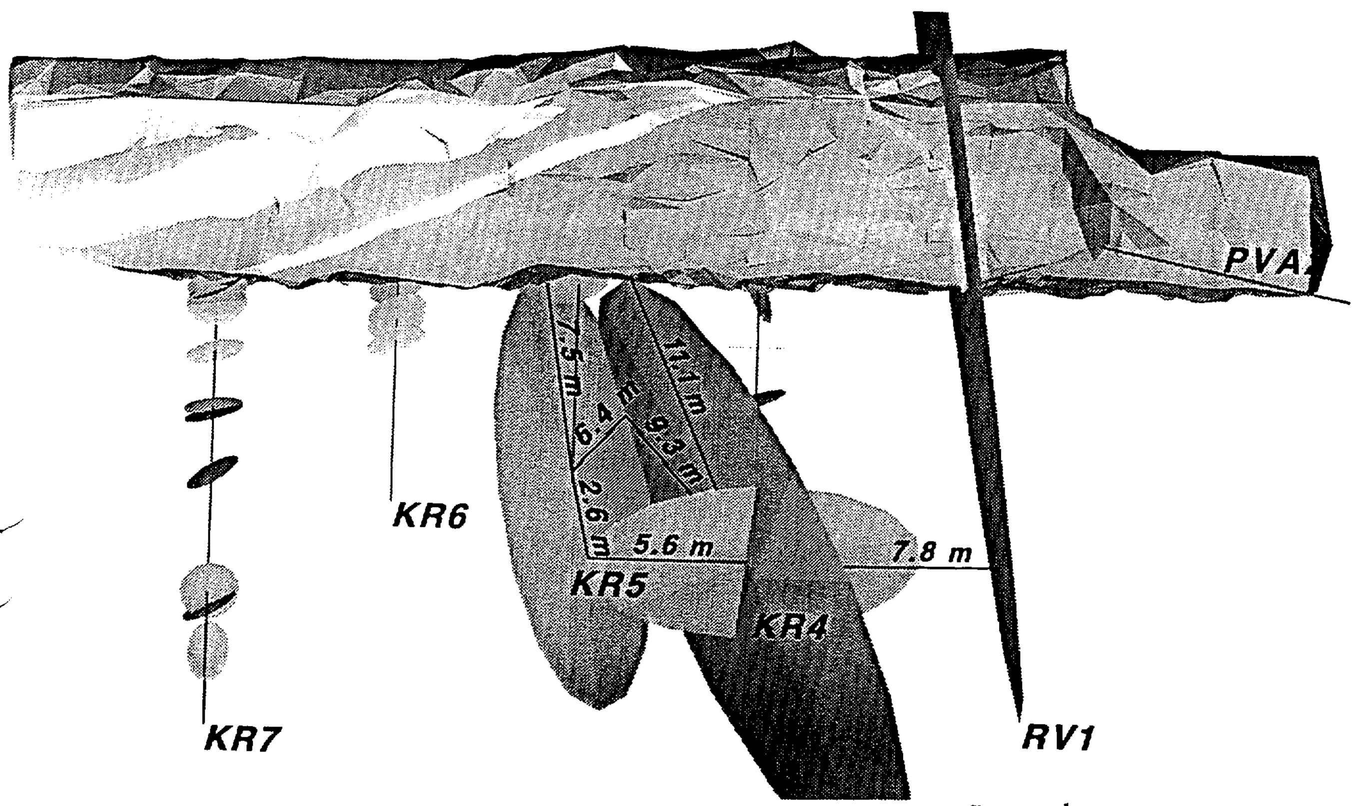

Figure 6-1. TVO-Research Tunnel and hydrological flowpaths.

The inflow rate of groundwater into the large holes is almost as high as the total inflow rate into the whole research tunnel which is 60 m under the bedrock, 50 m long and 7 m high. There appears to be a distinct skin over the mantle of the Research Tunnel and no such more conductive disturbed zone below the tunnel floor as assumed in the TVO-92 safety analysis has been revealed so far.

The characterization research which is focused on the above mentioned categories shall continue until 1995. The results of the forthcoming investigations shall be reported and discussed in the future in more detail especially in regard to determination of the locations of disposal holes and performance analysis.

DISCUSSIONS

PAPER A: **TBM-USE AT THE ÄSPÖ HARD ROCK LABORATORY**
Göran Bäckblom, Tommy Hedman
(Swedish Nuclear Fuel & Waste Management Co)

Bernard J Verna: *Will there be some turns ?*
Tommy Hedman: Yes, both a vertical and a horizontal curve will be excavated.

Bernard J Verna: *Why was Äspö chosen as a site for the laboratory?*
Göran Bäckblom: There were several reasons (in detailed described in the SKB R&D-Programme 89) such as:

- the infrastructure at hand at Simpevarp,
- possibility to show the interim storage of spent fuel (CLAB) and R&D for the repository at the same site,
- the island Äspö is uninhabited. Thus there will be no uncontrolled disturbances of the ground water situation,
- there are several types of rock and fracture zones at Äspö not limiting the research to only one rock type.

Bernard J Verna: *Why was an access ramp chosen at Äspö?*
Tommy Hedman: Shaft and ramp was evaluated and compared on factors like (see R&D-Programme 89) collection of data and characterization of rock, methods and knowledge for numerical modelling and validation of calculations, time schedule, method development and costs for investigation and construction and operation of the facility. The evaluation showed that the ramp was preferable to the shaft.

Dick Kovack: *What technique have you used for the hoist and ventilation shafts?*
Tommy Hedman: Raise-boring.

Öivind Toverud:	*What was the view of the authorities concerning access ramp or shaft?*
Tommy Hedman:	The authorities wished to see the reasoning. They as well recommended that the depth of the laboratory should be possible to extend down to 700 m.
Jukka-Pekka Salo:	*A ramp for the repository needs more backfilling material and can thus be more expensive.*
Göran Bäckblom:	SKB thinks that the choice of ramp or shaft will be site-specific.

PAPER B: **FEATURES OF THE TBM-MACHINE TO BE USED AT THE ÄSPÖ HARD ROCK LABORATORY**
Stig Eriksson (SKANSKA Stockholm AB)

Per Andersson:	*Will you change spacing/revolution speed/thrust increase the advance rate?*
Stig Eriksson:	We will change spacing.
Jukka-Pekka Salo:	What will be the most difficult task?
Stig Eriksson:	The main problem may be to handle the water problems in the decline.
Öivind Toverud:	*What previous experience do SKANSKA have from TBM-excavation?*
Stig Eriksson:	SKANSKA has experiences from earlier work in Panama, Peru and Sweden.
Jorma Autio:	*How much can you pump from the tunnel face?*
Stig Eriksson:	2000 l/min.
Jorma Autio:	*The advance rate?*
Stig Eriksson:	2 m/h, but depending of the muck-up system.
Jorma Autio:	*Utilization?*
Stig Eriksson:	Depending on muck-up system, grouting, cutter changes etc. We think 15-20 cutters out of 34 will be changed.

André Cournut:	*How to remove the TBM after the excavation is finished?*
Stig Eriksson:	The grippers will be reversed. It will probably take a week. The head may be disassembled by removing the sparks in order to pass sections of heavy reinforcement.
Bernard J Verna:	*When will the ground support be installed?*
Stig Eriksson:	preferably c. 20 m behind the head. If needed it can be done just at the cutter head. In severe conditions it can be done at section zero.
André Cournut:	*What radius can be used?*
Stig Eriksson:	Due to machine geometry and stroke length the preferred radius is 250 m. It can however be forced down to 150 m.
André Cournut:	*How heavy are the machine parts?*
Stig Eriksson:	We installed a 50 tonnes portal crane. The heaviest piece is the cutter head, 43 tonnes.

PAPER C: **METHODOLOGY FOR ROCK CHARACTERIZATION IN CONNECTION WITH TBM-EXCAVATION AND SOME PRELIMINARY RESULTS FROM THE CORED HOLE PARALLEL WITH TBM-TUNNEL**
Ingvar Rhén (VBB VIAK AB),
Roy Stanfors (RS Consulting AB),
Leif Stenberg (Swedish Nuclear Fuel & Waste Management Co)

Wolfgang Kickmaier:	Will you drill holes after the TBM-excavation to measure the water pressures close to the tunnel periphery?
Ingvar Rhén:	It will be done after the removal of the TBM.
Olle Olsson:	*Have you experienced any changes in the inflow pattern to the tunnel so far (weirs, drips)?*
Ingvar Rhén:	Not so far.

Dick Kovack:	*Have you had any problems with the grouting work?*
Ingvar Rhén:	Mostly in connection with major fracture zones, like the NE-1 zone.

Per Andersson:	*Will you perform measurements of inflow in the decline? Do you have inflow in fractures or in zones?*
Ingvar Rhén:	We will measure the total flow into the TBM tunnel. Rather high rates of water flow into the tunnel come from some of the fracture zones (zone according to the Äspö HRL definition) but some zones are quite dry. There are also water flowing into the tunnel from fractures between the zones.

PAPER D: **ZEDEX – A STUDY OF THE EXCAVATION DISTURBED ZONE FOR TBM AND DRILL & BLAST EXCAVATION**
Olle Olsson (Conterra AB)

PAPER E: **EXPLORATORY STUDIES FACILITIES TESTING IN CONJUNCTION WITH TBM OPERATIONS**
Dick Kovack (US/DOE YMP ESF Test Coordination Office)

Nick Davies:	*How much of the excavation will be done by TBM?*
Dick Kovack:	Most of the tunnel will be excavated by TBM.

Nick Davies:	*Where will the repository be located?*
Dick Kovack:	South of the Imbricate fault zone.

Nick Davies:	*What is the experimental effect on the site?*
Dick Kovack:	This is considered by the PI:s, both how their test will affect other tests as well as the influence of gas and fluids.

Göran Bäckblom:	*Do you have some precautions for influx of water or gas (methane) during excavation?*
Bernard J Verna:	Water and gas is not expected at Yucca Mountain. Construction water is traced by addition of Lithiumbromide.

Christer Svemar: *How do you handle oil spillage, stray materials?*

Bernard J Verna: The size of the oil containers is minimized. A special bolt system has been developed. There are drip protectors and invert sections. Electrical motors are used for vehicles instead of diesels to reduce the hydrocarbons.

Olle Olsson: *What is the turning radius of the TBM?*

Dick Kovach: 152 meters (500 ft) for the TBM but the muck conveyor system supporting the TBM has a 304 meters (1000 ft) turning radius.

Ingvar Rhén: *Will you stop the TBM while drilling from the platforms?*

Dick Kovack: Only to excavate the test alcoves and routine installations. The TBM will run 5 days/week. A 4 h stop will be done each day for maintenance.

Ingvar Rhén: *How detailed is the photogrammetry?*

Dick Kovack: Detail 1 cm in length can be observed.

Ingvar Rhén: *When will data come back to the site?*

Dick Kovack: The mapping crew will consist of 4-5 people that will characterize the geology and than process that data on site as preliminary information. This preliminary data will be available within 1 to 2 days.

Nick Davies: *When will convergence pins be installed?*

Dick Kovack: Close to the mapping platform. Small bars will be glued by epoxy.

Nick Davies: *Ground support predictions?*

Dick Kovack: Five ground support classes has been chosen – from bolts to steel sets. The ground support will be determined on site.

Bernard J Verna: Alternative machine designs are now evaluated for machine excavation of the alcoves.

PAPER F:	**DEMONSTRATION OF DEPOSITION HOLES BY FULL FACE BORING TECHNIQUE AT OLKILUOTO VLJ – RESEARCH TUNNEL** **Jukka-Pekka Salo (TVO),** **Jorma Autio (Saanio & Riekkola)**
Bernard J Verna:	*What is the life-time of the drilling head?*
Jorma Autio:	Not possible to measure the wear after 30 m of drilling. The cutter head buttons last c. 300 – 500 m.
Ingvar Rhén:	*Can the height of the equipment be reduced?*
Jorma Autio:	It can be designed for smaller tunnels.

Appendix A

ÄSPÖ HARD ROCK LABORATORY

TBM Workshop June 13-14, 1994

PROGRAMME:

Monday June 13, 1994

	Arrival at Äspö Site Office
12.00	Lunch at "Mässen"
13.30	OPENING OF THE MEETING
	PRACTICAL MATTERS
	THE RATIONALE FOR TBM AT ÄSPÖ (Göran Bäckblom, SKB)
	LAYOUT WORK FOR THE TBM (Tommy Hedman, SKB)
	SPECIAL FEATURES OF THE TBM-MACHINE (Stig Eriksson, SKANSKA)
	DISCUSSION
15.30	UNDERGROUND STUDY TOUR IN GROUPS
19.30	DINNER
22.30	BUS ARRANGED FOR HOTEL POST AND HOTEL CORALLEN

Tuesday June 14, 1994

7.45 BUS FROM HOTEL CORALLEN

8.00 BUS FROM HOTEL POST

8.30 STUDIES IN CONNECTION WITH THE TBM – OVERVIEW
(Göran Bäckblom, SKB)

METHODOLOGY FOR ROCK CHARACTERIZATION IN CONNECTION WITH TBM-EXCAVATION
(Roy Stanfors, RS Consulting AB; Ingvar Rhén, VBB Viak; Leif Stenberg, SKB)

STUDY OF THE EXCAVATION DISTURBED ZONE FOR DRILL&BLAST v. TBM
(Olle Olsson, Conterra AB)

DISCUSSION

10.30 EXPLORATORY STUDIES FACILITIES TESTING IN CONJUNCTION WITH TBM OPERATIONS
(Dick Kovack, US/DOE YMP ESF Test Coordination Office)

DEMONSTRATION OF DEPOSITION HOLES BY FULL FACE BORING TECHNIQUE AT OLKILUOTO VLJ – RESEARCH TUNNEL
(Jukka-Pekka Salo, TVO; Jorma Autio, Saanio & Riekkola)

DISCUSSION

12.00 LUNCH

13.00 CONTINUED DISCUSSIONS

15.00 END OF MEETING

Appendix B

PARTICIPANTS AT THE TBM WORKSHOP JUNE 13-14, 1994, ÄSPÖ

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List of International Cooperation Reports

ICR 93-01
Flowmeter measurement in borehole KAS 16
P Rouhiainen
June 1993
Supported by TVO, Finland

ICR 93-02
Development of ROCK-CAD model for Äspö Hard Rock Laboratory site
Pauli Saksa, Juha Lindh,
Eero Heikkinen
Fintact KY, Helsinki, Finland
December 1993
Supported by TVO, Finland

ICR 93-03
Scoping calculations for the Matrix Diffusion Experiment
Lars Birgersson[1], Hans Widén[1],
Thomas Ågren[1], Ivars Neretnieks[2],
Luis Moreno[2]
1 Kemakta Konsult AB, Stockholm, Sweden
2 Royal Institute of Technology, Stockholm, Sweden
November 1993
Supported by SKB, Sweden

ICR 93-04
Scoping calculations for the Multiple Well Tracer Experiment - efficient design for identifying transport processes
Rune Nordqvist, Erik Gustafsson,
Peter Andersson
Geosigma AB, Uppsala, Sweden
December 1993
Supported by SKB, Sweden

ICR 94-01
Scoping calculations for the Multiple Well Tracer Experiment using a variable aperture model
Luis Moreno, Ivars Neretnieks
Department of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden
January 1994
Supported by SKB, Sweden

ICR 94-02
Äspö Hard Rock Laboratory. Test plan for ZEDEX - Zone of Excavation Disturbance EXperiment. Release 1.0
February 1994
Supported by ANDRA, NIREX, SKB

ICR 94-03
The Multiple Well Tracer Experiment - Scoping calculations
Urban Svensson
Computer-Aided Fluid Engineering
March 1994
Supported by SKB, Sweden

ICR 94-04
Design constraints and process discrimination for the Detailed Scale Tracer Experiments at Äspö - Multiple Well Tracer Experiment and Matrix Diffusion Experiment
Jan-Olof Selroos[1], Anders Winberg[2],
Vladimir Cvetkovic[2]
1 Water Resources Eng., KTH
2 Conterra AB
April 1994
Supported by SKB, Sweden

ICR 94-05
Analysis of LPT2 using the Channel Network model
Björn Gylling[1], Luis Moreno[1],
Ivars Neretnieks[1], Lars Birgersson[2]
1 Department of Chemical Engineering
and Technology, Royal Institute
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2 Kemakta Konsult AB, Stockholm, Sweden
April 1994
Supported by SKB, Sweden

ICR 94-06
SKB/DOE Hard Rock Laboratory Studies
Task 3. Geochemical investigations using stable and radiogenic isotopic methods
Bill Wallin[1], Zell Peterman[2]
1 Geokema AB, Lidingö, Sweden
2 U.S. Geological Survey, Denver, Colorado, USA
January 1994
Supported by SKB and U.S.DOE

ICR 94-07

Analyses of LPT2 in the Äspö HRL with continuous anisotropic heterogeneous model

Akira Kobayashi[1], Ryo Yamashita[2], Masakazu Chijimatsu[2], Hiroyuki Nishiyama[3], Yuzo Ohnishi[3]
1 Iwate University, Iwate, Japan
2 Hazama Corporation, Ibaraki, Japan
3 Kyoto University, Kyoto, Japan
September 1994
Supported by PNC, Japan

ICR 94-08

Application of three-dimensional smeared fracture model to the groundwater flow and the solute migration of LPT-2 experiment

T Igarashi, Y Tanaka, M Kawanishi
Abiko Research Laboratory, Central Research Institute of Electric Power Industry, Abiko, Japan
October 1994
Supported by CRIEPI, Japan

ICR 94-09

Discrete-fracture modelling of the Äspö LPT-2, large-scale pumping and tracer test

Masahiro Uchida[1], Thomas Doe[2], William Dershowitz[2], Andrew Thomas[2], Peter Wallmann[2], Atsushi Sawada[1]
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March 1994
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