INCORPORATING THE EXCAVATION DISTURBED ZONE (EDZ) INTO THE DESIGN OF THE NIREX ROCK CHARACTERISATION FACILITY (RCF)

D W MELLOR and N DAVIES
United Kingdom Nirex Limited, Curie Avenue, Harwell, Oxfordshire, UK

ABSTRACT

United Kingdom Nirex Limited ('Nirex') has applied for permission to construct a Rock Characterisation Facility (RCF) within the Potential Repository Zone ('PRZ') at Sellafield in Cumbria (UK). The purpose of the RCF is to enable Nirex to decide whether or not to propose the development of a repository at Sellafield and, subsequently, to develop an evaluation of post-closure safety that will enable a decision to be made on the authorisation of disposal of wastes when, and if, a repository is constructed. The facility will be constructed in three phases. Phase 1 comprises construction of two shafts, and underground gallery development. Phase 2 involves construction of three 150m-long galleries and an intensive programme of scientific investigation. Phase 3 is an extension to Phase 2, providing greater coverage. All three phases integrate a range of scientific activities with the construction work. This paper describes the rock mechanical data acquisition to be undertaken within the proposed RCF, and outlines how these investigations will influence the design and construction programme of the facility.

The design of the geotechnical data acquisition programme will take cognisance of the practical experience gained in underground laboratories and in the ZEDEX project, in which Nirex is a participant. During Phase 1 temporary suspension of shaft sinking will be programmed to allow profile, convergence and stress measurements, rock mass response measurements, and to monitor the development of the Excavation Disturbed Zone. These measurements and their implications for shaft design and programme, are described. During Phases 2 and 3, two experiments are currently planned to measure the extent and magnitude of the Disturbed Zone; an EDZ experiment, to study the development of the EDZ, and a "mine-through experiment" which studies the mechanical and hydraulic response of a fault as it is mined through. Measurements before, during and after excavation will be made with the construction process operating on a "go-slow" basis to allow progressive deformation to be measured. These types of experiments have important effects on the construction of the RCF.

1. INTRODUCTION

United Kingdom Nirex Limited (Nirex) is responsible for developing and managing a national disposal facility for solid intermediate-level (ILW) and low-level (LLW) radioactive waste [1]. Investigations began in 1989, initially at two sites (Sellafield in West Cumbria and Dounreay in Northern Scotland), and in 1991 Nirex announced that it was to concentrate its investigations at Sellafield (Figure 1).

A range of surface-based investigations are proceeding in and around the Potential Repository Zone (PRZ - the block of rock within which the repository could be located) at Sellafield to provide data that will enable a Post-Closure Performance Assessment of the site to be undertaken to establish whether a repository at the site could meet regulatory requirements [2].

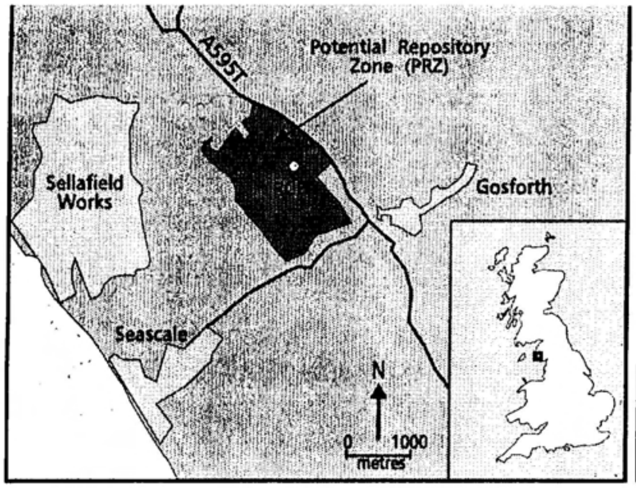

Figure 1 Location of Sellafield

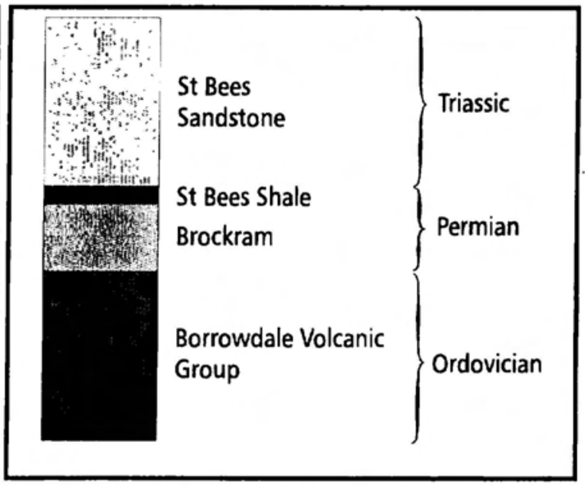

Figure 2 Schematic stratigraphy of the repository site

To date the investigations have comprised drilling at 22 borehole sites to obtain core, in-situ stress data, and to provide access for hydrogeological and geophysical investigations. These investigations have defined the geological structure and succession of the site. The potential repository host rock is the Ordovician Borrowdale Volcanic Group (BVG around 440 million years old) and comprise mainly andesitic and dacitic, pyroclastic and volcaniclastic rocks. These are unconformably overlain by the Permian Brockram (a basal breccia of BVG clasts set in a muddy, silty matrix) and St Bees Shales which are themselves overlain by the Triassic St Bees Sandstones (red, fine to medium grained sandstones). This is shown in Figure 2.

2. THE ROCK CHARACTERISATION FACILITY (RCF)

2.1 The need for an RCF

The surface based investigation programme has enabled Nirex to gain a very good appreciation and understanding of the geological and hydrogeological conditions that exist at the site. Investigations to date have been successful, however there remain 3 key areas of uncertainty that cannot be resolved adequately solely on the basis of surface investigations: (a) groundwater flow and radionuclide transport, (b) natural and induced changes to the geological barrier, and (c) design and construction of the repository. As a result, Nirex announced in October 1992 its decision to develop an underground Rock Characterisation Facility (RCF) at Sellafield [1]. The RCF will provide the means by which Nirex can acquire data to help understand the characteristics of the site in relation to the three remaining key areas of uncertainty. The data acquisition activities are planned for the RCF to deliver the necessary information to enable Nirex to make a decision on whether to submit a planning application to construct a repository at Sellafield and, subsequently, to develop an evaluation of post-closure safety that will enable a decision to be made on the authorisation of disposal of wastes when, and if, a repository is constructed. Geotechnical data, focused on excavation disturbance, are needed for the latter two key areas of uncertainty.

2.2 The design of the RCF

The RCF is designed as a three phase facility (Figure 3). Phase 1 comprises the construction by drill and blast of two 5m internal diameter shafts (termed North and South shafts), 50m apart, to the facility depth. The South shaft will start construction ahead of the North shaft. A cautious blasting technique will be used to limit blast damage. The final depth for the shafts will be decided during shaft sinking. It will be between 765m below ground level (bGL), and 1020m bGL. Measurements and tests will be conducted in the shafts, and during shaft sinking the groundwater response will be monitored from surface boreholes. Both shafts will have a hydrostatic concrete lining emplaced from surface to the Brockram at about 500m bGL. Subsequent to the connection of the shafts at the chosen depth, a 9 month period of experimentation will commence. Phase 2 will comprise the construction of 3 main galleries; two of these galleries are currently planned to be parallel to the average maximum horizontal principal stress direction (σ1), currently interpreted to be around 345° from True North, whilst the third will be perpendicular to it. Additional excavations will be made for specific experiments. These galleries will permit the Phase 2 experimentation and testing programme to commence. Phase 3 is planned to extend the NNW and SSE galleries between 375-600 m in length. The total duration of the project is around 10 years.

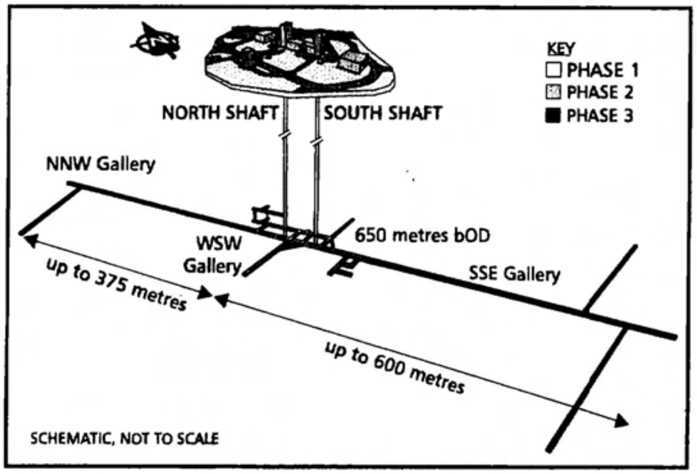

Figure 3 RCF phases and design

2.3 Managing and Planning data acquisition within the RCF

2.3.1 Flexibility. Nirex recognises that it is prudent to plan and manage the RCF on the basis that changes in the underground layout and/or the detail of the scientific activities are likely. This practical need for flexibility is a recurring theme in similar programmes elsewhere [3,4 10].

The approach that Nirex has adopted for providing a flexible method of managing data acquisition activities in the RCF is to divide the shafts and galleries into discrete sectors. Figure 4 illustrates the 12 sectors identified for use in managing the scientific programme during shaft sinking to 765m bGL (allowing construction of Phases 2 and 3 at 650m below Ordnance Datum). The choice of boundaries between the sectors has been based on the current geological data. Additional sectors will be required should the RCF be constructed at a deeper level. Nirex will release results from Phase 1 sector by sector, following completion of the work in each sector. Results and experience in completed sectors will be used iteratively to adapt work programmes and the detailed design for excavation in successive sectors.

Each sector will have a Test Plan setting out the activities and experiments which are to be undertaken. To design the tests in the light of the most up to date information so that the 'best' test is performed, each Sector Test Plan will be progressively developed in Outline form until three months before it is required for implementation. Whilst in Outline form each Sector Test Plan may be revised and updated in the light of results and understanding from previously completed sectors and from the continuing site characterisation programme. Three months before implementation, the Outline Sector Test Plans will be upgraded to 'Firm' status. The Firm Sector Test Plans will confirm activities and experiments to be carried out in any particular sector. Previous assumptions from the Outline Sector Test Plans will be modified and/or firmed up into requirements as distinct from working assumptions. The Firm Sector Test Plans will pass into the final category, 'Implementable Sector Test Plans', a matter of weeks before excavation of the particular sector. This presents a final confirmation of tests and experiments to be undertaken. This rationale allows the shaft sinking contractor to be informed progressively of the input to the data acquisition and experiment programme that is expected. This input, in terms of time, logistics, support, and personnel is essential to the effective implementation of both the experimental programme and shaft sinking.

2.3.2 Forward predictions. In radioactive waste safety assessment, validation is the term applied to the iterative process of building confidence in the fitness-for-purpose of models used in developing a performance assessment for a repository. Forward predictions before and during the excavation stage of the RCF will allow the validation process to be applied to a variety of contributing conceptual models relevant to developing the necessary assessment of the post closure performance of the site. This requires a range of information to be obtained from the RCF in order to test the predictions made from these models. Geotechnical predictions, undertaken prior to each sector's excavation will focus on rock mass response to excavation.

2.3.3 Excavation Disturbed Zone. Assessment of post-closure performance is based on the multi-barrier concept of waste disposal. The barriers are the physical containment afforded by the waste canisters themselves, a chemical barrier resulting from the use of a cement backfill emplaced around the waste canisters within the repository vaults, and the natural geological barrier. Measurements of excavation disturbance are a practical means of validating that the site characteristics are such that vault excavation disturbance will not significantly impair the containment performance of the natural geological barrier. Currently, views as to the extent and nature of the excavation disturbed zone (EDZ) are based on excavation projects at other sites and a knowledge of the in-situ stresses and rock quality at the site. On this basis, it is assumed that the hydraulic conductivity of the rock surrounding an excavation may increase by a factor of up to a hundred over a distance equivalent to twice the diameter of the excavation. During Phases 1 and 2, a programme of activities to monitor excavation is planned to be carried out in order to test this assumption. Integration with the construction programme is an important factor if the measurements are to be successful.

3. PROPOSED GEOTECHNICAL DATA ACQUISITION AND ITS INFLUENCE ON THE DESIGN OF THE RCF

This paper sets out an outline of geotechnical data acquisition for the RCF. Geological and hydrogeological programmes which form a major part of the RCF Science Programme are not described. It should be emphasised that the experimental plans are subject to change, particularly for Phase 2 and 3. What is described here is outline only giving an indication to the types of investigations Nirex may wish to carry out.

3.1 Rock Mass Quality

Establishing the rock mass quality of the shaft walls will be undertaken routinely as part of the shaft mapping activity. Mapping will take place from a specially designed shaft sinking stage (Figure 5). The stage, similar in design to that used at the Canadian URL shaft extension [5], will consist of two additional platforms slung underneath the main stage. The lower platform will allow an image of the shaft wall to be taken of the most recently blasted section of the shaft (termed round), whilst the platform above will allow geologists and geotechnical engineers to map the basic structure and rock mass conditions on to the image taken of the previous round. This constitutes the base mapping of the shaft, and will take about 2 hours per round. Specialist mapping will also take place at predetermined sections on particular areas of interest.

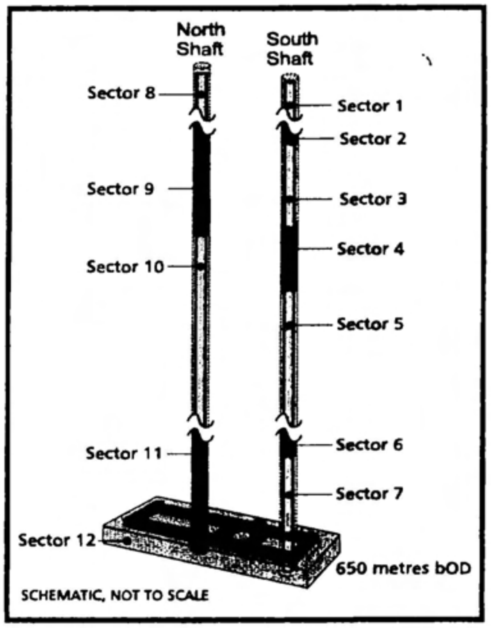

Figure 4 Phase 1 sectors

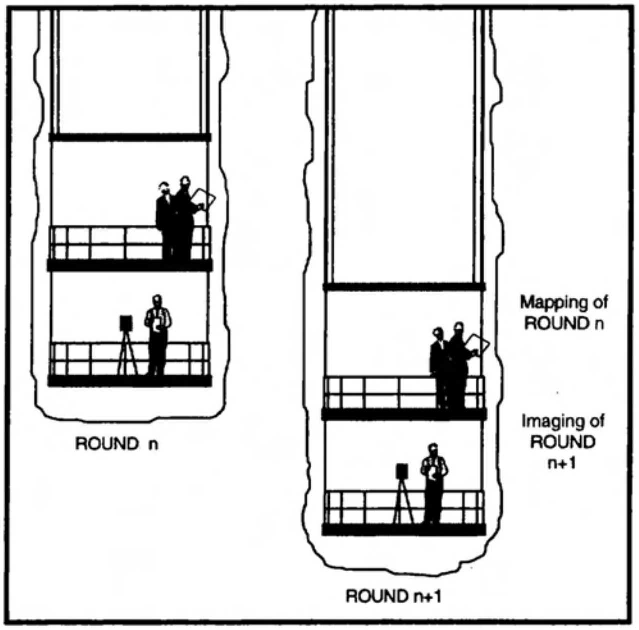

Figure 5 Mapping platforms

During horizontal gallery development, the morning shifts will be set aside for mapping. The design, and the schedule for excavation, incorporates the requirement for mapping.

The following geotechnical observations and measurements will be made as part of the base mapping activities in the shaft: general observations of the shaft wall, Q and Rock Mass Rating (RMR) from vertical and horizontal scanlines, geotechnical properties of the rock mass, and the rate of penetration of the drill per blast hole per round.

3.2 Measurement of Excavation Disturbance

Activities to measure and/or monitor excavation disturbance are of three types: (a) monitoring excavation response, (b) measuring the in-situ development of the EDZ, and (c) measuring excavation response of a fault or fracture. Measuring the development of the EDZ will occur only at a few selected horizons, but will, in association with excavation response measurements, characterise the extent of excavation disturbance and hence allow an evaluation of the implications for post-closure performance. Monitoring the performance of a fault or fracture zone as it is mined through will provide valuable information on flow paths and provide an assessment of vault stability in fractured areas that is required for the design and location of the repository.

3.2.1 Monitoring shaft excavation response.

(a) Displacements. Within each sector convergence arrays will be installed. These will consist of six or eight measurement pins mounted around the circumference of the excavation. Their installation will take place as soon as practically possible and as close as possible to the shaft sump. Measurements will be taken at frequent intervals. Instruments such as Multiple Point Borehole Extensometers (MPBX), and triaxial strain cells will be installed in boreholes drilled previously into the shaft wall. The boreholes are likely to be collared in a small recess that will be excavated as part of the sinking cycle. Predictions made before shaft sinking, will permit location of boreholes, and by association the recesses, in each sector. This information will be conveyed to the shaft sinking contractor via the Sector Test Plans. At each of these array stations the excavation process will be temporarily suspended to allow the boreholes to be drilled and the instruments to be installed. Each borehole will require a protective plate to be installed over the collar. MPBX's will be hardwired to portable dataloggers which will be housed in a protective recess above the array station, or hardwired to surface. Most of the arrays will be located in the BVG, however should any arrays be required in the sandstones, the design of the lining will incorporate access to the boreholes for monitoring purposes.

(b) Stress. These measurements will be undertaken by the overcore method. Stress measurements and back-analysis of stress from convergence and MPBX data at the same location will make an important contribution to confirming the overall picture of stress magnitudes and directions.

(c) Acoustic Emissions. Monitoring Acoustic Emissions (AE) induced by excavation has been used successfully at the Canadian URL [11], and at the Swedish Äspö HRL ZEDEX project [6] to measure the extent of the EDZ in terms of its temporal and spatial development. This technique will also be used to monitor the excavation response during shaft sinking. In ZEDEX, a period of 8 hours was allowed after every blast round to record AE events.

3.2.2 In-situ development of the EDZ

There are two types of investigations that will monitor the in-situ development of the EDZ:

(a) Under excavation during shaft sinking. The South shaft will be excavated in advance of the North shaft. This will enable instruments to be installed in boreholes drilled from the South shaft into the path of the North shaft. In this way it will be possible to measure undisturbed hydraulic and geomechanical properties of the rock mass, and then to monitor how these properties change as the North shaft approaches and passes through the instrument array. (Figure 6). This "before, during and after" measurement technique has been successfully deployed at the Canadian URL [7] and at the Äspö HRL [8].

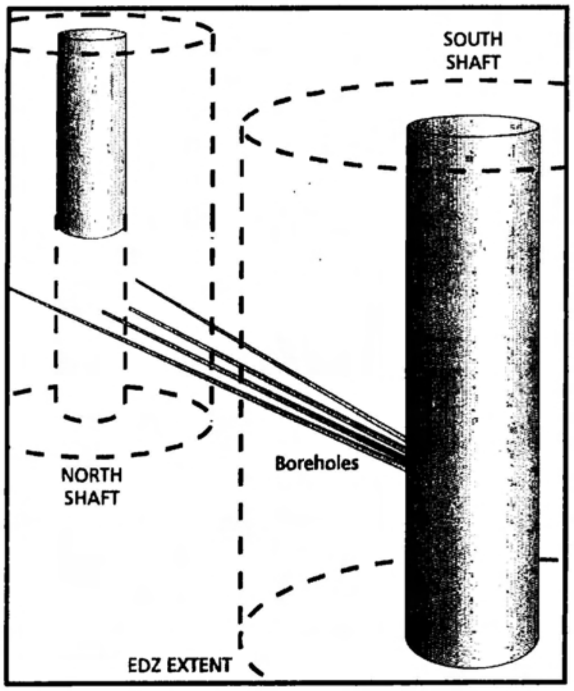

Figure 6 Conceptual 'Under-Excavation' array

Hydraulic conductivity and changes in hydraulic conductivity will be studied using specific hydraulic features intersected within the array location in the vicinity of the North shaft. Straddle packers will likely be deployed across selected intervals containing fractures to measure changes as the shaft is excavated past the array. Extensometers will be installed close to the path of the North shaft to measure radial displacements and stress cells will be installed to measure change in stress. In addition, convergence arrays will be installed in the North shaft in the vicinity of the array and AE data will be gathered during an 8 hour window after every blast in the vicinity of the test section. This will be built into the shaft sinking schedule.

The instrumented boreholes in both shafts will be hardwired into portable dataloggers located in protected recesses, or hardwired to surface. It is likely that an EDZ array such as this will be installed in a sector of the BVG. Any arrays located in the overlying units will require discussions with the shaft sinking designers and contractors to establish what is operationally viable at these locations.

Shaft sinking within the under-excavation array in the North shaft will operate on a 'go-slow' basis to allow convergence measurements to be taken at every station, detailed geotechnical and discontinuity mapping and profile measurements of all the rounds associated with the test section, and AE data to be recorded after every round. The test section will be focused on 1 or 2 rounds in the North shaft, but monitoring will take place a number of rounds before and after the test section (to be decided from pre-modelling).

<u>(b) EDZ Experiment after shaft sinking.</u> Measuring the development of the EDZ during shaft sinking is limited by the constraints imposed by shaft operational safety, programme, logistics and ultimately, cost. Measuring the EDZ from horizontal galleries however, provides for more scope and flexibility to allow a fuller investigation. Three EDZ experiments are currently planned after shaft sinking: one in Sector 12 at the close of Phase 1 which will help to inform the decision on whether to propose development of a repository, and two in Phase 2 to assess the influence of the principal stress direction on the development of the EDZ. The Phase 2 tests will be conducted in dedicated galleries excavated parallel to and perpendicular to $\sigma 1$. The final locations of experiments are likely to be confirmed via a peripheral drilling programme which is integral to the design of the RCF. The conceptual design of all three experiments is similar, drawing on experience of comparable experiments conducted overseas, in particular the Swedish Äspö HRL Zedex project [8], the Canadian URL mine-by [9] and Room 209 [7] experiments.

The objectives of an EDZ experiment in a horizontal gallery are to monitor the progressive development of rock mass disturbance induced by excavation, to measure the extent of the EDZ in terms of its hydraulic significance, and to measure the magnitude of change in rock mass properties. The direction of the test gallery in relation to σ1 will influence the size and magnitude of the EDZ. To achieve these objectives will require before, during and after measurements of the rock mass. Each experiment will be conducted in a dedicated gallery away from the main galleries of the RCF itself, this will allow the experiment to progress to its own programme rather than 'fit in' to the RCF construction programme. To enable measurements to be taken before construction of the test gallery will necessitate dedicated drilling recesses either to the side as depicted in Figure 7, or well ahead of the test gallery itself. The experiment concept is likely to contain the following elements:

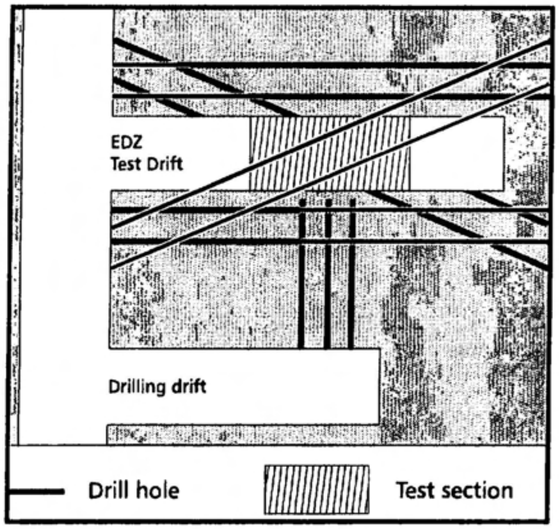

Figure 7. Conceptual layout of the investigation areas of the Phase 1 EDZ experiment (plan view)

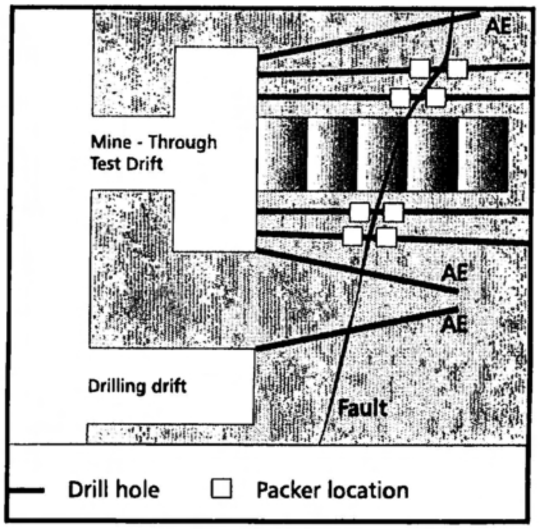

Figure 8. Conceptual layout of Mine-through test

Diamond-drilling of radial and axial boreholes ahead of gallery excavation to intersect the 'test' section for installation of:- MPBX's, stress cells, AE arrays to surround the test section, packer systems, and seismic tomography close to the gallery path before and after excavation to allow comparisons of P and S wave velocities to be made and related to preferential displacement paths. The gallery, which is likely to be around 5 metres in diameter, will be excavated by cautious blasting. Each round will be excavated at pre-determined lengths in the range of 1-2 metres. Each round, which will be monitored for blast diagnostics, will be geotechnically mapped, have convergence measurements made, and have borehole measurements taken after each blast. When the experiment drift has been completed (length in the order of 30 metres), monitoring of some of the instruments will be continued for the life of the RCF to assess any transient effects. In addition, as in the ZEDEX project, the properties of the immediate damage zone (in particular the microcracking) will be investigated by high resolution permeability measurements and P and S wave velocity profile techniques undertaken in 3-4 m long radial boreholes drilled at selected intervals.

3.3 Measuring the excavation response of a fault or fracture zone

To determine the flow paths, and hence the flux of groundwater into the proposed repository, an understanding of the effects excavation will have on flowing features is needed. An experiment is therefore planned to be carried out in Phase 3 that will provide information on the mechanical and hydraulic response of a fault or fracture zone to excavation. The experiment, termed 'mine-through', will involve locating an hydraulically active feature, characterising it, and then mining through it to monitor the response. This is similar to the Room 209 Excavation Response experiment conducted in the Canadian URL [7].

The test configuration will be similar to the EDZ experiments in that before, during, and after measurements will be made. Boreholes drilled ahead of the dedicated test gallery from drilling recesses will intersect the test fracture. Extensometers will be installed with their anchors placed either side of the fracture to enable actual dilation and/closing to be monitored. Similarly, straddle packers will be placed across the fracture to monitor change in hydraulic pressure. In addition triaxial strain cells will be installed in boreholes close to the fracture to measure change in stress. The test gallery will be mined on a 'go-slow' basis with rounds in the range of 1-2 metres in length. Measurements will be made in all boreholes after every round. The drift will be mined through and beyond the fracture (the length of the drift will be decided from pre-modelling) to assess any transient effects. AE monitoring focused on the fracture away from the drift could be used to measure the zone of influence of excavation. A conceptual layout for the mine-through experiment is shown in Figure 8.

4. SUMMARY AND CONCLUSIONS

Geotechnical investigations are required to provide data to address two key areas of uncertainty; natural and induced changes to the geological barrier, and design and construction of the repository. Surface investigations currently underway at the preferred repository site (Sellafield) are proposed to be complemented by underground investigations in a site specific Rock Characterisation Facility.

The planning of investigations for Phase 1 of the RCF is centred on providing information necessary to quantify the development of the disturbance induced by shaft and gallery excavation. The following geotechnical investigations are planned to be undertaken during shaft sinking: pre-modelling of shaft excavation response, mapping, convergence and stress measurements in every sector, shaft wall response arrays in selected sectors, rock support monitoring in every sector, and under-excavation to measure EDZ development around the North shaft, installed from the South shaft.
A major EDZ experiment is planned to be undertaken in a dedicated gallery following completion of shaft construction. It will be designed to measure the progressive development of the EDZ around an instrumented gallery, and provide data on the immediate damaged zone. This experiment will be conducted away from the main RCF galleries so that it is not constrained by the RCF construction programme. The site of the experiment, as with all experiments in Phases 2 and 3, will be confirmed using peripheral drilling. Investigations in Phase 1 are designed to provide data to help inform the decision on whether to apply to develop a repository at Sellafield. Two additional EDZ tests are planned for Phase 2. These will be conducted in dedicated galleries parallel and perpendicular to $\sigma 1$ to assess the influence of stress on the

development of the EDZ. A mine-through experiment in a dedicated gallery is planned for Phase 3 where a previously characterised fracture is instrumented and monitored as a drift is mined through it.

REFERENCES

[1] NIREX, 1992; - "A Rock Characterisation Facility Consultative Document"; Nirex Report No. 327 UK Nirex Ltd,. Harwell. October 21, 1992.

[2] HICKFORD, G., BILLINGTON, D.E., "1994 NUCLEAR ENERGY" - Journal of the British Nuclear Energy Society, Volume 33 Number 1; pp 19-24, Special Issue - The Nirex Repository, February 1994.

[3] SIMMONS, G.R., BILINSKY, D.M., DAVISON, C.C., GRAY, M.N., KJARTANSON, B.H., MARTIN, C.D., PETER, D.A., KEIL, L.D., LANG, P.A. "Programme of experiments for the operating phase of the Underground Research Laboratory"; page 2; 1992. Atomic Energy of Canada Limited. -10554, COG-92-280, AECL, Pinawa, Manitoba. September 1992.

[4] OLSSON, O., "Test plan for ZEDEX - Zone of Excavation Disturbance Experiment." Äspö Hard Rock Laboratory Release 1.0, February 1994.

[5] EVERITT, R.A., CHAPMAN, A.E., GROGAN, A.V., LADEROUTE, D., BROWN A., "Geological Characterization for the Underground Research Laboratory Shaft Extension" Atomic Energy of Canada Limited, TR-495. URL-EXP-006-R2. AECL, Pinawa, Manitoba. August 1990.

[6] FALLS, S.D., YOUNG, R.P., "Acoustic Emission Monitoring of the Drill and Blast Drift". Äspö Hard Rock Laboratory Technical Note 25-95-13z, May 1995.

[7] SIMMONS, G.R., "The Underground Research Laboratory, Room 209 Excavation Response Test, A Summary Report," Atomic Energy of Canada Limited, a-10564, COG-92-56. AECL Pinawa, Manitoba. February 1992.

[8] OLSSON, O. (Ed), "A Preliminary Assessment of Results from the D & B Drift." Äspö Hard Rock Laboratory, Technical Note 25-95-27z, June 1995.

[9] READ, R.S., MARTIN, C.D., "Monitoring the excavation-induced response of granite." U.S. Symposium on Rock Mechanics, Santa Fe, NM, June 1992.

[10] SKB, "Äspö Hard Rock Laboratory Annual Report 1993"; page 22; SKB Technical Report 94- June 1994.

[11] MARTIN, C.D., YOUNG, R.P., COLLINS, D.S., "Monitoring Progressive Failure Around a Tunnel in Massive Granite". 8th International Congress of the International Society for Rock mechanics, Tokyo, Japan. September 1995.