SKB

ÄSPÖLABORATORIET

INTERNATIONAL COOPERATION REPORT

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

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# ÄSPÖ HARD ROCK LABORATORY. TEST PLAN FOR ZEDEX - ZONE OF EXCAVATION DISTURBANCE EXPERIMENT. RELEASE 1.0

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# ÄSPÖ HARD ROCK LABORATORY

## TEST PLAN FOR

## ZEDEX - ZONE OF EXCAVATION DISTURBANCE EXPERIMENT

**RELEASE 1.0**

**February 1994**

CONTENTS

# 1 BACKGROUND

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 method of excavation used for the Äspö HRL spiral will change in the summer of 1994 from drill and blast to tunnel boring (TBM). This gives an opportunity to study the effects of different excavation methods on the rock surrounding the tunnel.

The ZEDEX project is expected to contribute to the basis for selecting or optimizing the construction method or combination of methods for a deep repository and subsequent sealing,

# 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.

The project does not include, as a major aim, the study of possible changes in hydraulic properties in the disturbed zone caused by the two excavation methods. The main reason is that we do not expect to be able to resolve the issues of hydraulic effects in the disturbed zone within the time and funding constraints of the project. However, a limited hydraulic testing program is included in the project.

The following success criteria for the ZEDEX Project have been defined to qualify if 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 RATIONALE

## 3.1 RELEVANCE TO REPOSITORY PERFORMANCE

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 test has relevance to repository construction and performance in that it will attempt to relate physical measurements of displacement and disturbance to excavation method and geological conditions.

## 3.2 PREVIOUS EXPERIENCE

ANDRA were involved in a smooth blasting experiment carried out in 1991 at the URL in Canada. The main result was to prove that it was possible to reduce the extension of the damaged zone significantly (from >1 m to 10 or 20 cm) using gas-energy explosives combined with appropriate blast designs.

The Norwegian Geotechnical Institute (Nirex's Geotechnical Consultants) have previously been involved with international projects on EDZ estimation at the Canadian URL and Stripa. It is intended to build on existing experience and to develop current technology for the measurement of the EDZ.

During 1991 SKB performed an experiment to study the extent and character of the disturbed zone at the Äspö HRL. The aim of this experiment, the "Blasting Damage Investigation", was to study the extent of the zone damaged by blasting for three different drill and blast schemes. The experiment showed that the damage in the floor of the drift was more extensive than in the walls for all drill and blast schemes used.

Professor R. Paul Young and the Applied Seismology Group (Nirex's Consultants) are responsible for acoustic emission (AE) studies. They developed AE technology for the URL in Canada and have extensive experience in the application of AE in rock mechanics and underground mining.

## 3.3 JUSTIFICATION FOR THE EXPERIMENTAL WORK

There is a need to demonstrate that we can quantify the EDZ and relate this to its impact on hydraulic conductivity (especially in the vicinity of plugs) in support of safety assessment.

SKB has decided to change the method of excavation of the tunnel spiral of the Äspö HRL from drill and blast to tunnel boring. This provides an opportunity for a direct comparison of the disturbance to the rock induced by the different excavation methods. A detailed comparison of these effects for different excavation techniques have previously not been performed at realistic repository depths.

There is a need to demonstrate that the extent of the EDZ can be reduced by the selection of the optimum drilling pattern for a blasted drift. In this instance this experiment will add to and complete similar experiments carried out at the Canadian URL on two aspects:

- Industrial aspect: after defining the optimum blast design, we should obtain constant and repetitive results.
- Measurement aspect: the tools that the Bundesanstalt für Geowissenshaft und Rohstoffe (BGR) intends to use in support of the ANDRA project should be more accurate than the ones used previously by ANDRA at URL.

There is a need to select and develop equipment for the measurement of EDZ properties and extent and gain experience in its use before application to the planned Nirex RCF.

Äspö offers the opportunity to test out equipment and methods under similar conditions before application to the Nirex RCF and the planned ANDRA underground laboratories.

# 4 EXPERIMENTAL CONCEPTS

## 4.1 LOCALIZATION OF EXPERIMENT

The test site for a comparative study of excavation disturbance has to be located somewhere along the planned (and procured) TBM drift as this is the only place where TBM excavation can be performed at a reasonable costs. A dedicated TBM drift for these tests would have incurred large extra costs. The flexibility in locating a drill and blast excavated drift are relatively large and it could in principle be placed anywhere along the TBM drift. However, a study of excavation induced disturbance to the rock requires drilling of test boreholes at appropriate locations before excavation commences. As the TBM drift will be excavated into virgin rock volumes the only possibility to drill test boreholes for the TBM drift will be at the very beginning of the drift. Hence, the most appropriate location of this experiment will be where the excavation method is changed from drill and blast to TBM. This implies that the experimental drifts will be located adjacent to the TBM Assembly Hall (Figure 4-1).

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 430 m below ground surface and the orientation of the drifts will be roughly perpendicular to the main horizontal stress direction.

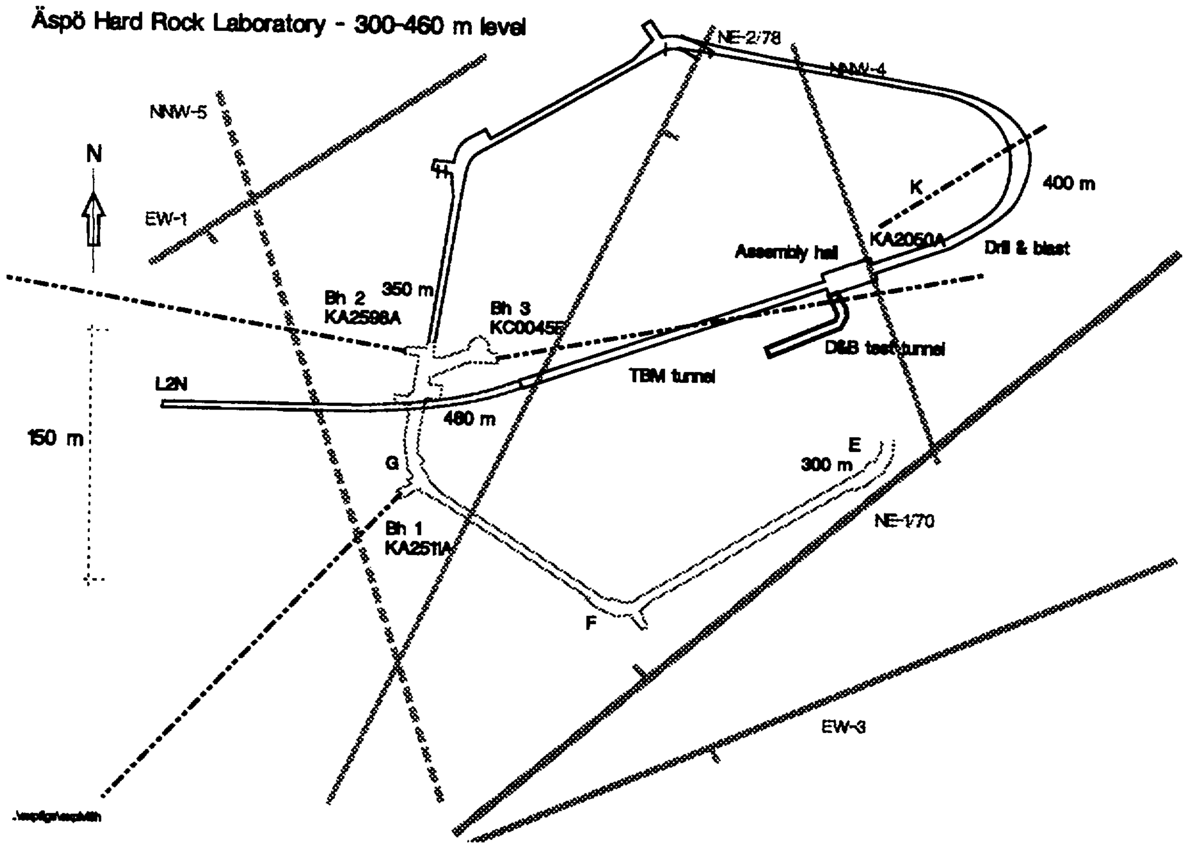


Figure 4-1 The test drifts are located adjacent to the TBM Assembly hall of the Äspö HRL tunnel.

## 4.2 TESTED HYPOTHESIS

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 430 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.

## 4.3 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 4-2. An access drift (12 in Figure 4-2) 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.

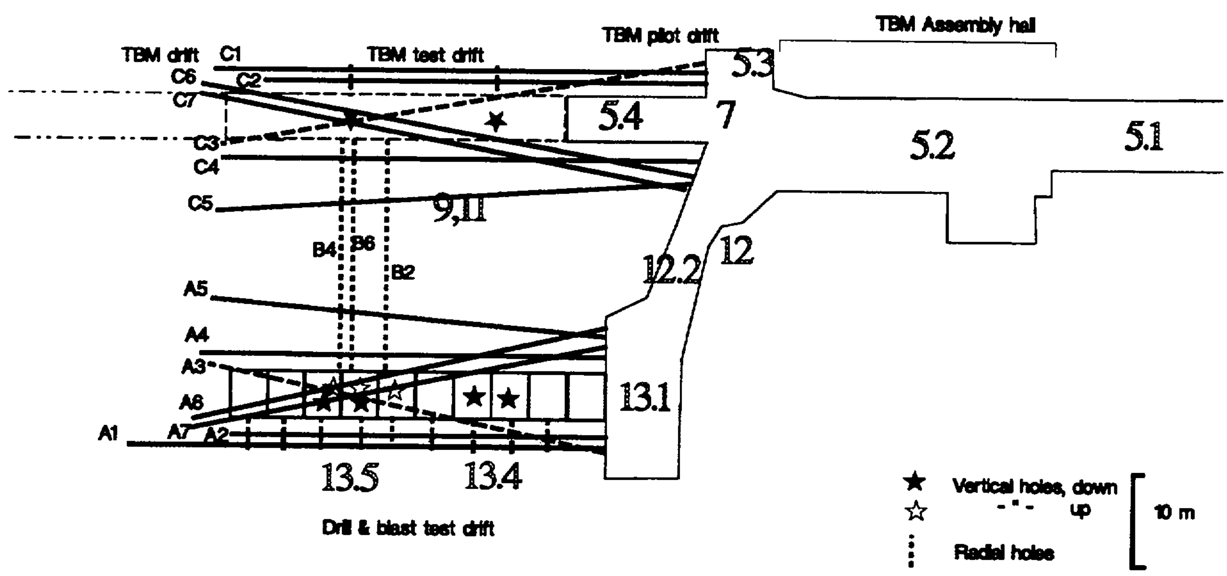


Figure 4-2 Proposed experimental configuration for the ZEDEX project. Numbers in the figure refer to major project items that are referred to in Section 5.

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 4-2 and 4-3, 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, two above and one 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. The primary usage of the boreholes and the diameter of each borehole are given in Table 4-1.

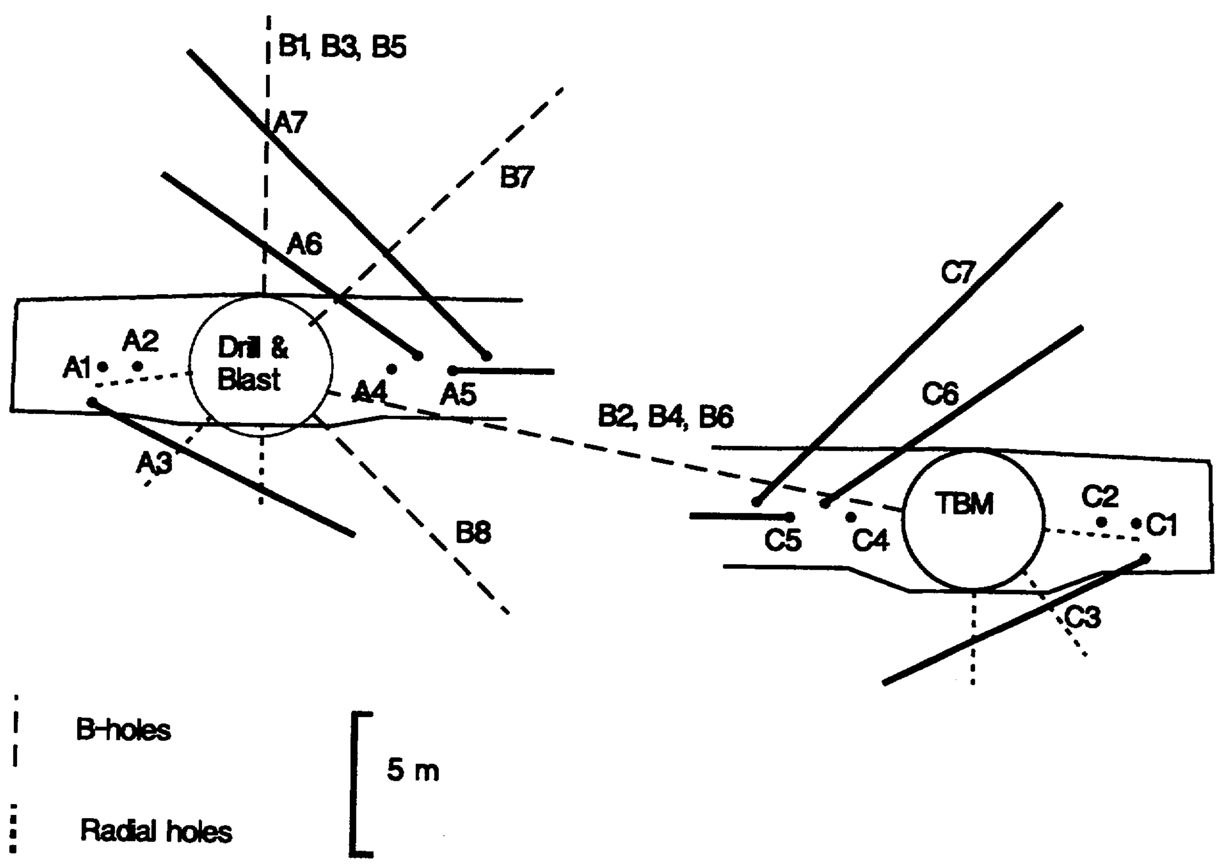


Figure 4-3 Vertical section showing location of boreholes in relation to the test drifts.

Table 4-1 Borehole usage and diameters.

| Borehole number | Purpose | Orientation, location | Diameter (mm) | Length (m) |
|---|---|---|---|---|
| A1 | vibration monitoring | horizontal, sidewall | 86 | 40 |
| A2 | AE, directional radar | horizontal, sidewall | 56 | 40 |
| A3 | AE, directional radar | plunging, floor | 56 | 45 |
| A4 | AE, seismic, permeability | horizontal, sidewall | 56 | 40 |
| A5 | seismic, permeability | horizontal, sidewall | 56 | 40 |
| A6 | AE, seismic, directional radar | inclined, arch | 56 | 45 |
| A7 | Seismic | inclined, arch | 56 | 45 |
| | | | | |
| B1 | seismic | radial, up; from D&B | 56 | 10 |
| B2 | seismic, permeability | radial, horizontal; from TBM | 56 | 25 |
| B3 | seismic | radial, up; from D&B | 56 | 10 |
| B4 | seismic, permeability | radial, horizontal; from TBM | 56 | 25 |
| B5 | MPBX | radial, up; from D&B | 76 | 15 |
| B6 | MPBX | radial, horizontal; from TBM | 76 | 25 |
| B7 | MPBX | radial, 45° up; from D&B | 76 | 15 |
| B8 | MPBX | radial, 45° down; from D&B | 76 | 15 |
| | | | | |
| C1 | vibration monitoring | horizontal, sidewall | 86 | 40 |
| C2 | AE, directional radar | horizontal, sidewall | 56 | 40 |
| C3 | AE, directional radar | plunging, floor | 56 | 45 |
| C4 | AE, seismic, permeability | horizontal, sidewall | 56 | 40 |
| C5 | seismic, permeability | horizontal, sidewall | 56 | 40 |
| C6 | AE, seismic, directional radar | inclined, arch | 56 | 45 |
| C7 | Seismic | inclined, arch | 56 | 45 |
| C8 | stress | horizontal (not at drift) | 86 | 20 |
| | | | | |
| Radial | P-wave velocity, borehole resonance, permeability | radial: down, 45° down, horizontal | 86 | 3 |
| | | | | |

## 4.4 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 4-2 gives a summary of the methods applied within the project, where and when they are applied in relation to excavation of the drifts. The purpose for applying a specific method and the technical specifications for each method are given in Appendix 1.

Table 4-2 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

## 4.5 QUANTITY VS QUALITY

Only one test for each excavation method is planned, but measurements will be made with several methods at multiple locations along the tunnels. The length of each test drift is 30-40 m which should facilitate discrimination of excavation disturbances from geological heterogeneity.

## 4.6 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.

## 4.7 PROBLEM AREAS

To identify a suitable experimental area with appropriate rock conditions (sufficient similarity in conditions at the two test drifts) considering the constraints imposed by tunnel construction. The flexibility in selecting a site is limited and it is not possible to guarantee ideal experimental conditions in advance. SKB has performed a comprehensive investigation program in borehole KC0045F (Bh 3 in Figure 4-1) in order to provide information to select the location of the test drifts.

The coordination of the experimental work with construction work will be a major endeavor. This may cause delays, increase costs, and possibly compromise the quality of experimental results if not managed properly. If there is malfunction of equipment it may not be possible to perform the planned measurement within the allotted time and in worst case not at all.

Integrating near EDZ and far EDZ data sets into a total assessment of the whole EDZ. This should be overcome by good cooperation between the different groups involved and close management of the project.

Optimization of smooth blast designs. The special explosives and detonators should be in sufficient quantity to be able to adapt the next blast design to the results obtained with the previous blast.

Proper function of measurement tools during the experiment. Two different tools will be used by BGR to measure the extension of the damaged zone. These tools were tested in a mine in Germany in August 1993 prior to the experiment in Sweden.

# 5 SCOPE

## 5.1 PREPARATORY WORK

A borehole (KC0045F, Figure 4-1) has been drilled toward the potential experimental site. A comprehensive investigation program has been performed in this borehole to provide a basis for defining the detailed layout of the test drift. These investigations are performed as a part of the SKB Project "Localization of experimental sites and layout of turn 2" and does not constitute a part of the ZEDEX Project.

## 5.2 INVESTIGATIONS, TBM DRIFT

### 5.2.1 Drilling, axial holes

A total of 7 boreholes will be drilled axially along the drift. The boreholes will be named C1 through C7. Their location and orientation is shown in Figures 4-2 and 4-3.

In addition a short borehole, C8, will be drilled for the purpose of performing stress measurements.

### 5.2.2 Investigations, prior to excavation

To assess the rock properties before excavation the following methods will be applied in the axial boreholes:

- Directional radar in boreholes C2, C3, and C6.
- High resolution seismic tomography in borehole sections C4-C5 and C6-C7.
- Permeability measurements with a packer spacing of 3.5 m in boreholes C4 and C5.
- Core mapping
- Stress measurements near the test drifts to determine absolute stress levels and orientation.

### 5.2.3 Investigations, during excavation

The following methods will be used to monitor changes in rock properties during excavation:

- Acceleration and temperature will be monitored by instrumentation placed in borehole C1.
- Acoustic Emission monitoring will be made by instrumentation placed in boreholes C2, C3, C4, and C6. Observations will be focussed to a 10 m cube towards the end of the test drift.
- Convergence pins will be installed at the tunnel front at 3 locations in the TBM tunnel to measure displacements. Readings will be repeated after excavation has been completed.

### 5.2.4 Investigations, after excavation

After excavation has been completed 6 radial boreholes, each 3 m long, will be drilled. There will be three boreholes each at two locations, as indicated in Figures 4-2 and 4-3, to study the EDZ properties in the near field. The two sets of boreholes will be placed in different geological settings if possible. Boreholes B2, B4, and B6 will be drilled to study EDZ properties as a function of radius for both test drifts.

After excavation and drilling has been completed the following investigations will be made:

- Geological and geotechnical mapping of the test drift.
- Permeability measurements with a packer spacing of 3.5 m in boreholes C4 and C5.
- Permeability measurements in boreholes B2 and B4 with a packer spacing of 1 m.
- High resolution seismic tomography in borehole sections C4-C5, C6-C7, and B2-B4.
- P-wave velocity and acoustic resonance measurements in the short radial holes.
- High resolution permeability measurements in the short radial holes with a packer spacing of 50 mm.
- Mapping of the cores from the short radial holes.
- Observation of induced fracturing in all boreholes by borehole television.

In addition the following investigations will be made:

- surveying of boreholes and collar locations
- laboratory tests on core samples including: isotropic compression tests on cubes, permeability measurements, acoustic measurements,

mercury porosity, unconfined compressive strength, Young's modulus, and thin sections to study micro-cracks.

## 5.3 INVESTIGATIONS, DRILL AND BLAST DRIFT

### 5.3.1 Drilling, axial holes

A total of 7 boreholes will be drilled axially along the drift. The boreholes will be named A1 through A7. Their location and orientation is shown in Figures 4-2 and 4-3.

### 5.3.2 Investigations, prior to excavation

To assess the rock properties before excavation the following methods will be applied in the axial boreholes:

- Directional radar in boreholes A2, A3, and A6.
- High resolution seismic tomography in borehole sections A4-A5, A6-A7, and B2-B4.
- Permeability measurements with a packer spacing of 3.5 m in boreholes A4 and A5.
- Permeability measurements in boreholes B2 and B4 with a packer spacing of 1 m. This will provide permeability data prior to excavation of the D&B drift.
- Core mapping

### 5.3.3 Test rounds, smooth blasting

To define an optimized blast design in terms of productivity and minimum apparent damage to the drift walls, 3-4 test rounds will blasted in the Access drift (12.2 in Figure 4-2) to the D&B test drift. The best blast design will be used in the subsequent tests of smooth blasting. First, two test rounds will be shot in the Access drift to assess the EDZ for a drift in a direction nearly parallel to maximum stress. Second, four test rounds (13.4 in Figure 4-2) will be shot in the D&B test drift which has a direction nearly perpendicular to the main stress direction.

The purpose of the first round in the D&B test drift is to move the test rounds away from the anomalous stress field caused by the drilling niches.

### 5.3.4 Test rounds, normal blasting

The next five rounds (13.5 in Figure 4-2) of the Drill and Blast drift will be excavated using a normal blasting procedure. This study of the EDZ will be focussed to a relatively fractured part of the drift where relatively large deformations are expected.

### 5.3.5 Investigations, during excavation

The following methods will be used to monitor changes in rock properties during excavation:

- Acceleration and temperature will be monitored by instrumentation placed in borehole A1.
- Acoustic Emission monitoring will be made by instrumentation placed in boreholes A2, A3, A4, and A6. Observations will be focussed to two 10 m cubes centered on rounds 3 (smooth blasting) and 6 (normal blasting). The AE monitoring array will be moved from round 3 to round 6 after blasting of round 4.
- Convergence pin arrays will be installed at the tunnel front at the end of each blast cycle and readings taken after each round at all array locations.
- Displacements will be monitored using MPBX extensometers. The extensometer in borehole B6 will be installed prior to start of excavation and readings will be taken after each round. Boreholes B5, B7, and B8 will be drilled after excavation of round 6 and equipped with extensometers. For these extensometers readings will be taken after each following round.

### 5.3.6 Investigations, after excavation

After excavation of all rounds has been completed, two 10 m long radial boreholes will be drilled (B1, B3, Figure 4-3). Boreholes B1 will be drilled from round 5 while borehole B3 will be drilled from round 7. These boreholes will be used for high resolution seismic tomography measurements in radially located sections. Then a total of 20 short radial boreholes, each 3 m long, will be drilled and used to assess the EDZ properties in the near field. There will be one horizontal borehole per round. In rounds 2, 3, 6, and 7, there will be 3 short radial holes; one vertically down, one with a plunge of 45°, and one horizontal (Figure 4-3). In addition, 3 short radial holes will be drilled to assess the EDZ for the smooth blasting rounds excavated nearly parallel to maximum stress (12.2 in Figure 4-2).

After excavation and drilling has been completed the following investigations will be made:

- Geological and geotechnical mapping of the test drift.
- High resolution seismic tomography in borehole sections A4-A5, A6-A7, B1-B3, and B2-B4.
- Tunnel radar measurements.
- P-wave velocity and acoustic resonance measurements in the short radial holes.
- Permeability measurements with a packer spacing of 3.5 m in boreholes C4 and C5.
- Permeability measurements in boreholes B2 and B4 with a packer spacing of 1 m.
- High resolution permeability measurements with a packer spacing of 50 mm in the short radial holes at rounds 3 and 6.
- Mapping of the cores from the short radial holes.
- Observation of induced fracturing in all boreholes by borehole television.

In addition the following investigations will be made:

- surveying of boreholes and collar locations
- laboratory tests on core samples including: isotropic compression tests on cubes, permeability measurements, acoustic measurements, mercury porosity, unconfined compressive strength, Young's modulus, and thin sections to study micro-cracks.

## 5.4 DATA ANALYSIS AND REPORTING

The results from each major measurement activity will be reported in Technical Notes which should be printed and distributed shortly after completion of the field work.

An integrated analysis will be made of the results obtained from the Drill & Blast and TBM test drifts, respectively. These results from each drift will be compared and evaluated with respect to the excavation method used. The results will be presented in the final report of the ZEDEX Project which will be published as an Äspö Project International Cooperation Report.

## 5.5 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.

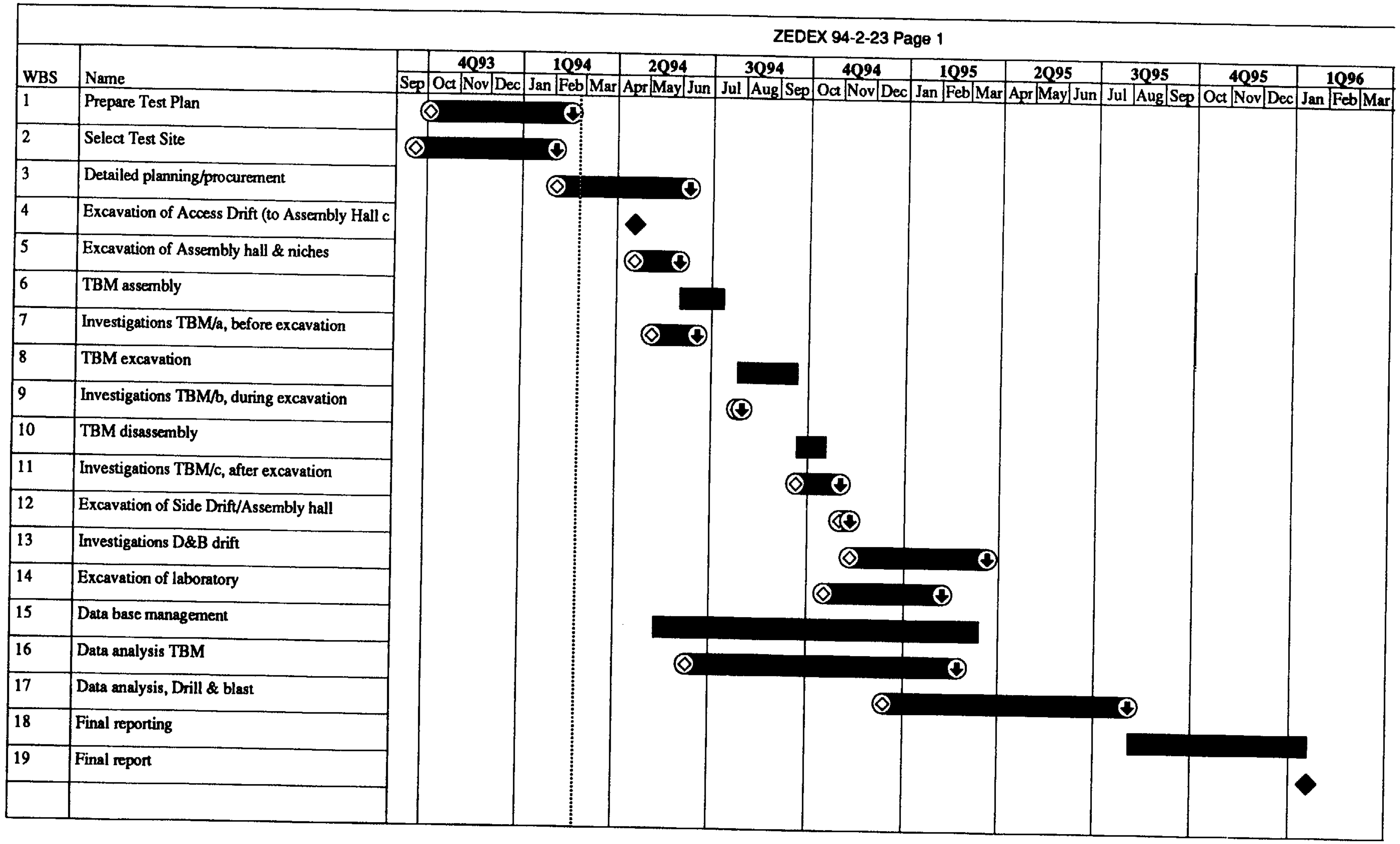


Figure 5-1 Time schedule for the ZEDEX Project.

# 6 PROJECT ORGANIZATION AND RESOURCE REQUIREMENTS

## 6.1 INTRODUCTION

The project is organized according to the guidelines given in the Quality Handbook for the Äspö HRL Project (in preparation) and/or the corresponding quality documents of ANDRA and UK Nirex.

## 6.2 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.

There will be an On-Site Coordinator with responsibility to coordinate on-site activities. The On-Site Coordinator is Gunnar Ramqvist.

There will be an on-site Data Manager with responsibility to file data collected in the Äspö HRL Project database. The Data Manager is Mats Ohlsson.

## 6.3 DATA MANAGEMENT

All data (including raw data) collected as part of the project should be stored in the Äspö HRL Project database. All data submitted to the data base should be accompanied by a description of how the data were collected, with what instruments, and how the data are formatted.

After quality control of the data by the contractor, Mats Ohlsson is responsible for filing the data according to given instructions and for subsequent transfer of data to the GEOTAB database.

## 6.4 REPORTING

The reporting of results is done continually during the progress of the project in the form of Technical Notes. This documentation must follow immediately after execution of each task. The Technical Notes should be formatted according to instructions in "Äspö Write Right".

All Technical Notes prepared as a part of this project should be titled as follows:

Äspö Hard Rock Laboratory International Cooperation Project

ZEDEX

Technical Note

Subtitle: xxxx

The Technical Notes are the responsibility of each contractor and will be published and distributed within the project group without review by the funding organizations.

The final report should be published as Äspö Project International Cooperation Reports. The Äspö ICR reports should be formatted according to instructions given in "Äspö Write Right".

Any Äspö ICR reports will be reviewed by the funding organizations prior to publication.

## 6.5 COST

The total project cost is estimated to 13.5 MSEK of which 1.5 MSEK is reserved as a contingency to be spent under the authority of the Steering Committee. The estimated cost for the activities described in this Test Plan is 12 MSEK.

APPENDICES

# A SPECIFICATION OF METHODS USED

## Measuring while blasting (MWB), acceleration

| | |
|---|---|
| Purpose: | Provide seismic data to control the quality of the blasts (detection of misfire) and to estimate the force applied to the rock during excavation both by tunnel boring and blasting. |
| Measurement specification: | The measurements will be made by one or two, three components accelerometer stations (borehole A1 and C1) and will produce information on the time control of the blast and check the quality of individual detonations in the blast series. |
| Measurement density: | For every blast in the drill an blast drift. |
| Measurement limits: | Not applicable. |
| Accuracy: | Not applicable. |
| Resolution: | Not applicable. |

*PCB accelerometer motion sensor*

| | |
|---|---|
| Range: | ± 500 g |
| Resolution: | 0.01 g |
| Sensitivity: | 10 mV/g |
| Resonant frequency: | 40 kHz |
| Frequency range: | 1-7 000 Hz |

## Seismic up-hole measurements in radial short holes, P-wave velocity

| | |
|---|---|
| Purpose: | Provide data on the acoustic characteristics of the rock mass in the vicinity of the wall of the drift. A hammer source is used on the surface. |

Measurement specification: Travel time and frequency content is registered and analyzed.

Measurement density: Every 50 mm between 0.05 m and 1 m, every 100 mm between 1 m and 2 m.

Measurement limits: Global measurements with "averaging" effect.

Accuracy: Dependent on the sampling rate and the accuracy of the tool location.

Resolution: 50 mm.

Mechanical impedance measurements in radial short holes

Purpose: Provide data on the mechanical impedance of the rock mass in the vicinity of a borehole. The impedance can be assessed directly by coupling the material with a transducer mechanism which simultaneously measures the force and motion response from an energy source as a broad function of frequency.

Changes in the material properties are reflected as decreased (or increased) levels in impedance function magnitude and a sudden jump in impedance function phase.

Measurement specification: The measuring device BORET (for BOrehole Resonance Tool) is the application of an energy source (frequency 50-100 kHz, driving force) to the borehole wall and to measure the force and acceleration response on the borehole wall directly at the point where the source is applied.

Measurement density: Continuous measurements.

Measurement limits: Identification of the disturbed zone dependant on the homogeneity and the natural fractures pattern of the rock mass.

Accuracy : Not yet known.

Resolution: 20 mm

Permeability measurements in axial holes

| | |
|---|---|
| Purpose: | Provide data on hydraulic properties of rock mass along the test drifts and on the changes in hydraulic properties induced by excavation. |
| Measurement specification: | Measurements will be made in boreholes A4 - A5 and C4 - C5 prior to and after excavation. Tests will be made as pressure build-up tests or injection tests with a double packer system. Packer spacing will be 3.5 m (equal to length of round). |
| Measurement density: | 10 tests/borehole with 3.5 m spacing. |
| Measurement limits: | T $\approx 1\ 10^{-10}\ m^2/s$. |
| Accuracy: | The evaluated transmissivity ($T_e$) is estimated to roughly be no more than 5 times larger or less than the "real" transmissivity, and in most cases better than this. |
| Resolution: | Not applicable. |

Permeability measurements in radial holes

| | |
|---|---|
| Purpose: | Provide data on hydraulic properties of the rock mass perpendicular to the test drift and on the changes in hydraulic properties induced by the excavation. |
| Measurement specification: | Measurements will be made in boreholes B2 and B4, drilled from TBM tunnel toward drill and blast tunnel, prior to and after excavation. Tests will be made as pressure build-up tests or injection test with a double packer system. Packer spacing will be 1.0 m. |
| Measurement density: | 10 tests with 1.0 m spacing. Start 0.5 m from expected tunnel wall in drill and blast tunnel. |
| Measurement limits: | T $\approx 1\ 10^{-10}\ m^2/s$. |
| Accuracy: | The evaluated transmissivity ($T_e$) is estimated to roughly be no more than 5 times larger or less than the "real" transmissivity, and in most cases better than this. |
| Resolution: | Not applicable. |

High resolution permeability measurements in radial short holes

| | |
|---|---|
| Purpose: | Quantify the hydraulic properties modified by excavation in the near field as a function of radius. |
| Measurement specifications: | Measurement will be made in short radial holes (3 m) in a section (3 holes) for each excavation method.<br><br>Tests will be made as pulse tests with a double packer system. Packer spacing will be 50 mm. Possibility of saturating the rock before making the measurements with a system of double injection chambers on each side of the test zone. |
| Measurement density: | Every 50 mm between 0.1 m and 0.5 m, every 100 mm between 0.5 and 1 m and every 200 mm between 1 m and 2 m. |
| Measurement limits: | ≈ $10^{-13}$ m/s ($10^{-20}$ $m^2$) |
| Accuracy: | 10 % |
| Resolution: | 50 mm |

Borehole Extensometers (MPBX)

| | |
|---|---|
| Purpose: | Determine the radial distribution of displacement towards the tunnel periphery as a result of excavation and further tunnel advance. The data will be used to understand and interpret the distributions of EDZ phenomena seen from other measurement techniques, such as the possible locally increasing and decreasing seismic velocities and permeabilities, etc. The deformation that has already occurred at the face is not recorded by the MPBX (except for the horizontal installation for the D&B drift) and will be a limitation in interpreting all EDZ phenomena. |
| Measurement specification: | Measurements will be made in borehole B6 immediately after excavation in the TBM and before excavation in the D&B drift, and in borehole B5 immediately after excavation in the D&B drift. |
| Measurement density: | 1-8 m between anchors. |
| Measurement limits: | 200 m (max anchor depth). |

Expected range: ± 10 mm displacement.

Accuracy: 0.2 mm displacement.

Convergence

Purpose: Provide the coarse check of MPBX results where measurement sections correspond with one another. Since convergence measurements will be taken with more frequency, they serve as a means of extrapolation of behavior from section to section, and may help to explain anomalies or particular behavior patterns seen in other measurements (seismic velocity or permeability change, etc.). Convergence also serves as a coarse calibration of numerical models. In addition they should supply information on the time dependency of deformation induced by excavation advance.

Measurement specification: Measurements will be made between fixed marks installed along three diameters at each location.

Measurement density: 3.5 m spacing in the D&B drift, 3 locations in the TBM drift.

Measurement limits: 1 - 30 m.

Expected range: 5 m.

Accuracy: 0.2 mm displacement.

Core mapping

Purpose: Axial holes: Provide data on lithology and fracturing prior to excavation. Quantify discontinuities using the Q system of rock mass classification. Important background information for interpreting measurements of EDZ properties.
Radial holes: Provide data on induced fracturing close to the drift wall. In addition, data on lithology and natural discontinuities will be obtained, which will help to position MPBX anchors.

Measurement specification: Core mapping according to normal SKB standards complemented by collection of Q-system data.

Measurement density: Continuous

Measurement limits: Not applicable

Accuracy: Location of fractures: 25 mm

Borehole TV inspection

Purpose: Provide data on induced fracturing and orientation of such fractures. In addition, data will be obtained on the small scale orientation of natural fractures and other geologic structures.

Measurement specification: Observation of borehole wall by axially oriented TV-camera. Orientation determination by observation of fracture trace on video image. Images recorded on video tape.

Measurement density: Continuous measurement.

Measurement limits: Identification of fractures dependent on the color of fracture infillings and apertures.

Accuracy: Location (borehole depth): 10 mm, Orientation <20 degrees (solid angle)

Drift mapping

Purpose: Provide data on induced and natural fracturing and lithology along the test drifts. Needed to assess excavation damage on drift wall and geological heterogeneity in test drifts. Quantify discontinuities using the Q system of rock mass classification to help identify specific features contributing to deformation.

Measurement specification: Drift mapping according to normal SKB standards complemented by collection of Q-system data.

Measurement density: Continuous.

Measurement limits: Fracture trace length cut off 0.5 m

Accuracy: 0.5 m

Seismic tomography

| | |
|---|---|
| Purpose: | Detection of the location and extent of the more jointed zones (and their contrast to the more massive rock). Due to excavation, the former will attenuate seismic signals to differing degrees depending on stress increase and decrease and joint deformation effects. This will be reflected in changed velocity, attenuation and dynamic modulus tomograms, which can logically be related to some of the results of direct measurements of deformation and permeability. Correlations between Q-value, seismic velocity ($V_p$) and dynamic modulus ($E_d$) will be validated/improved where possible. |
| Measurement specification: | Measurements will be made between boreholes A4-A5, A6-A7, C4-C5, C6-C7, B1-B3, and B2-B4 before and after excavation. |
| Nominal frequency: | 15-50 kHz. |
| Measurement density: | Between holes, 0.150 m spacing between measuring points in each hole. |
| Measurement limit: | Not applicable. |
| Expected range: | 4 m. |
| Accuracy: | Determination of velocity ±25 m/s. |
| Resolution: | Of the order of 0.5 m (areal dimension of a fracture plane). |

Tunnel radar

| | |
|---|---|
| Purpose: | Detection of water bearing joints. The stronger reflection coefficients in areas of the EDZ where joints have displaced may allow complementary detection of such features in relation to changes seen in their seismic signature. |
| Measurement specification: | Measurements will be made from the TBM and D&B drifts after excavation. |
| Nominal frequency: | 200 MHz. |
| Measurement density: | Spacing between measurement points: 0.1 m. |

Measurement limits: Not applicable.

Expected range: 5 m.

Accuracy: Not yet known.

Resolution: About 0.5 m (approx 10% of the detection distance) for the areal dimension of a fracture plane.

Acoustic emission

Purpose: Provide 3-D remote sensing of micro-crack movements induced by excavation. The nature and extent of the EDZ will be investigated, using the spatial and temporal distribution of source-located acoustic events, to determine the distance from the tunnel wall where elastic displacements start to dominate over micro-crack movements.

Measurement specification: Measurements will be made in boreholes A2-A4 & A6 and C2-C4 & C6 using a 16 channel ultrasonic data acquisition system and sensors with a nominal center frequency of 50 kHz.

Measurement density: Excavation induced acoustic events will be source located within a 10m x 10m x 10m array volume.

Measurement limits: Not applicable.

Expected range: 10 m.

Accuracy: 100 mm.

Directional radar measurements

Purpose: Provide 3-D description of geologic structures at the test drifts prior to excavation. Will be used as background information on rock mass heterogeneity along test drifts, important in evaluating EDZ properties measured by other methods and assessing their dependance on geologic conditions. Data will be used to determine exact location of test rounds in D&B drift.

Measurement specification: Measurements will be made in boreholes C2, C3, C6 and A2, A3, A6 prior to excavation using the RAMAC directional radar system.

Nominal frequency: 60 MHz .

Measurement density: Single hole measurement. 0.5 m spacing between measurement points in each hole.

Measurement limits: Not applicable.

Expected range: 20-25 m.

Accuracy: Location of identified reflectors: ± 1 m
Orientation: <10-15 degrees (solid angle).

Resolution: 1 m.

Stress magnitude and orientation

Purpose: Determine the magnitude and orientation of principal stress components in the neighborhood of the test area. Important reference data for interpreting observed EDZ properties.

Measurement specification: Measurements by overcoring. Three successful measurements in the same hole.

Measurement density: One location

Measurement limits: 0-1000 MPa

Accuracy: Stress magnitude: 1 MPa (depends on modulus)
Orientation: 15 degrees (solid angle)

Borehole surveying

Purpose: Determine location of borehole along its extent. Essential for processing of tomography data and location of instruments close to drift perimeter.

Measurement specification: Measurement by Maxibor.

Measurement density: 3 m spacing.

Accuracy: 10 mm

Surveying

| | |
|---|---|
| Purpose: | Determine location of boreholes (collar locations), drift perimeters, remaining core barrels, fractures, etc. |
| Measurement specification: | Measurement by standard geodetic instrument. |
| Measurement density: | Two tunnel profiles at every round. |
| Accuracy: | 1 mm |

## B ON-SITE REQUIREMENTS FOR PERFORMING THE TEST

The following equipment or services are required:

- One production drill rig
- One diamond drill rig
- Ventilation
- Pressured air (12 to 15 bars with very small volume)
- Power (220 V - 3 A)
- After each blast:
  - scaling
  - bolting
  - mucking
  - transport

- A container or shelter to protect the equipment (3 x 4m)
- Protection for cables

- Adjustable access platform (0-4m)

# List of International Cooperations 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

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