

TECHNICAL REPORT 87-23

**Program for the Stripa Project Phase 3
1986–1991**

May 1987

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FOREWORD

The history of the planning and implementation of Phase 3 of the OECD/NEA Stripa Project encompasses a time period of over two years. At a meeting of the Technical Subgroups in Sweden in September 1984, it was decided that a more comprehensive plan with well defined goals should be developed prior to initiating any further investigations of fluid flow in fractured rock masses at the Stripa Mine. During the months following that meeting, a small group of technical specialists met for the purpose of developing a preliminary notion of how to integrate site characterization, groundwater flow and transport, and geochemistry technology in future investigations at the Stripa Mine. Consideration would be given to a sizable volume of rock mass in the Stripa Mine for the purpose of such investigations. Additionally, the Principal Investigator for the borehole and shaft sealing tests was asked to suggest an initial framework of an integrated project that covered the research areas of interest to engineered barriers and rock mechanics. In March 1985, the Technical Subgroups convened a meeting in Switzerland. During that meeting, a preliminary program for a tentative Phase 3 of the Stripa Project was discussed. The intended duration of a Phase 3 was established as five years, beginning in 1986. Emphasis would be placed on investigations that would represent an integration of the technical knowledge developed in Phases I and II of the Stripa Project. Specific goals were established, and proposals for tentative investigations were reviewed.

In June 1985, the Joint Technical Committee met in Sweden and agreed to proceed with the planning required for the initiation of a Phase 3. The following general objectives of a third phase were agreed upon:

- * To integrate various site characterization techniques and methods of analysis for the prediction and validation of ground-water flow and nuclide transport in an unexplored volume of Stripa granite.
- * To demonstrate and verify the use of different materials and techniques for sealing ground-water flow paths in the Stripa granite.

A schedule for the solicitation review of proposals was established, and the authors were instructed by the Joint Technical Committee to develop a Program Plan for review by the member countries.

In August 1985, the Project Manager and the two Chairmen of the Technical Subgroups met in Switzerland and developed this Program Plan, complete with both technical and budgetary elements, for a Phase 3 of the Stripa Project. The general areas of investigations were defined as:

- * Site characterization and validation.
- * Improvement of site assessment methods and concepts.
- * Sealing of fractured rock.

The plan was subsequently reviewed by the member countries, and the various investigators were asked to submit more detailed research proposals.

In March 1986, the Technical Subgroups met in Sweden and reviewed the proposed investigations under a Phase 3 of the Stripa Project. In May 1986, the Joint Technical Committee met in Sweden and (a) approved Phase 3 of the Stripa Project, (b) combined the two Technical Subgroups into a single Technical Subgroup, and (c) established a Task Force on Sealing Materials and Techniques. In August 1986, the Principal Investigators were asked to submit detailed work plans for their research through December 1987. In September 1986, the Task Force on Sealing Materials and Techniques met in Sweden for the purpose of establishing an outline on the Table of Contents for a State-of-the-Art Report on Sealing Materials and Techniques, along with a schedule for the preparation, review, and publication of the document. In October 1986, the two chairmen of the Technical Subgroup met with the Stripa Project Manager in Sweden for the purpose of reviewing the various details and logistics required for implementation of the numerous investigations in Phase 3 and to evaluate the revision of the proposed investigation on tracer migration in channels in fractured rock. At a meeting of the Technical Subgroup in Finland in March 1987, the Principal Investigators for Phase 3 made detailed presentations of their intended work plans for review and comment. In May 1987, the Joint Technical Committee met in France and reviewed the implementation of the investigations in Phase 3.

The Project Management and the two cochairmen of the Technical Subgroup wish to express their gratitude to the various Principal Investigators and members of the Technical Subgroups for their contributions and suggestions for the development of a research program for Phase 3 and to the Joint Technical Committee for their guidance and encouragement in the implementation of this Program Plan.

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June 1987

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INTRODUCTION

This document presents the program plan for Phase 3 of the International Stripa Project. In order to place the document in perspective, several questions need to be answered. First, why choose granite as a potential host medium for a waste repository? Second, why carry out research? Third, what is the status of this research? Finally, and fourth, what is the rationale behind the research program presented in this document for Phase 3 of the Stripa Project?

1.1 WHY LOCATE A REPOSITORY IN GRANITIC ROCK?

Granites and gneissic rocks, being typically very hard, crystalline, igneous rocks of low inherent permeability with any significant flow being restricted to joints and fissures, are considered by many experts to possess physical and chemical properties which make them suitable for the isolation of radioactive wastes. This reasoning has led to a considerable research effort being devoted to the assessment of the technical feasibility and safety of disposal deep within granitic rock.

1.2 WHY CARRY OUT IN SITU RESEARCH?

It has been found that although generic studies indicate that disposal of radioactive waste in granitic rock is technically feasible and would possess a high degree of safety, research is needed to confirm these assessments and demonstrate, as far as practicable, that these judgements are correct. Such research can only be achieved by carrying out in situ experiments under conditions which closely mirror those to be encountered in an actual repository. It is only by carrying out such activities that confidence will be generated in proposed disposal solutions.

Preliminary safety assessments show that the most important components of a disposal system in granite in terms of the optimisation of protection are the engineered (vault) and geological (geosphere) barriers. For this reason, in situ research has concentrated on the development of techniques to maximise the effectiveness of the engineered barriers and methods to obtain detailed hydrological and hydrochemical information under field conditions. Both these activities require a high degree of innovation because these are areas where

previously very little work has been carried out. It was primarily for these reasons that in situ research was started in 1977 at the Stripa Mine. A series of initial experiments were carried out under the Swedish American Cooperative (SAC) Programme to develop techniques to measure certain in situ properties in the Stripa granite. These included thermomechanical, hydrological, geophysical and geochemical aspects. The International Stripa Project began in May 1980 based on the strength of the results of the SAC Programme and the interest shown by OECD Member countries. Phase 1 was carried out from 1980-85 and Phase 2 began in 1983 and is due to be completed in 1986. The research is carried out under four main headings:

- Hydrogeological investigations of the Stripa granite and migration of nuclides within single and multiple fracture systems,
- The hydrogeochemistry of groundwaters at the Stripa Mine,
- The detection and characterization of fracture zones in granite, and
- The behaviour of bentonite clay as a backfilling and sealing material under field conditions.

1.3

WHAT IS THE CURRENT STATUS OF RESEARCH?

The latest results and current status of research are summarised in the Proceedings of the Second NEA Stripa Project Symposium on In Situ Experiments in Granite Associated with the Disposal of Radioactive Waste, which includes results from Phase 1 and early findings from Phase 2. This is backed-up by comprehensive reports of research carried out under Phase 1 and numerous supporting documentation. From these, it is clear that Phases 1 and 2 can be regarded as periods where suitable tools were acquired and developed to meet the particular needs of those wishing to locate and investigate potential sites. It has been found that a suite of measurements should be made to map the distribution and extent of fracture zones, including specifically adapted geophysical, radar and hydraulic investigation techniques. Methods have been developed to assess the migration in single and multiple fractures of sorbing and non-sorbing tracers in large scale in situ experiments within the Stripa Mine. Complementary to this, a comprehensive series of sampling and chemical analyses of Stripa groundwaters has yielded an improved understanding of the hydrogeochemical properties and history of the groundwater in the granite. From the engineering design viewpoint, the

Buffer Mass Test validated mathematical predictions of the behaviour of bentonite clay under the temperatures likely to be encountered in a repository. Further, borehole, shaft and tunnel sealing experiments are underway in Phase 2 to assess the effectiveness and behaviour of bentonite as a sealing medium.

1.4 WHY CARRY-OUT A PHASE 3?

From the results already generated from Phases 1 and 2, it is clear that significant progress has been made in developing the tools necessary for the detailed investigation of a potential repository site and in optimising the isolation capability of the vault. The natural progression of the project would be to continue the development of these techniques by applying them under strictly controlled research conditions to an unexplored volume of granite. Furthermore, linking the measurement techniques with predictive mathematical models so that predictions made of groundwater flow and solute migration can be compared with data from field measurements. Concurrent with this should be the continued refinement of more innovative field investigation such as the cross-hole and migration tests and the development of a site specific 3-D network model of the research area. In addition, further effort is required to identify and assess, by demonstration and verification, the long term stability and injection technique for sealing materials which will be necessary to optimise the performance of a repository in granitic rock.

1.5 THE PHASE 3 PROGRAM

The above rationale was discussed by the Joint Technical Committee of the Stripa Project at its meeting on 7th June 1985. Broad objectives were agreed for a Phase 3 to run from 1986 to 1991 at roughly the present annual level of funding. Following this, an outline five-year program was drafted by the two chairmen of the Technical Sub-Groups (TSG's) and the project management, using as a basis the agreed objectives and proposals made by the Participating countries. This was then circulated to project members for comments and preferences and using the revised outlines a group of leading researchers and the project management developed the detailed program described in this document (2nd-6th December 1985). Some hard decisions have been taken to restrict the program to the funding available, but nevertheless, it is considered that the

program fully addresses the objectives agreed by the Joint Technical Committee.

The Phase 3 Program continues and builds on the work carried out under Phases 1 and 2 and also develops new areas of research. An unexplored volume of granite (about 125 m x 125 m x 50 m) will be studied for which a combined deterministic/statistical flow model will be developed and compared with data from field measurements. This modelling approach will be used because several members of the Stripa project consider it important for their programs to investigate a method of analysis alternative to equivalent porous media modelling, for volumes of fissured crystalline granitic rock of this magnitude. If successful, this will significantly enhance the confidence in the application of predictive mathematical models to site specific conditions.

The further development of the high resolution and directional radar, the Stripa Project is already considered to be at the forefront of the development of this tool, together with high resolution borehole seismics will ensure the transformation of these research tools to fully fledged site investigation techniques. It must be emphasised that such non-destructive crosshole measurement techniques will be indispensable when investigations of actual disposal sites are proposed such that there must be as little disturbance of the host medium as possible and yet yield sufficient information to satisfy the needs of safety assessments and engineering design.

Observations at Stripa on flow in fractures has revealed that it is not realistic to treat a fracture as two planar parallel surfaces with constant width, rather, what appears to be randomly distributed channels, are thought to exist. The present concept of these channels suggests that mixing of waters occurs irregularly and that zones of stagnant or near stagnant water are present where diffusion controlled transport dominates. Phase 3 includes provision for the continuation of tracer experiments to investigate flow in fractures so that this important phenomenon, "channeling", can be more fully understood. The culmination of this will be a large scale tracer experiment as part of the Phase 3 investigation of the unexplored volume of granite. Comparison of the results with mathematical predictions will be made in a further validation exercise.

New work on the estimation of fracture length and aperture using hydraulic measurement techniques will yield a tool to complement fracture analysis carried out in tunnel excavations. Again this is important in predicting water flow and in optimising the engineering

design. Also of importance in engineering is the use of sealing materials to restrict the migration of radionuclides from a repository. A project is included which comprehensively evaluates available sealants for use in the optimization of a repository.

It can be seen from this document that the ultimate product of the Phase 3 Program will be the applicability of the tools and know how to assess a potential radioactive waste disposal site. Techniques will be available to carry out non-destructive site investigations which will have been fully evaluated under rigorously controlled in situ conditions, together with sealing methods designed to optimize the isolation potential of a repository established within crystalline granitic rock.

OBJECTIVES

The research activities in the third phase of the Stripa Project will be carried out under two headings

- Fracture Flow and Nuclide Transport; and
- Groundwater Flow Path Sealing.

2.1 FRACTURE FLOW AND NUCLIDE TRANSPORT

The main objectives are

- to predict groundwater flow and nuclide transport in a specific unexplored volume of the Stripa granite and make a comparison with data from field measurements. The comparison will be made by means of an integrated approach with existing site characterization tools and methods, particularly those developed under Phases 1 and 2,
- to continue the development of site assessment methods and strategies and, where found appropriate, apply them in later stages of the integrated site characterization exercise outlined above.

2.2 GROUNDWATER FLOW PATH SEALING

The principal objectives are

- to identify, select and evaluate sealing substances which promise to possess long-term chemical and mechanical stability; and
- to demonstrate in a pilot test, by use of suitable methods and techniques, the effectiveness of such substances for the long-term sealing of groundwater flow paths in the Stripa granite.

3 APPROACH

3.1 FRACTURE FLOW AND NUCLIDE TRANSPORT

In Phases 1 and 2 of the Stripa Project the research emphasis was placed on

- the development of tools and methods for the geological, hydrogeological and geochemical characterization of crystalline (granitic) rock; and
- the study and evaluation of possible mechanisms of nuclide transport by groundwater flow in fractures within the crystalline rock.

In Phase 3 the primary emphasis will lie on the application of the technology developed in Phases 1 and 2 to an unexplored and relatively undisturbed rock mass with the aim of

- predicting groundwater flow and nuclide transport inside the rock mass; and
- subsequently comparing these predictions with data from field measurements.

The relevant investigations in the Stripa mine are to be conducted in a granitic rock mass of the following approximate dimensions: 125 m by 125 m by 50 m (length-width-thickness).

In order to attain the objectives stipulated in Section 2.1 above, the envisaged research effort will be apportioned to two major subprojects, viz.

- Site Characterization and Validation; and
- Improvement of Site Assessment Concepts and Methods.

3.1.1 Site Characterization and Validation

This subproject will be carried out in five successive stages:

Stage I - Preliminary site characterization

To outline the boundaries of the "unexplored" rock mass an "optimum" number of boreholes is determined and the

location, length and direction of these holes established.

After drilling the "boundary boreholes", a series of characterization tests will be performed to provide a preliminary geological, hydrogeological and geochemical data base.

Stage II - Preliminary predictions

By means of the preliminary data base a conceptual model of the envisaged rock volume will be constructed. Preliminary predictions in terms of the geometry of the major features and the physical properties of the individual fractures will be made.

Stage III - Detailed characterization and preliminary validation

Several "detailed characterization holes" are drilled into the rock mass followed by a number of "validation drift holes" along the perimeter and the center line of a planned validation drift into the investigated rock mass.

On the basis of the data obtained from the detailed investigation of these boreholes the accuracy of the predictions by the conceptual model will be evaluated.

Stage IV - Detailed predictions

Prior to the excavation of the validation drift a final prediction of the fracture network geometry within the investigated rock volume will be attempted.

By the aid of data collected in Stages I and III as well as results from supporting investigations on fracture flow characteristics described in Section 4.2, a combined deterministic/statistical model will be calibrated and used for the prediction of results to be expected from water flow and tracer migration tests in the vicinity of and into the validation drift.

Stage V - Detailed evaluation

The validation drift into the site is excavated. The water inflow is measured and tracers are injected into the rock at selected intervals in the "validation drift holes" and if necessary, in additional injection holes.

The information obtained from the validation drift and the water inflow and tracer experiments will make it

possible to evaluate the accuracy of the final predictions made in Stage IV and develop a comprehensive set of characterization models of the investigated site.

3.1.2 Improvement of Site Assessment Methods and Concepts

The aim of this subproject is to improve existing tools, methods and concepts in order to enhance the quality of predictions, particularly with respect to the aspect of fracture flow.

In Phase 3 of the Stripa Project, research in the realm of fracture flow and nuclide transport will include, therefore the following supporting activities:

Development of High Resolution and Directional Radar

This subproject aims at a considerable improvement of the accuracy of the radar tool in determining the location of water bearing features.

Improvement of Techniques for High Resolution Borehole Seismics

To provide enhanced means for seismic and generally geophysical structure assessment.

Network Modelling

A three-dimensional fracture network flow model will be developed combining both statistic and deterministic approaches. It should enhance our ability to predict water flow and tracer migration into the validation drift at the test site.

Channeling Experiments

A number of experiments will be performed to improve our understanding of the physical and chemical conditions and processes that cause the very uneven flow (channeling) of water in fracture systems.

Estimation of Fracture Length and Aperture from Single Fracture Packer Tests

Certain essential parameters for fracture network modelling such as fracture length and aperture are

difficult to determine with existing techniques. A new method to achieve greater accuracy will be tested.

3.2 GROUNDWATER FLOW PATH SEALING

To meet the principal objectives set forth in Section 2.2 the research activities planned under this heading for Phase 3 will be grouped under the subproject

- Sealing of Fractured Rock

3.2.1 Sealing of Fractured Rock

In Phase 1 of the Stripa Project a large scale experiment (Buffer Mass Test) investigated the suitability of bentonite for

- the isolation of simulated heat-producing waste canisters from the groundwater in the surrounding granite; and
- the backfilling of a simulated disposal room with heat-producing deposition holes in the floor.

In Phase 2, the effectiveness of bentonite under isothermal conditions for the sealing of man-made openings in the granite, such as boreholes, small diameter shafts and tunnels, was tested.

In Phase 3, the emphasis will lay on the sealing of groundwater flow paths in the granite.

The programmed investigations will be conducted in the following successive stages:

Stage I - State-of-the-art survey of fracture sealing materials

A Task Force of experts in the field of sealing materials and techniques, representing the member countries, will be formed to convene and carry out a state-of-the-art survey of sealing materials and sealing techniques. Special emphasis will be placed on identifying substances that are expected to retain their sealing characteristics and capacity under repository conditions over long periods of time.

The Task Force will establish the range of thermal, thermomechanical, hydrogeological and geochemical conditions likely to prevail in a crystalline repository rock mass that could affect the sealing capacity

of selected materials in course of time.

Stage II - Determination of sealing materials and tests

For those materials that show the highest promise for the effective long-term sealing of groundwater flow paths in fractured crystalline rock, the Task Force will determine the methods by which the long-term stability of these materials can be convincingly demonstrated. Proposals for accelerated laboratory and, if considered useful, in situ tests will be made.

Stage III - Determination of the long-term stability

The tests proposed by the Task Force in Stage II will be performed according to their recommendations.

Stage IV - Field pilot tests

If the experiments under Stage III show that the selected materials can be expected to remain stable over very long periods, a field pilot test will be carried out to demonstrate the injection technique(s) appropriate for those materials and give information on the sealing efficiency under present-day conditions.

Stage V - Planning of large scale sealing test

If the field pilot tests are positive, the sealing efficiency of the grout will be tested in a large scale field test.

The present project comprise planning of this field test as well as finding ways of determining the distribution of the grouts in the fractures by applying radar technique or similar methods.

4 TASKS

4.1 SITE CHARACTERIZATION AND VALIDATION

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4.1.1 Introduction

The proposal aims to take measurements from a large volume of rock and predict the rock and groundwater conditions within a smaller part of this region. A series of numerical models will be used to make these predictions. The accuracy (validity) of these predictions will be assessed by excavating a drift and measuring the geometrical, water flow and solute transport properties of the fractures in the drift.

The predictions will be made using numerical models. The needs of these models determine what sort of data that will be collected within the "Site Characterization and Validation" project. In general there are three basic types of data required for both individual fractures and major features;

- geometry
- groundwater flow properties
- solute transport properties

The proposal is arranged in five stages so that data collection (Stages I and III) is followed by model prediction (Stages II and IV) in an iterative manner. The last stage is validation where the more detailed prediction (Stage IV) is checked by a final period of data collection (Stage V). Thus during the course of the Project there is a constant interplay between modelling and data collection.

4.1.2 Stage I - Preliminary Site Characterization

4.1.2.1 Drilling

The location of the new site makes it possible to drill the investigation holes from existing drifts. Five "boundary boreholes" will be drilled for preliminary characterization of the site: three holes towards the North (N2-N4) and two towards the West (W1-W2). These holes of 200 m length will be approximately 75 m apart, see Figure 4.1.2.1.

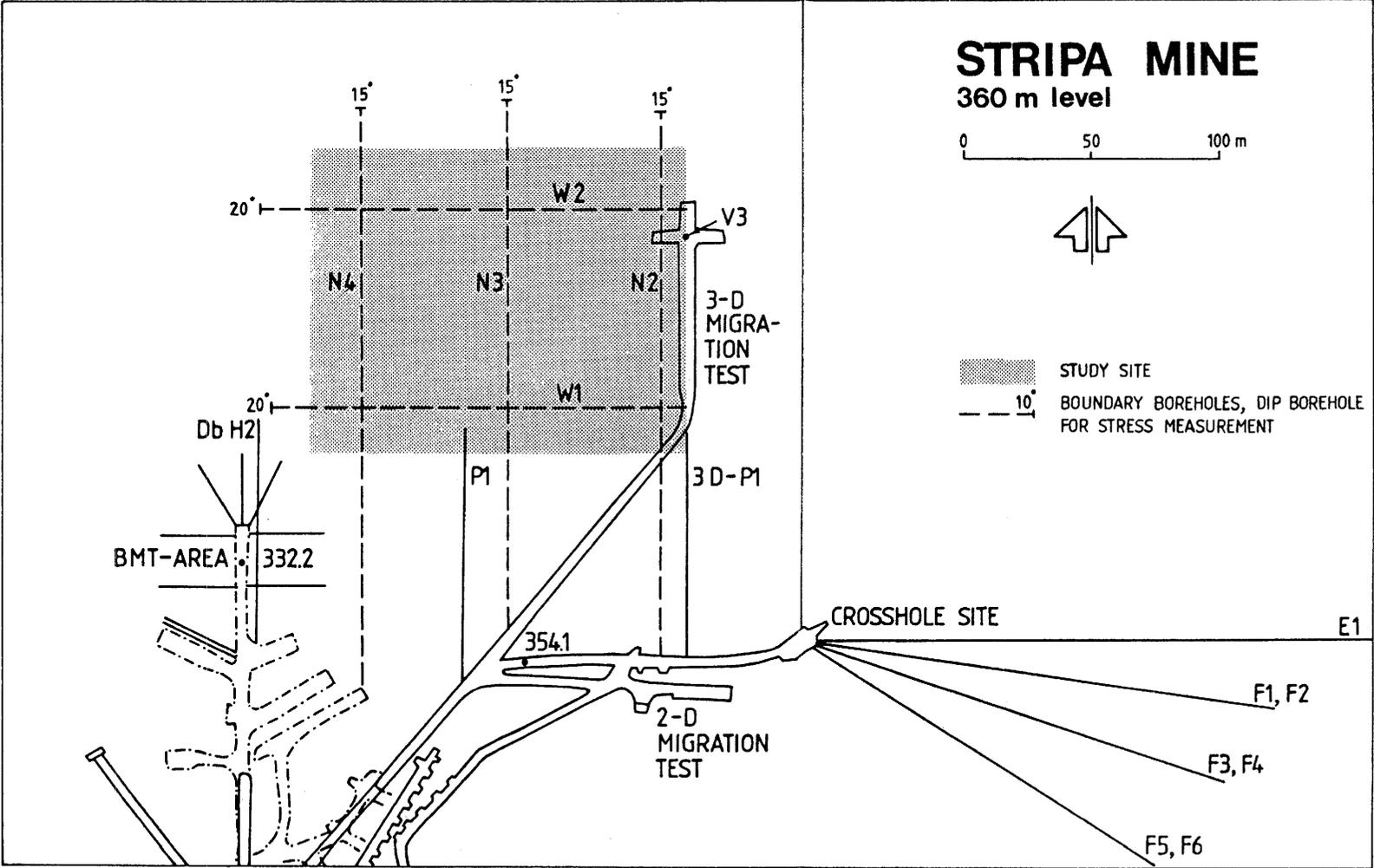


Figure 4.1.2.1 Location at the study site and Stage I boreholes.

A 50 m long vertical hole will be drilled at the end of the 3D-migration drift mainly for the purpose of measuring rock stress.

The total length of holes to be drilled within Stage I is estimated to be 950 m. The holes will be 76 mm in diameter (in order to make televiewer surveys possible) and fully cored.

4.1.2.2 Core logging and fracture mapping in drifts

Cores from each of the boreholes drilled during the preliminary site characterization will be mapped to show lithology, fracture locations and apparent dips, fracture minerals and fracture surface characteristics. This core data will be integrated with televiewer logs to provide structured computer files of the raw fracture data.

Drift walls will be photographed to provide a base for mapping the fractures intersecting the drift walls using both scan line and areal mapping approaches. This mapping program will produce detailed, user oriented, drift maps and structured computer data files.

The collected fracture data will be subjected to a detailed analysis in order to provide a statistical characterization of the orientations, trace lengths and spacings of each fracture set making up the fracture system. The fracture data will be integrated with the collected hydraulic data and a description will be provided, consistent with the fracture statistics, of the fracture permeability and apertures (corrected for roughness and contact area). This analysis will be designed to provide the basis for predicting and validating the fracture geometry of the test area and the data needed to generate the fracture network in the test area for both flow and pathway predictions.

4.1.2.3 Geophysical single hole logging

A set of geophysical logs will be used to obtain data on the physical properties of the rock in the vicinity of the holes. Data will be provided on lithological variations and fracture orientation. Fracture zones will be identified and characterized. The logs will also provide preliminary indications of hydraulically significant features and salinity variations. The following set of logs will be run;

- borehole deviation
- natural gamma log
- neutron
- point resistance
- normal resistivity
- sonic
- televiewer
- temperature
- salinity

This set of data will be used in the classification of large scale features and calibration of the radar and seismic investigations. The televiewer will orientate individual fractures.

4.1.2.4 Measurements on small core samples

A set of mechanical and geophysical properties will be measured on core samples.

Fracture surface features such as roughness and compression strength will be quantified, using the core from the boreholes. This quantification is designed to provide data for preliminary modelling of stress - closure - hydraulic conductivity coupling and shear - dilation - hydraulic conductivity coupling. Both these processes may influence the water inflow into the validation drift. Few of the fracture surfaces are expected to be longer than 100-150 mm and empirical methods are therefore needed to extrapolate the predicted behaviour to full-scale block sizes.

The fracture wall strengths are influenced by mineral coatings and alteration. The different strengths expected for each fracture set will be measured with a Schmidt hammer.

Fracture roughness will be characterized using the tilt test. About 50 samples per major joint set will be tested.

Geophysically important parameters such as high frequency electrical properties, density and porosity will also be measured on a few pieces of core.

4.1.2.5 Rock stresses

The stresses in the rock affect the openings of fractures and thus the hydraulic conductivity of the rock mass. The state of stress has been measured extensively at Stripa during the Swedish American Cooperative program and the Phase 1 investigations. However, it is not clear what the stress situation is like in the selected site to be studied. The direction

of the stresses should be known early in the program in order to optimize the direction of boreholes and drifts.

A 50 meter vertical, 76 mm borehole (V3), will be drilled at the end of the 3-D drift, see Figure 4.1.2.1. Five to eight hydraulic fracturing stress measurements will be performed between a depth of 10 m and the end of the hole. The fractures will be oriented using impression packers.

4.1.2.6 Borehole radar

The borehole radar measurements are expected to identify the large scale features which intersect the site and give information on their physical properties and lateral extent.

Single hole reflection measurements will be made in the five holes at two different frequencies. A low frequency to identify large scale features which extend far from the boreholes and a high frequency to identify smaller features closer to the boreholes.

Crosshole measurements will be made in the planes spanned by the boreholes and the drifts. Source positions in the drifts will be included. A tomographic inversion will be made of amplitude and traveltime data. The geometry of the fracture zones will be further assessed through the analysis of reflections identified in the crosshole data.

Based on experience from the Stripa Phase 2 investigations the range for low frequency reflection measurements is expected to be 100 m. It is expected that fracture zones with a thickness of a few tens of centimeters can be identified in the high frequency reflection measurements. The crosshole tomography is expected to give a resolution in the order of 3-4 m.

Directional antennas will not be used at this stage.

4.1.2.7 Borehole seismics

The equipment and processing techniques for the seismics will be similar to those used in Stripa Phase 2 but with a higher dynamic range and better contact between probes and boreholes. Additionally, the data will be processed on site.

Data will be collected for crosshole interpretation. Four sections are possible between the proposed boreholes: one between the holes going westwards and three using combinations of the three holes heading North, see

Figure 4.1.2.1. Measurements from the 3-D drift and the westward boreholes will also be carried out. Interpretation will use tomographic processing, reflection analysis and tube wave analysis.

The expected resolution with tomography alone is approximately 3 to 5 m which is acceptable for detecting large scale features. Reflection and tube wave analysis may improve this resolution.

The reader is referred to Section 4.2.2 for further details on the expected improvements of the seismic investigations.

4.1.2.8 Hydraulic investigations

An essential part of the site characterization is to determine the distribution of fracture permeabilities and hence fracture apertures. This applies to both small scale features and "major features".

The water-flow properties of the five new boreholes will be measured by the "single borehole" technique using straddle packers. The testing will adopt a variable spacing approach designed to provide adequate data on both the small scale fractures and the larger more conductive features.

Two of the boreholes will be tested with a short minimum spacing, low measurement limit configuration to assess the permeability and apertures of the small-scale fractures. This data set will be compared to and combined with the data set available from the nearby BMT area. This will provide the parameters for permeability and effective aperture distributions. These parameters are used to simulate flow through the fracture network and also to determine how much more data is needed for adequate site characterization.

Depending on the need for additional permeability and aperture data on the small scale features the other three boreholes will be tested primarily with a coarser interval designed to locate the more conductive features (identified by the geophysics). Additionally a limited number of short intervals (10-20) will be tested using a constant pressure injection method for a prolonged period (up to a day). This is to investigate the possibility of determining the size and spacing of effective conduits and distances to intersections/boundaries (see Section 4.2.5). Heads will be measured throughout this programme of testing to provide data for the boundary conditions of the model.

4.1.2.9 Hydrochemistry

The objective of the hydrochemical work is to supplement the geophysical and hydrogeological interpretation of major flow paths with data on groundwater chemistry. This data might indicate the interconnection of existing fracture zones and/or the presence of separate flow systems.

A movable straddle packer system with a 2 m spacing will be used for the collection of water samples from all the water bearing sections in the "boundary boreholes". The selection of the sections will be based on the results of the hydraulic tests.

The water will be analysed for main constituents; Na, K, Ca, Mg, Sr, HCO₃, Cl, F, Br, SO₄, isotopes; ¹⁸O, ³H, and redox sensitive components; Fe(tot), Fe²⁺, S²⁻, U. All water sampled will be filtered and the redox sensitive constituents will be analysed on site.

The contents of major ions and isotopes may be used to indicate different groundwater flow paths, whereas the redox sensitive elements will describe the redox conditions of the rock-water system.

4.1.3 Stage II - Preliminary Prediction

The data obtained as a part of Stage I will be compiled and integrated to construct a conceptual model of the investigated volume. This model should describe the location and extent of the major features (fracture zones) and their geological, hydraulic and physical characteristics. A statistical analysis of the fracture data will define the different fracture sets. The hydraulic, geophysical and rock stress data will be analysed in relation to the fracture sets to quantify the hydraulic significance of each set.

The properties of the small scale fractures will be described in terms of probability distributions and these will be included more generally within the modelling. Some assessment of the relative importance of different sets in controlling the overall flow would also be aimed at. This effect will be modified by the relationships between fracture deformation (resulting from changing stress) and hydraulic conductivity. A preliminary assessment, based on tilt tests, Schmidt hammer tests and using the model described by Barton, Bandios and Bakhtar (1985), will be undertaken at this stage.

The preliminary predictions that can be based on the described model will be mainly in terms of the geometry of the major features and the statistical properties of

the individual fractures. Based on the resulting model a part of the site will be selected for detailed characterization and preliminary validation of the predictions made on the geometry. This part of the site will later be excavated as a part of the final validation (Stage V).

4.1.4 Stage III - Detailed Characterization and Preliminary Validation

4.1.4.1 Drilling and excavation

It is estimated that 300 m of additional boreholes will be sufficient to characterize the smaller volume around the proposed drift. These "detailed characterization holes" (C1-C3) will be drilled parallel to the planned validation drift but some distance away (between 5 and 50 m). The location of the holes shown in Figure 4.1.4.1 is tentative.

During this stage of the program the access drift to the validation drift will be constructed, see Figure 4.1.4.1. The access drift may start either from the 360 m or the 410 m levels, but this will be decided when the results of the preliminary modelling become available. The length of the access drift is estimated to be about 120 m.

Five boreholes will be drilled just outside the perimeter of the validation drift together with a hole along its center line. Each of these "validation drift holes" (D1-D6) will be 100 m long, which will give a total borehole length of 600 m, see Figure 4.1.4.1.

4.1.4.2 Core logging and fracture mapping of access drift

The same procedures for core logging and fracture statistics as in "Stage I - Preliminary site characterization" (Section 4.1.2.2) will be used in this stage. However, the data obtained in this stage will also be used to validate the geometrical characterization of fractures from previous core and borehole measurements carried out in Stage I.

4.1.4.3 Geophysical single hole logging

The geophysical borehole logging in this stage will be similar to that of Stage I (Section 4.1.2.3). A major emphasis will be put on the use of the televiewer in the validation drift holes.

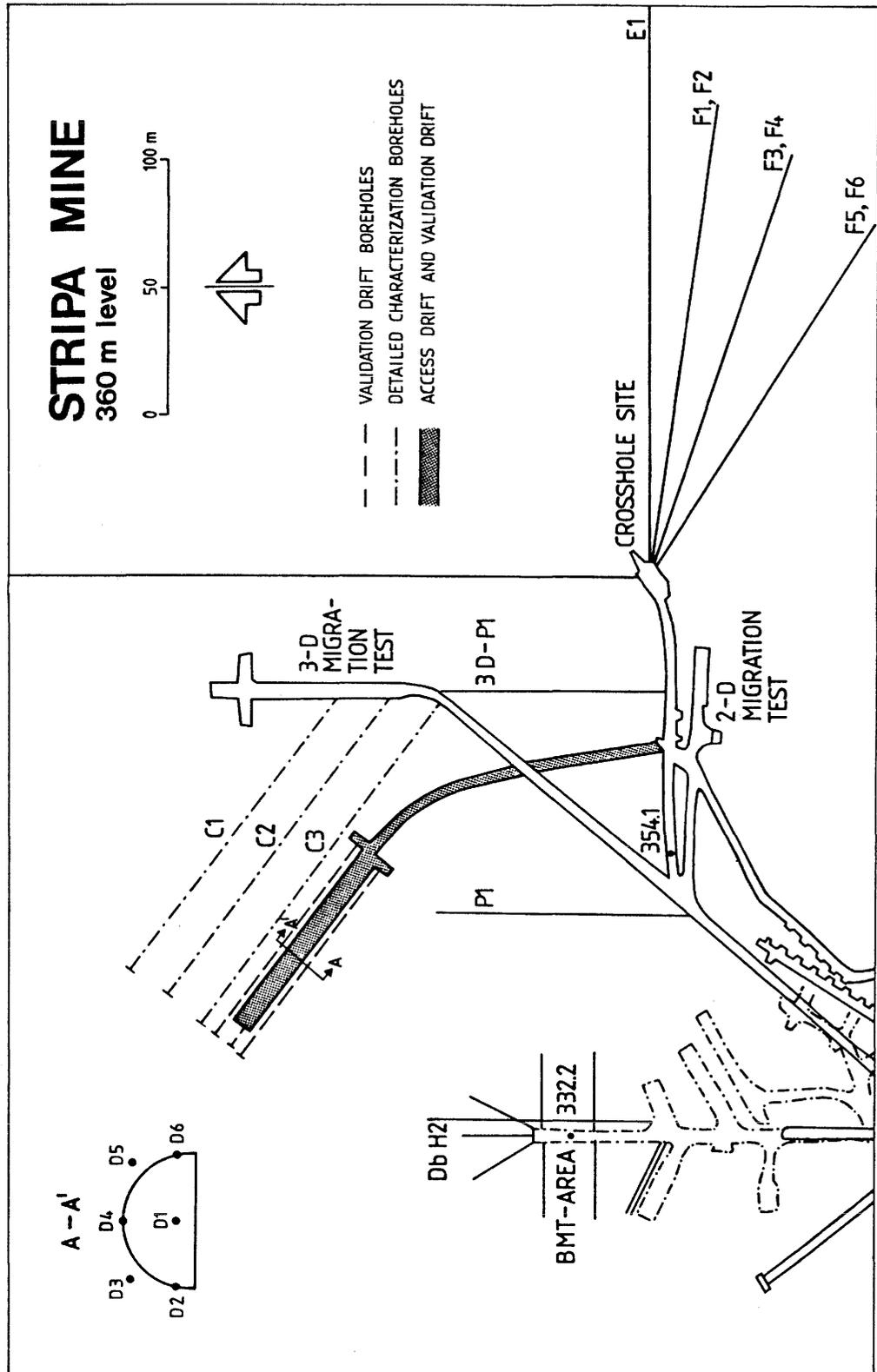


Figure 4.1.4.1

Tentative location of boreholes and drifts in Stages III and V.

4.1.4.4 Measurements on large core samples

In this detailed characterization stage the extrapolated small-scale mechanical data from tests on small core samples will be supplemented by tests on larger cores (around 150 mm in diameter). Samples will be recovered from the Channeling Experiments described in Section 4.2.4 and tested in a special biaxial loading facility developed at the Norwegian Geotechnical Institute, NGI.

This equipment allows joints to be flow tested while under different levels of effective normal stress and shear stress. It will therefore be possible to validate (and improve) the constitutive model describing stress-closure-conductivity and shear-dilation-conductivity coupling.

Following each volumetric flow rate measurement at different stress levels, the above samples will be tested for flow velocity using a tracer. This may indicate the degree of channeling that is occurring at a small scale, and it will also indicate how much the fracture opening is affected by changes in normal stress (causing closure and larger contact areas), and how much it is affected by shear stress (causing shear, dilation and reduced contact areas).

Channeling experiments using injected resin will be performed on additional large diameter cores. Tests will also be performed using clear epoxy cast replicas of fracture surfaces, and coloured dyes.

4.1.4.5 In situ test of fracture deformation.

One large scale in situ test is planned to help extrapolate predictions on deformation-conductivity coupling.

The typical mean spacing of principle fracture sets at Stripa is approximately 1 meter. A 1x1x2 m block containing a diagonal water conducting fracture will be isolated by overlapping line-drilling of its four sides. Stainless-steel flat-jacks will provide in situ stress simulation up to 20 MPa on each side of the block. Two parallel boreholes will be drilled along the selected, water conducting fracture plane, to provide access for straddle packers and tracer monitoring equipment. Deformation - conductivity coupling and channeling effects will be studied, both under pure closure and shear.

Pure closure of the selected fracture is achieved by applying equal pressure in each flatjack. Shearing of the fracture (up to 1 or 2 mm maximum) can be achieved

by applying a uniaxial load, i.e. increased stress in the N-S flatjacks, reduced stress in the E-W flatjacks.

4.1.4.6 Borehole radar

Single and crosshole radar measurements will be performed with the high frequency radar system in the "detailed characterization holes" with the double objective of characterizing the smaller volume in greater detail and checking the predictions and consistency in results from Stage I.

Single hole reflection measurements will be made in the "validation drift holes" to check the predictions of the geometry.

4.1.4.7 Borehole seismics

The objective is the detection of smaller features than the ones mapped in Stage I but which could still be hydraulically important. The results will be compared with those from the crosshole hydraulic tests.

Most of the equipment and processing techniques developed and tested within the Project "Improvement of Techniques for High Resolution Borehole Seismics", see Section 4.2.2, will be ready for use for detailed characterization.

The tests will consist of measurements within and between the "detailed characterization holes" and the holes outlined by the validation drift, see Figure 4.1.4.1. Performing tests in the holes drilled just outside the perimeter of the validation drift before and immediately after excavation will provide an estimate of the change in the mechanical conditions of the rock in the vicinity of the drift.

Holographic processing will start to be used at this stage. The theoretical resolution with holography is approximately 1 % of the measured distance, i.e. 5-30 cm for 5-30 m separated holes. Increased fracture frequency and changes in aperture as a result of excavation will be perceived as an integrated effect.

4.1.4.8 Hydraulic investigations

The objective of the testing at this stage will be to improve the existing "single-borehole derived" data set where necessary and measure heads to improve the definition of the boundaries of the modelled area. Additionally the hydraulic "connectivity" of major features will be examined by testing between boreholes

of the "simulated" drift. Some additional crosshole sinusoidal measurements may be undertaken between existing boreholes if thought necessary for the detailed characterization.

The major hydraulic effort will be to simulate a drift within the "validation drift boreholes". The objective of this simulation is to gain insight into the way in which eventual drift excavation alters the flows in the fractures it intersects. This is necessary since the inflows to the drift are due to be used as "validation" of the flow predictions from the modelling.

The idea is to gradually reduce the water pressure in the boreholes which lie along the circumference of the as-yet-unexcavated validation drift. The pressure will be reduced in steps (Figure 4.1.4.2 b) in adjacent sections of boreholes (Figure 4.1.4.2 a). It is envisaged that all 5 boreholes plus the central borehole would be depressurized over about a 20 m length. The boreholes would be divided into smaller intervals by short packers about every 2 m and the pressure kept constant by computer-controlled valves. The outflow from each interval within a section will be measured for each pressure step and recorded.

After all the steps have been carried out for a particular section, all the packers in all the boreholes will be moved along to the next section. Given 6 boreholes and 2 m intervals within a 20 m section this will require the computer control of about 60 packed-off intervals. The size of interval and the length of section will be adjusted to suit the time available for the testing and the priority attached to the statistics of the results. Obviously the shorter the interval, the larger the number of results and the better the definition of individual fractures.

It is hoped that it is possible to identify individual fractures within the circumferential boreholes. These fractures will then be exposed by subsequent excavation and re-identified. In this way the performance of differently oriented fractures under the stress of dewatering and drift excavation (Figure 4.1.4.2 c) can be assessed.

4.1.4.9 Hydrochemistry

Water from the outflow measurements described in section 4.1.4.8 will be sampled and analysed. This water sampling is directly related to the water inflow tests and will therefore continue as long as these continue (6-9 months). The water samples will be filtered and analysed for major constituents; Na, K,

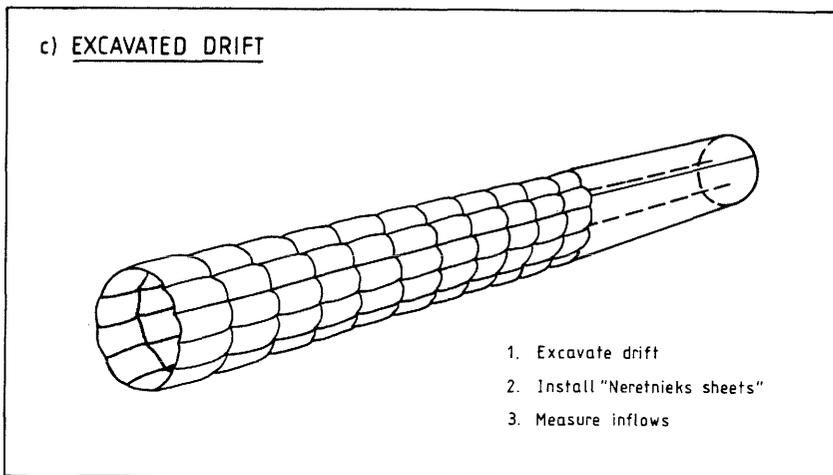
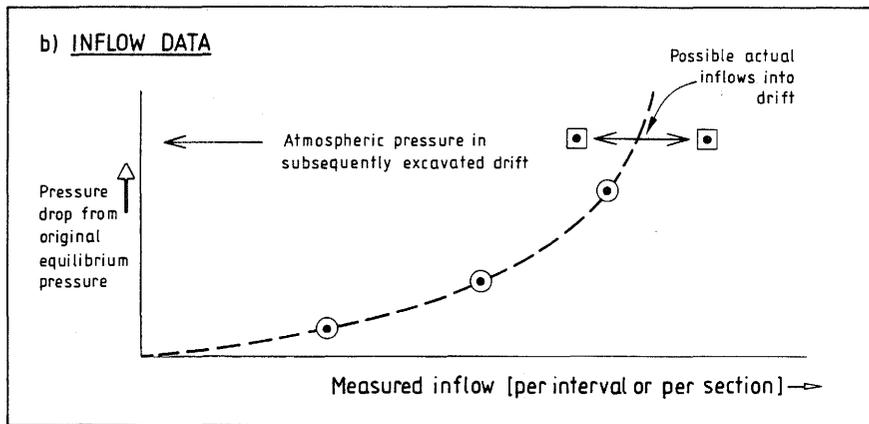
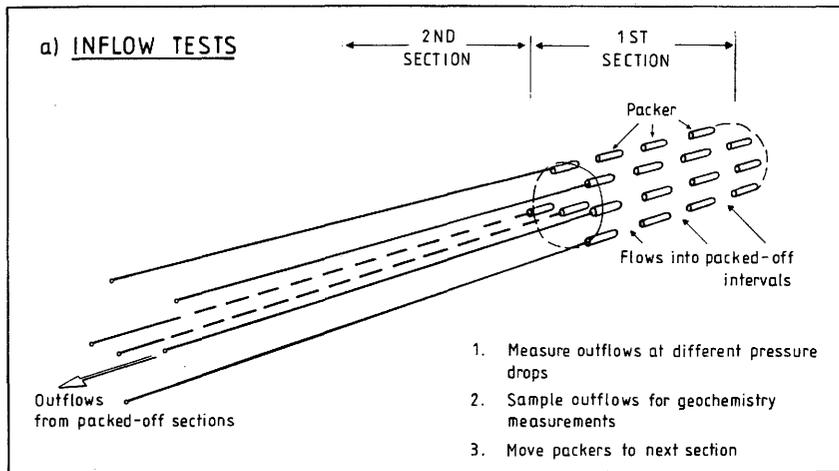


Figure 4.1.4.2

Outline of the hydraulic investigation program to simulate a drift within the "validation drift boreholes" prior to excavation of the drift.

Ca, Mg, Sr, HCO₃, Cl, F, Br, SO₄, and isotopes; 18O, 3H.

4.1.5 Stage IV - Detailed Predictions

4.1.5.1 Geometry

The final prediction prior to drift excavation will have the generic description of the fractures as its basis. This description will include the nature, position and extent of the major features (geological and geophysical) where they cut the validation drift. The remaining rock will be described in terms of probability distributions of the properties of the fractures (i.e. trace length, orientation and frequency). Additionally there may well be some identification of particular geophysically defined features (such as offsets in major fracture zones) which can be investigated during excavation.

4.1.5.2 Water flow

The investigations performed in Stages I and III together with the results of the Channelling Experiments, see Sections 4.1.4.4, 4.1.4.5 and 4.2.4 provide the input data required to calibrate the fracture network model. Essentially this data consists of the geometric parameters, transmissivities and channelling characteristics of fractures together with information about the hydraulic boundary conditions. At the present stage, the calibrated model is to be used to predict the water inflow in the validation drift. Details on the model development are given in Section 4.2.3.

It is important to recognise that in general the fracture characteristics are treated statistically within the model, although the location, extent and orientation of the more important fracture zones are likely to be treated deterministically. Consequently, it is not possible to make explicit predictions of the amount of water entering specific locations on the surface of the drift. However, statistical aspects of the model can be compared with statistical aspects of the measured inflows. For example, the mean and standard deviation of the inflow into ten meter sections of the drift could be compared.

The three-dimensional network model described above takes no account of fracture deformation as water pressure changes. It also takes no account of the mechanical changes of fracture apertures that will occur locally, when the validation drift is excavated. These coupled effects need to be modelled separately in

a near-field model that allows for fracture deformation and the associated changes in flow and water pressure, which again effect the apertures. The UDEC ("Universal Distinct Element Code") developed by Cundall will be utilized in this modelling, using the coupled fracture - deformation - hydraulic conductivity model used in Stage I as a subroutine. The calculated distribution of fracture apertures around the drift will be used as input to modify the three-dimensional network model, as appropriate.

4.1.5.3 Tracer migration

The fracture network model calibrated by investigations referred to in previous sections will also be used to predict the results of tracer migration tests in the vicinity of the validation drift. The results are likely to be highly sensitive to the experimental data on channelling within single fractures and fracture zones. Some sensitivity studies may be required if the channeling data is rather sparse. It should be possible to compare model predictions and experimental results for the mean and variance of the tracer travel time. Further details are given in Section 4.2.3 "Network modelling".

4.1.6 Stage V - Detailed Evaluation

4.1.6.1 Drift excavation and associated measurements

A 75 m long validation drift will be excavated along the line of the "validation drift boreholes". The length may be altered in the light of model predictions if insufficient validation is likely to be accomplished otherwise. Once excavated, the drift will be extensively mapped to provide data on the fracture frequency, orientation and observed trace length. Any major features intercepted by the drift will be included in this comprehensive data set.

This drift will provide three forms of geometrical validation. Firstly there will be the ability to examine geophysically-detected features (branches and offsets, point reflectors etc.) as the drift is excavated. Secondly the major zones identified by geology and geophysics can be examined in the drift. Thirdly the statistics of the mapped fractures can be expressed in terms of a degree of confidence dependent on the size of the data set.

4.1.6.2 Water flow validation

The excavated validation drift will be covered in water-collection sheets (i.e. like the present 3D Migration drift) and the natural inflow of water will be measured. This measurement of water flow will continue until steady state conditions are reached. Additionally water samples will be supplied from some of the sheets to complete the set of hydrochemical data.

The water inflows will be compared with those measured in the "validation drift boreholes" and also with those predicted by the combined network and UDEC models. Since these predictions will be in the form of probability distributions various comparisons will be carried out. These will include the average inflow to the drift, the variation of flow between different sheets and the pattern of inflow. Throughout these comparisons, criteria of acceptability that a prediction is similar to a measurement will be required. In the same manner the level of confidence in the applicability of the drift as a measure of network performance will be assessed.

4.1.6.3 Tracer test in the validation drift

The objective of this investigation is to make such measurements that a comparison can be made between the predictions of tracer movement in the rock around the validation drift and the actual tracer movements. Another objective is to make the observations in such a way that the results can be used to further improve the understanding of water flow and tracer movement in fractured crystalline rock.

When the drift is excavated and covered with plastic sheets, non-sorbing tracers can be injected in suitable locations around the drift. If suitable injection points (up to 6 if possible) have been found in the boreholes previously used for characterization, these points will be used. It may also be necessary to drill holes specifically for injection of tracers. At least 1, preferably 2-3 injection points should be located in a fracture zone if one conveniently intersects the drift. The injection points are located at distances ranging from 10 to 40 m from the drift.

A different tracer will be used in every injection point in the same way as is done in the ongoing 3D-experiment. The number of tracers and the injection points will be selected based on information obtained from the hydraulic measurements in the characterization holes. It is envisaged that no less than 3 and no more than 6 tracers will be used.

Injection and monitoring should be made during 1,5 years to ensure that the tracers from the furthest locations arrive in sufficient concentrations. Pressure changes and flowrates are monitored to ensure that this information is available when the tracer break-through curves are analyzed. Previous experience shows that changes in water pressure and flow-rates may be expected.

The results from tracer tests will show where, how fast and with what concentration the tracers arrive. The data will be computerized so that they are easily transferable and can be used to compare with the results predicted by the fracture network model. The comparison will be made by dispersion, possible channeling effects and tracer travel times and their spread in time. It may also be possible to compare, in a statistical sense, the uneven distribution of flow-rates which are expected to occur.

In addition to the artificial tracers an attempt will be made to model the possible inflow of tritiated water from the ground surface into the drift. Tritium has previously been found in a few other locations in Stripa and is deemed to have infiltrated from the surface or from near surface locations. This indicates the presence of fast channels over considerable distances. The frequency of such channels may be estimated by the fracture model and compared with observations of tritium in the groundwater infiltrating into the experimental drift as well as into other drifts and observation points in Stripa.

4.1.6.4 Final evaluation and reporting

The Project will be concluded by a detailed evaluation and reporting of results obtained from the validation experiments performed during Stage V. The results will be analyzed and compared to the predictions made during previous stages. As described above, predictions will be made on the nature and geometry of major zones and individual fractures, the water flow distribution, the transport of tracers, and how flow and transport is affected by mechanical changes in the rock. In order to make these predictions, several different investigation methods and modelling codes have been developed and applied within the project. An essential part of the validation process will be to evaluate the applicability, and the potential for further improvement of each method and modelling code. The integrated approach to site characterization and the data contributed by each method to the different models will also be evaluated.

The final analysis is expected to give an understanding of our capability, at the end of the project, to describe the groundwater flow and nuclide transport in

fractured rock. That is, to what extent the models can be relied upon, where improvements can be made and in what areas further research is needed. Experience will also be gained on the staging of an integrated site characterization program and the safety assessment of a future repository.

4.2 IMPROVEMENT OF SITE ASSESSMENT METHODS AND CONCEPTS

4.2.1 Development of High Resolution and Directional Radar

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4.2.1.1 Introduction

As a part of the crosshole program of Phase 2 of the Stripa Project development of a new borehole radar system was initiated. The Phase 2 two program comprised the development of equipment, field measurement procedures, and interpretation techniques. The outcome of the radar development efforts have been positive and at Stripa it has been possible to identify fracture zones at a distance of 100 m from the boreholes. In crosshole measurements radar waves have been detected after propagation through 300 m of granite.

The radar system can be applied in a number of measurement configurations such as; single hole reflection, cross-hole reflection, and cross-hole tomography of attenuation and travel time data.

Single hole reflection measurements give information on the presence of inhomogeneities such as fracture zones within a cylinder around the borehole. The present system gives information on the distance to a reflecting point but not on its location in space due to the cylindrical symmetry of the radiation emitted by the antennas. This implies that the location of a point reflector can be determined to be somewhere on a circle with a certain radius around the borehole. In the case of a fracture zone the angle between the hole and the fracture plane can be determined.

If single hole reflection measurements have been made in a number of adjacent holes and the same fracture plane has been identified in them then it will be possible to determine the actual orientation of that fracture plane. The geometric problem in the interpretation of radar reflection data is similar to what is encountered in some radio navigation systems used on the earth's surface, but in this case the problem is 3-dimensional. The orientation of a fracture zone may be uniquely determined under certain conditions (e.g. 3 holes are needed and they should not be parallel).

Reflections are also obtained in cross-hole radar measurements and may be analysed much in the same way as single hole measurements. The geometric information obtained is different and consequently the requirements

for a unique solution. A combination of single hole and cross-hole reflection measurements will in most cases give data that unambiguously will determine the location and orientation of a fracture zone.

Cross-hole tomography measurements will give the location and electrical properties of a fracture zone in the plane spanned by the boreholes. It should be noted that a crosshole tomography measurement will also give cross-hole reflection data and the data sets may be analyzed together to build a model of the investigated rock volume.

It is evident that when there is only a single borehole or when the borehole separation is large the information from the present radar system will not be sufficient to describe the fracture zone geometry. In these situations a radar system with directional antennas would be useful. Such a system should be capable of determining of the dip and strike of a fracture zone through measurement in one borehole only. Consequently development of a radar system with directional antennas is proposed.

Experience from the phase 2 program has also shown that in many cases very detailed information on the fracture zones is needed at short distances from the boreholes. In order to describe the hydraulic characteristics of the rock mass it is often essential to get information on the geometry of the smaller water bearing features. A radar system which is using shorter wavelengths should be able to obtain such information.

A continued development of interpretation techniques is required to support the new directional capabilities of the radar system and the experience gained from measurements in new geological and geometrical settings. Such efforts should concentrate on 3D interpretation and presentation techniques.

4.2.1.2 Objectives

The objectives of the continued radar development are;

- to develop directional antennas which facilitate the determination of dip and strike of a fracture zone through measurement in only one hole.
- to increase the resolution of the radar system in order to describe the geometry of the smaller water bearing features.
- to further develop 3D interpretation and presentation techniques for borehole radar.

4.2.1.3 Project description

Directional antennas

The development of directional antennas will begin with an analysis of the components of a directional radar system such as antennas, data collection procedures, data analysis, and data presentation. It is envisaged that the system will have a set of antennas for measuring two perpendicular components of either the electric or the magnetic field.

Theoretical and numerical simulations will be made of different antenna designs, test antennas will be constructed and tested at the Stripa mine. New high-frequency amplifiers will have to be constructed to compensate for the lower signal levels expected with directional antennas compared to dipole antennas.

When a satisfactory directional antenna has been designed a complete radar system will be constructed. This involves a control system in the radar receiver to select the field component to be measured, a directional transducer to give the orientation of the antenna system, a fiberoptic communication system, a new control unit and development of control software for the system.

Field tests with the new system to test functionality and to test achieved accuracy of the directional system. These tests will be performed in the site for the "Site Characterization and Validation" project within Phase 3 and at the crosshole site investigated during Phase 2.

High resolution system

Antennas for the frequencies 20, 45, and 60 MHz have been constructed within the Phase 2 program. For a high resolution system with the capability to detect the smaller waterbearing features close to the hole, antennas for the frequencies 120 and 200 MHz would be suitable.

This part of the project would comprise the development of antennas for the frequencies 120 and 200 MHz, the subsequent modification of transmitter and receiver electronics, and field tests.

Interpretation and presentation techniques

A further development of interpretation and processing techniques for radar data is needed to adapt to new geological and geometrical settings (borehole and fracture plane geometries). The data produced by the directional antenna system will be of a different character compared to the data obtained with the present system. This part of the project will mainly attend to the following tasks;

- develop interpretation and presentation algorithms for data obtained with a directional antenna system.
- develop 3D interpretation algorithms for interpretation of data obtained from several adjacent boreholes.
- develop processing techniques to enhance radar data.

4.2.1.4 Time schedule and costs

Table 1 shows the time-schedule for the radar development and Table 2 shows the estimated costs. All costs are given in MSEK, price level January 1986.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
System considerations	—	—				
Directional antenna development	—	—				
High resolution system	—	—				
System design			—			
Interpretation techniques	—	—	—			
Field test	—	—	—			
Reporting			—			

Table 2. Estimated costs, MSEK, price level January 1986.

Activity	1986	1987	1988	1989	1990	1991	Total
System considerations	0.30	0.15					0.45
Directional antenna development	0.40	0.90					1.30
High resolution system	0.10	0.15					0.25
System design		0.80	0.90				1.70
Interpretation techniques	0.10	0.10	0.30				0.50
Field tests	0.10	0.10	0.20				0.40
Reporting			0.10				0.10
TOTAL	1.00	2.20	1.50				4.70

4.2.2 Improvement of Techniques for High Resolution Borehole Seismics

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4.2.2.1 Background

In fractured rock, the fractures are the pathways for water movement and seismic investigations must therefore aim to describe these conductive features.

For general characterization, the current interpretation algorithms and instrumentation provide adequate definition. However, it appears that the hydraulically conductive features are not always particularly large or thick and, using current techniques, may either be indistinctly positioned or remain undetected. To detect these features increased resolution is required. This could be achieved using more flexible data collection equipment and more efficient algorithms.

The velocity method of seismic analysis which is applied at present uses only one piece of information (the travel time) from each complex received signal which is recorded. Changes in the signal shape between source and receiver are ignored. One of the reasons for this is the multiple scattering of the "pulse" type signals. A better-defined source signal would allow interpretation of the change of the wave form between source and receiver.

A further improvement could be obtained by interpreting the spatial variation of wavetrains rather than point determinations. This can be achieved by a form of "holographic" interpretation. It has the advantage that detection and reliability is less dependent on the position of the feature relative to the instrumentation boreholes than tomographic interpretation.

4.2.2.2 Objective

The objective of the proposal is to enhance the reliability and improve the definition of interpretations from seismic investigations in particular and geophysical methods in general. These new enhanced techniques will be applied in the later stages of the "Site Characterization and Validation" project.

The objective will be achieved by:

- the application of waveform reconstruction techniques (holography) and
- the development of a new borehole source.

4.2.2.3 Proposed work

Application of waveform reconstruction methods (holography)

Preliminary research aimed at converting a holographic algorithm for application to borehole seismics has already begun. The algorithm was developed at Oulu University, Finland, for the detection of ionospheric disturbances from satellite signals and is similar to one used in ultrasonic investigations. A seismic version has been applied to synthetic transmission (crosshole geometry) and reflection (single hole geometry) data. The technique resolves the position of the object to within 1% of the source-object distance.

The sources which can be recognized may be either virtual reflection images or real point diffractors. The method is also applicable to electromagnetic techniques such as radar.

Development of a modulated seismic source

The main problem with "pulse-type" sources is the unpredictable effects associated with the coupling of the source-tool to the borehole and the surrounding rock mass. The proposed device would improve the regularity of the signals which are effectively transmitted to the rock mass. The modulated source consists of two piezoelectric transducers at either end of a borehole section.

For operation as a sonic source (1.5 - 5 kHz) the transducers will be approximately 150 - 500 mm apart whilst for operation as an ultrasonic source (50 kHz) they will be about 15 mm apart. In operation, the fluid-filled section of the borehole will form a resonant cavity (at certain frequencies) with virtually perfect coupling to the rock mass. Open fractures crossing the resonating section of the borehole will affect the parameters of the resonance and give additional information on the near-field. In dry boreholes a rubber packer will be connected to the probe in order to seal the borehole beyond the transducers. A small quantity of water will be poured into the hole to keep the probe sunk.

4.2.2.4 Time schedule and costs

Table 1 shows the time schedule for the improvement of the seismic technique and Table 2 shows the estimated costs in price level January 1986.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
Construction of source prototype	—	—				
Laboratory tests		—				
Development of processing algorithms and programs	—	—	—	—		
Construction of field data acquisition/processing system	—	—				
Field tests			—			
Data processing			—	—		
Improvement of equipment			—	—		
Field tests				—		
Data processing and interpretation				—	—	

Table 2. Estimated costs, MSEK. Figures are given in price level January 1986.

Activity	1986	1987	1988	1989	1990	1991	Total
Construction of source prototype	0.20	0.20					0.40
Laboratory tests		0.20					0.20
Development of processing algorithms and programs	0.30	0.20	0.10	0.10			0.70
Construction of field data acquisition/processing system	0.10	0.10					0.20
Field tests			0.30				0.30
Data processing			0.30				0.30
Improvement of equipment			0.20				0.20
Field tests				0.20			0.20
Data processing and interpretation				0.30			0.30
Travel (Meetings)	0.03	0.04	0.04	0.03	0.03	0.03	0.20
TOTAL	0.63	0.74	0.94	0.63	0.03	0.03	3.00

4.2.3 Fracture Network Modelling

D.P. Hodkinson, P.C. Robinson, D.A. Lever and A.W. Herbert
Theoretical Physics Division, AERE Harwell, Oxfordshire, UK.

4.2.3.1 Introduction

Flow and migration at Stripa is thought to take place in channels within approximately planar fractures which intersect one another to form a three-dimensional network. Most of the water is likely to pass through fracture zones whose geometric characteristics can be determined using a combination of geophysical and hydrogeological tests. The location of these zones can be incorporated into the models deterministically, while the remaining smaller fractures will have to be treated in a statistical manner. Also the channels within the fracture zones may have to be treated in a statistical manner.

The geometrical properties of fractures which are required for modelling are their size, spacing and orientation. In addition, their internal structure needs to be specified. The approximation used in the present generation of models is to treat fractures as if they are bounded by smooth or rough parallel plates of rock. However, there are indications that flow may take place in relatively narrow channels separated by islands where there is little or no flow.

Computational models have been developed which take account of many of the above features. However, their realism in describing field measurements has not yet been tested. It is hoped that the feasibility of the fracture network approach can be demonstrated in Phase 3 of the Stripa Project. This would be done by obtaining the required input data and performing calculations for a substantial volume of rock. These predictions would then be compared with the results of independent experiments on a sufficiently large scale.

It is inevitable that a number of inadequacies in the present models will become apparent during the proposed project. Some have already been identified, such as the treatment of channeling within fractures and clustering of fractures with similar characteristics. The present work aims to improve the realism of the current models so that reliable calculations can be made of flow and migration at the Stripa site.

4.2.3.2 Objective

The overall objective of this work is to demonstrate the feasibility of the fracture network approach to flow and migration modelling. This is to be done by obtaining the required input data, performing flow and migration calculations over relevant distances and comparing the model results with data from independent experiments.

To achieve the above objective, models of flow and transport through single fractures and fracture networks will need to be developed and refined.

4.2.3.3 Scope

In contrast to the large research and development effort expended over the past few decades on continuum models for flow and transport through permeable media, the subject of fracture network modelling is in its infancy. To date, the models have largely been used to investigate the regimes of applicability of continuum approximations, using idealised assumptions and data. The present proposal is seen as a first step to making these models realistic enough such that they can be used in conjunction with field data to make meaningful predictions for flow and migration in fractured rock.

The approach requires input data in the form of experimentally determined probability distributions for the major fracture variables. These are randomly sampled to produce a computer representation of the fracture system. The flow of water and transport of water-borne radionuclides through this particular representation is then calculated.

In many respects, statistical fracture network models are ideally suited to performing safety assessments of radioactive waste disposal. First, the hydraulic data required by these models can be readily measured using experiments in boreholes. This is in contrast to the permeable medium approach where the scale of the hydraulic source (e.g. the borehole diameter) should, strictly speaking, be many times larger than the average spacing between fractures. At Stripa and other crystalline rock sites this length scale could be many tens or hundreds of metres. If conventional borehole diameters are used and the results interpreted in terms of a permeability, values ranging over many orders of magnitude are obtained and there is no unambiguous way of choosing the value to be used in a permeable medium model. Secondly, the transport mechanisms observed in single fracture experiments can be directly incorporated into the model rather than having to find some approximate porous medium equivalent. Finally, certain

important uncertainties and sensitivities are intrinsically incorporated within the model.

The major drawback with statistical fracture network models is that they are not as highly developed as permeable medium models. In particular they are not yet sufficiently realistic, in that they do not incorporate all of the important features observed in the field. The Stripa Project provides an outstanding opportunity for rectifying this situation.

Statistical information is required for the properties of fractures which have an important impact on radionuclide migration. These fall into two broad classes, namely the geometry of the fracture system and the hydraulic and transport properties of single fractures.

The geometric properties of the fracture system quantify the way in which fractures fit together into a three-dimensional intersecting network. Fractures are considered to be two-dimensional planar features of finite extent described by statistical information on their size, spacing and orientation.

Statistical information is required for the hydraulic and migration characteristics of single fractures. At the lowest level of approximation this would amount to specification of a hydraulic aperture (or transmissivity) and a transport aperture for each fracture.

It is probable that the use of hydraulic and transport apertures will not be sufficiently realistic for safety assessment studies. Thus it will be necessary to quantify the effect of channelling within fractures. Once again, statistical information will be required but its precise specification depends upon the results of present and future experiments.

Up to the present time, most calculations have been performed for two-dimensional fracture networks. In these calculations the fractures are treated as one-dimensional flow paths described by probability distributions for orientation, length and aperture. They have largely been used as an aid to understanding the general features of fracture flow and migration. A notable exception to the above rule is the pioneering work performed by Gale and his collaborators during Phase 2 of the Stripa Project which analysed the flow into the ventilation drift in terms of a two-dimensional fracture network model.

4.2.3.4 Proposed work

The time is now right for statistical fracture network models to be developed so that they can accommodate real

field data and so that they can be used to perform realistic flow and radionuclide migration calculations. This is the main thrust of the present proposal.

The primary requirement for performing realistic calculations is that current work on extending the model to three dimensions should be completed. Fractures will be treated as planes of a simple shape such as a square, rectangle or circle intersecting one another in an otherwise impermeable medium. The first task of the proposed work would be to complete the extension to three dimensions. This is by no means a trivial exercise since large numbers of fractures must be treated in an efficient manner.

Once the three-dimensional model with constant aperture fractures has been developed the following features, which are required for realistic field simulations, will be incorporated:

- i) clustering of fractures,
- ii) mixed deterministic/statistical treatment of fractures.

The latter requirement arises from the need to include the known properties of particular fractures explicitly, in order that the predictions should be made for conditions which are as close as possible to the validation measurements. The resulting model will be used to perform preliminary hydraulic calculations of relevance to the experimental program. Three-dimensional transport calculations will be attempted in order to gain an idea as to the likely magnitude of hydrodynamic dispersion due to mixing at fracture intersections. This should aid the interpretation of the three-dimensional tracer test being performed in Phase 2 of the Stripa Project.

The above model assumes that the entire surface area of fractures is available for flow and that each fracture has a fixed aperture. Thus the second major task of the proposed work will be to take some account of channeling within fracture planes. In view of the present lack of a convincing conceptual model for channelling, it is rather difficult to specify at this stage what exactly will be done. As a first step, a review should be made of the current state of knowledge. On the basis of this review a reasonable but relatively straightforward working hypothesis should be made. For example this could treat channeling in a fracture plane in a similar manner to a two-dimensional fracture network. The major thrust of this work will be to examine the effect of channeling on water flow but the effects on solute transport will also be studied.

The extended model described above will be used to perform some simulations of water flow in the vicinity of the Stripa mine which relate to measurements being performed in the experimental program. These could be compared with continuum model calculations based on the same data.

It is intended that calculations of flow and transport in the vicinity of the test site should be performed from the start of Phase 3 and be continually upgraded in the light of model developments and the availability of experimental data. Initially, the fracture statistics from the Ventilation drift (Buffer Mass Test area) would be used and the results would be compared with the inflow into that drift, and the inflow of water and tracers into the 3-D Migration Experiment. It is hoped that these preliminary calculations will help to guide the planning of the investigations within the "Site Characterization and Validation" project. Eventually, final predictions will be made based on all the data from the characterisation tests and supporting studies on channeling within single fractures. These will then be compared with the validation experiments and an assessment of the feasibility and reliability of the fracture network approach will be made.

In addition to the development of network models discussed above, it is anticipated that certain specialised models will need to be developed in order to aid the understanding and interpretation of experiments. Perhaps the greatest need will be to develop special models of channeling within single fractures to try and interpret the results of hydraulic and tracer experiments. It is intended that such models should be developed and used, in close collaboration with the experimental groups.

4.2.3.5 Organisation

The development and application of the models described in this proposal will be carried out primarily in the Theoretical Physics Division at the Atomic Energy Research Establishment at Harwell in the United Kingdom. Close collaboration will be maintained with the groups obtaining experimental data at the Stripa site. In particular, it is envisaged that the primary responsibility for processing the raw data into a form suitable for network modelling will rest with the experimental groups.

4.2.3.6 Time schedule and costs

Phase 3 of the Stripa Project is intended to last for a five year period between July 1st, 1986 and June 31st,

1991. A bar chart showing the activities to be undertaken in the calendar years 1986-1991 are shown in Table 1, while Table 2 shows the estimated annual charges for this work given in MSEK and in price level January 1986.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
Preliminary calculations	—					
Model developments	—			—		
Final calculations				—		
Final report						—

Table 2. Proposed Annual Charges (MSEK), price level January 1986.

Activity	1986	1987	1988	1989	1990	1991	Total
Preliminary calculations	0.2	0.6	0.6				1.4
Model developments	0.4	0.6	0.6	0.6	0.6	0.2	3.0
Final calculations				0.6	0.6	0.3	1.5
Final report						0.1	0.1
TOTAL	0.6	1.2	1.2	1.2	1.2	0.6	6.0

4.2.4 Channeling Experiments

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Stockholm, SWEDEN

4.2.4.1 Introduction

Observations in the 2D and 3D migration experiments at Stripa as well as recent observations by other investigators show that water flows very unevenly in the fractures. Only a minor part of a fracture carries water. We call this channeling.

Channeling may have several consequences for the transport of dissolved species such as radionuclides.

If the channels within a fracture plane have very different water velocities, the fast channels will permit less retention time and thus less decay of the radionuclides.

There will also be less of the fracture surface which is in contact with the mobile water and thus less surface with which to interact by sorption and from which to diffuse into the micropores of the rock matrix. Retardation may thus become considerably smaller than if all the fracture surface were equally accessible to the water.

Previous experience shows that often what seems to be a single fracture actually consists of a few more or less parallel displaced but connected fractures. Such features will be called "small fracture zones" in this proposal.

There is a large difference between the actual fracture width and what can be deduced from hydraulic conductivity measurements. If used to predict travel times the latter may give an underestimate.

The mixing (or nonmixing) between the waters in the various channels strongly influences transport of dissolved species. If mixing occurs frequently between channels, the concentration is averaged over all the water in the fracture, effectively retarding the transport in the faster channels.

The channels in individual fractures connect with channels in other fractures to form pathways over longer distances in the rock mass. In order to understand and model transport on the larger scale, there is a need to have data and models on transport in the individual fracture planes and small fracture zones.

The data will be obtained by a combination of field experiments and laboratory experiments. The field experiments will give data on the hydraulic conductivity, widths, frequency and breadth of channels as well as the size of the closed portion of the fractures. The laboratory experiments, described in Section 4.1.4.4, will give data on how these properties are influenced by rock stress and shear.

4.2.4.2 Objective

The objectives of this investigation are to determine hydraulic properties of channels within fracture planes and small fracture zones.

4.2.4.3 Scope

There is very little data available on channeling effects although the phenomenon seems to be well known by people working in crystalline rock. Several fractures will be investigated by fast simple methods which give information on the distribution of channels within the fractures. Some small fracture zones, which can be detected by geophysical methods, will also be investigated to obtain information on the flow distribution and to some extent the transport properties of these features.

Laboratory tests and a field test will give information on the influence of rock stress and shear on the hydraulic properties of some natural fractures, as described in Sections 4.1.4.4 and 4.1.4.5.

The experiments may provide a minimum of the information needed to assess the influence of channeling on the hydraulic and transport properties of fractured rock.

4.2.4.4 Proposed work

Single hole channeling tests

A hole will be drilled in the plane of a fracture. The hole will be up to two meters long if the fracture does not change direction before this. A specially designed packer system with close packer spacing is used to measure the hydraulic conductivity along the fracture in sections of 5 to 10 cm. The packer is designed in such a way that only one side of the hole is measured at a time. This makes it possible to measure the hydraulic properties of the same fracture plane along two lines at a distance of about 15 cm (the diameter of the hole).

About 10 fractures will be investigated in this way. This will need about 25 fractures to be drilled because previous experience shows that not all holes will succeed in following the fracture as the fractures often change direction.

Flow in a small fracture zone

The small fracture zones are expected to be wider than a few tens of centimeters. They cannot be investigated by the methods used in the single fracture experiments. Instead the water flow distribution will be measured by covering the zone with plastic sheets in a similar way as was done in the 3D experiment. Two or possibly three such zones will be located in the drifts and tunnels in Stripa. This will be done primarily by use of radar measurements combined with visual observations.

Only the distribution of flowrates over the zone will be measured. No tracer tests will be performed because of time and cost constraints.

4.2.4.5 Organization

Principal investigator will be professor Ivars Neretnieks at the Royal Institute of Technology, KTH, in Stockholm. Neretnieks will coordinate the project and be responsible for the work. The planning and execution of the field work and the design of field equipment as well as data management and conventional data analysis will be done by Harald Abelin and Lars Birgersson, KTH. Abelin and Birgersson have participated in leading positions in the two previous projects dealing with tracer transport in the rock at Stripa in Phases 1 and 2.

4.2.4.6 Time schedule and costs

A bar chart showing the activities to be undertaken within the Channeling Experiments is presented in Table 1, while Table 2 shows the estimated annual charges in MSEK based on price level January, 1986.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
Single hole tests						
Planning and preinvestigations		—				
Design & manufac equipment		—				
Drilling		—	—			
Test equipment		—				
Test channeling			—			
Evaluation			—	—		
Flow in fracture zones						
Planning and preinvestigations	—	—				
Site preparations			—			
Flow monitoring			—	—		
Water sampling			—	—		
Evaluation			—	—		

Table 2. Estimated costs, MSEK, price level January, 1986.

Activity	1986	1987	1988	1989	1990	1991	Total
Single hole tests							
Planning and preinvestigations		0.26					0.26
Design & manufac equipment		1.16					1.16
Drilling		0.18	0.18				0.36
Test equipment		0.07					0.07
Test channeling		0.43	0.80				1.23
Evaluation			0.14	0.17			0.31
Contingencies		0.10	0.08	0.02			0.20
Flow in fracture zones							
Planning and preinvestigations	0.04	0.42					0.46
Site preparations		0.72	0.33				1.05
Flow monitoring			0.36	0.10			0.46
Water sampling			0.20	0.03			0.23
Evaluation			0.14	0.27			0.41
Contingencies		0.04	0.11	0.05			0.20
TOTAL	0.04	3.38	2.34	0.64			6.40

4.2.5 Estimation of Fracture Length and Aperture from Single Fracture Packer Tests

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4.2.5.1 Introduction

The major focus of the Stripa Phase 3 work will be characterizing the hydraulic properties of an as yet unpenetrated part of the Stripa granite. The predictions of the hydraulic response of the rock to excavation of a new drift will be made using network models. The representation of the fracture system in a network model is generated using statistical distributions of the fracture geometric parameters, specifically, the length, aperture, orientation, and spacing of fracturing. Some of the information required for a network model can be obtained from core logging and fracture mapping on the walls of tunnels. However, the aperture and length data so derived may not reflect the hydraulic lengths and apertures, that is the portion of the fracture which is conducting. Furthermore, actual repository site investigations will require fracture statistical information long before underground exposures are available, hence it is desirable to be able to obtain length and aperture data from the borehole testing alone.

Our approach (Doe and Osnes, 1985) is to use transient flowrate data from constant pressure injection tests to infer fracture lengths and apertures. The basis for the approach relies on the response of flow rate to constrictions at the edges of fractures or to intersections with other fractures. The flow rate into a finite fracture will eventually drop to zero or to a very low figure reflecting the permeability of the intact rock. The time between the initiation of the injection and the decline in flow is a measure of the distance from the well to the edge of the fracture. Similarly, if a fracture is interconnected with other fractures, one may expect the flow rate to approach a constant value. The time required for the flow rate to achieve a steady rate is a measure of the distance from the well to interconnection.

4.2.5.2 Objective

The objective of the proposed work is to determine the viability of the use of transient flow rate data for determining the lengths and apertures of fractures. If successful, these data may be used for input to the

statistical generations of fracture systems in the network model.

4.2.5.3 Scope

The scope of this proposal will be to assist in the design of transient rate or pressure injection tests to detect fracture boundaries and interconnections. The well testing work will be performed by the hydrologic testing crew performing the Phase 3 tests. The data will be analyzed to provide information on length and interconnection of the fractures tested.

4.2.5.4 Proposed tasks

Analysis of Single Fracture Well Tests

This task will consist of analysis of 10 to 20 single fracture constant head or constant pressure injection tests. The tests will be primarily performed at low injection overpressures, and the data will be analyzed using methods described by Doe and Osnes(1985) for determining the length to a constant pressure or no flow boundary. Additional higher pressure injection tests will be run to evaluate the linearity of the pressure flow curve and to check for the onset of turbulence (Elsworth and Doe, in press) and fracture deformation (Noorishad and Doe, 1982). The results, if diagnostic, will be used to calculate effective fracture areas for input to network models.

Analysis of Cumulative Density Functions of Fixed Spaced Packer Tests

This task will evaluate spacing and aperture distribution information from packer tests run with a fixed spacing using methods developed by Doe and Osnes (1985) and Snow (1970). Fixed spaced packer tests will be a part of Stage I of the "Site Characterization and Validation" project. These methods use the frequency of no flow tests to separate the aperture, or transmissivity, component of the distribution from the spacing. These separated distributions may then be used as input to network models. Conductivity distributions from the packer tests run in holes at various orientation relative to the maximum in situ stress, will be compared to assess the influence of stress on directional permeability.

4.2.5.5 Organization

This work will be performed with Dr. Thomas Doe of Golder Associates, Berkeley as principal investigator. Mr. John Osnes of RE/SPEC Inc. Rapid City, and Dr. Derek Elsworth, of Pennsylvania State University, will aid in the interpretation of well test results.

4.2.5.6 Time schedule and costs

Calendar year 1986 activities will include preparation of equipment to complement instrumentation at the site. During 1987 personnel from the US will be present during the single fracture hydraulic testing. Data will be analyzed during 1987. A final report on the results of the injection testing will be prepared during 1988.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
Analysis of Single Fracture Well Tests						
Analysis of Cumulative Density Functions of Fixed..						

Table 2. Costs*, MSEK, Price level 1985/86.

Activity	1986	1987	1988	1989	1990	1991	Total
Analysis of Single Fracture Well Tests	0.1	0.2	0.1				0.4
Analysis of Cumulative Density Functions of Fixed..	0.1	0.2	0.1				0.4
TOTAL	0.2	0.4	0.2				0.8

* Costs to be supplemented by ongoing US DOE projects.

4.3 SEALING OF FRACTURED ROCK

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4.3.1 Background, Scope of Study

Water flow through repositories is of great concern with respect to the migration of dissolved substances which affect the physico/chemical state of clay canister overpacks, and to the corrosion rate of the canisters, as well as to the transportation of radionuclides at a late stage of the operational lifetime. Time is obvious from the fact that hydrology is of major importance in most waste disposal studies, including the Stripa project. It follows from this that the creation of non-conductivity conditions of the close vicinity of the canisters would be very much desired, and this is offered by the very dense smectite clay used as canister overpack in the KBS-3 and Nagra concepts.

For temperatures lower than about 90°C the chemical stability of such an overpack has been concluded to be very high, but for temperatures in the range of 130°C to 150°C, which is actually aimed at in some countries, crystal lattice changes that form the first phase of transformation to illite, may appear in less than a hundred years. The conversion of smectites to illitic clay will then be a matter of time, since it is directly related to the rate at which potassium migrates into the dense clay. This rate can be very much delayed if the major water-bearing fractures can be sealed to within a few tens of centimeters or meters distance from the deposition holes. A second beneficial effect of such sealing would be that the net hydraulic conductivity of the integrated rock/clay system immediately surrounding the canisters can be preserved despite possible partial illitization. The isolating effect can be further improved if conduits connecting sealed rock or plugged shafts with hydraulically active zones can also be sealed. The major aim of the study is to find suitable sealants and practical techniques for inserting them in rock fractures.

4.3.2 Factors Influencing the Sealing Efficiency

Once in the fractures, the sealant will be exposed to conditions that may have an impact on its physical and chemical integrity. The following physical processes are known to be of importance with respect to the sealing function:

- a Flowing groundwater exerts drag forces on the sealant. Fracture apertures and hydraulic gradients determine these forces, while interparticle forces and particle size govern the erosion resistance.
- b Rock displacements in the form of shear, compression or expansion of sealed fractures produces strain in the sealant. The rock stress state and the fracture "geometry" (topography) determine this strain, while the expandability and rock/sealant interaction govern the physical state and sealing efficiency of the strained gel.
- c Gas flow caused by radiolysis or canister metal corrosion. Flexible sealants may retain their low conductivity, while brittle ones may be broken up and become very permeable.

As to the chemical integrity, earlier investigations indicate that the longevity depends on:

- d pH-changes. These need to be considered for cement/clay groutings since lattice breakdown of phyllosilicates is foreseen at low clay contents.
- e Temperature effects. One such effect is the expected charge change of smectite minerals at temperatures exceeding about 100°C.
- f Pressure effects. Water pressures exceeding a few MPa, usually in connection with elevated temperature, may induce mineral alterations.

4.3.3 Basic Selection Principles

The sealant must be groutable with a potential of entering also narrow fractures.

Rock displacements produced by creep, temperature pulses, altered water pressures and differential loading due to glaciations, are likely to take place. Long term durability therefore requires that the sealant remains flexible and fills up the fractures in the expected complex scenario of fracture closure, opening and shear in the operational lifetime of a repository.

Mineral alterations may be accepted if they do not lead to unacceptable changes in the physical properties.

During the construction period of a repository high hydraulic gradients may persist in sealed fractures, by which groundwater erosion and piping may take place.

Erosion resistance may require composite sealing materials or temporary plugging of part of the fractures with cementitious substances. The erodibility needs to be considered with special respect to the groundwater chemistry.

4.3.4 Proposed Investigation

The scope is to define the operational conditions of fracture sealings, and to select a few candidate materials for characterization and determination of their physical and chemical properties, as well as to conduct one or a few pilot tests in Stripa to verify the suitability of these materials and suggested injection techniques, and to outline a comprehensive field test to determine how effectively fractures and fracture zones can be sealed. The work will be defined by an ad hoc Task Force group representing the member countries. The following stages are suggested:

Stage I - State of the art survey of fracture sealing materials

Definition of operational conditions concerning the expected range of thermal, thermomechanical, hydrological, and geochemical conditions, fracture characteristics, and time durations under repository conditions.

The Task Force will convene and conduct a state-of-the-art survey of sealing materials, emphasizing their durability. This will be taken as a basis for the selection and characterization of substances that are most promising for sealing groundwater flow paths in fractured crystalline rock over long periods of time.

Stage II - Determination of the long-term stability

The Task Force will determine and evaluate the methods by which the long term stability and groutability can be demonstrated in the laboratory or on site in Stripa. Those tests considered feasible for the determination of the long-term stability will then be executed.

Stage III - Field pilot tests

If the selected materials are considered to be stable for very long periods of time, pilot field tests are planned and executed in order to test the full scale groutability in rock fractures and to select and optimize a suitable injection technique. These tests concern fractures exposed in drifts.

Stage IV - Large scale sealing test in "deposition holes"

If the field pilot tests are positive, a large scale sealing test in the BMT heater holes is planned to determine the efficiency of the grouting to "shunt off" water from deposition holes by conducting flow tests with hydraulic gradients that are representative of deep-sited repositories.

This test also involves detailed determination of the distribution of the groutings by applying radar technique, and drillings.

4.3.5 Time Schedule and Costs

Table 1 shows the time schedule for the experiment "Sealing of Fractured Rock" and Table 2 shows the estimated costs given in price level January 1986.

Table 1. Time Schedule

Activity	1986	1987	1988	1989	1990	1991
Stage I - State of the art	—					
Stage II - Determination of long-term sta- bility		—	—			
Stage III - Field pilot tests			—			
Stage IV - Large scale sealing test, planning stage			—			

Table 2. Estimated costs, price level January 1986.

Activity	1986	1987	1988	1989	1990	1991	Total
Stage I - Stage of the art	1.5						1.5
Stage II - Determination of long-term stability		4.5					4.5
Stage III - Field pilot tests			0.8				0.8
Stage IV - Large scale sealing test, planning stage			0.2				0.2
TOTAL	1.5	4.5	1.0				7.0

ORGANIZATION

It is foreseen that the general organization of the Stripa Project Phase 3 will remain the same as for previous phases.

Responsibility for supervision of the research programme and for its finance resides with the Joint Technical Committee (JTC). This is composed of representatives from each of the national organizations. It also provides information on the general progress of work to the OECD Steering Committee for Nuclear Energy, through the NEA Committee on Radioactive Waste Management and its Advisory Group on In Situ Research and Investigations for Geological Disposal.

Each research activity is assigned to a principal investigator, a scientist with particular expertise in the research field in question. The conception of the experiments, and their realisation, are periodically reviewed by the Technical Subgroup (TSG). The sub-group is composed of scientists from the participating countries.

The Division Research and Development of the Swedish Nuclear Fuel and Waste Management Company (SKB) acts as the host organization, and provides the management for the Project. It is responsible for mine operations, and for the procurement of equipment and material for experimental work. Meetings of the Technical Subgroups, the Joint Technical Committee, the principal investigators and the project management are held on a regular basis to review the progress of the Project.

5.1 **SITE CHARACTERIZATION AND VALIDATION**

5.1.1 Coordination

The Stripa Project Manager Dr Bengt Stillborg, SKB, will be responsible for the overall integration of the "Site Characterization and Validation" project. For the scientific coordination of the project he will be assisted by Drs John Black, British Geological Survey and Olle Olsson, Swedish Geological Co. In particular the scientific coordinators, in close cooperation with the principal investigators, will have the main responsibility for the preliminary predictions (Stage II), detailed predictions (Stage IV), final evaluation and reporting (Stage V).

5.1.2 Drilling and Excavation

The contract for drilling and excavation will be appointed to a suitable contractor selected and coordinated by the Project Management.

5.1.3 Core Logging and Fracture Mapping

The core logging and fracture mapping will be a joint effort between Fracflow Consultants Inc. and Swedish Geological Co. (SGAB). The main responsibility for the field investigations will rest with Dr Olle Olsson, Swedish Geological Co. while Prof John Gale, Fracflow Consultants will accept the main responsibility for statistical analysis of fracture data.

5.1.4 Geophysical Single Hole Logging

The main contractor and responsible for interpretation of the geophysical single hole logging will be Dr Olle Olsson, Swedish Geological Co.

5.1.5 Measurement on Small Core Samples

The main responsibility for the measurement of the different properties of small diameter core fracture surfaces will rest with Dr Nick Barton, Norwegian Geotechnical Institute.

Dr Olle Olsson, Swedish Geological Co. will be responsible for the measurement of geophysical parameters.

5.1.6 Rock Stresses

The rock stress measurements will be performed by Prof Ove Stephansson, Division of Rock Mechanics, University of Luleå, Sweden.

5.1.7 Borehole Radar

The borehole radar investigations will be performed by Dr Olle Olsson, Swedish Geological Co.

5.1.8 Borehole Seismics

The borehole seismic investigations will be carried out jointly between Dr Calin Cosma, Vibrometric Oy, Finland, and Dr Jörgen Pihl, Swedish National Defense Research Institute, FOA, Sweden.

5.1.9 Hydraulic Investigations

Dr John Black, British Geological Survey will be responsible for the hydraulic measurement program and interpretation of data. Dr Olle Olsson, Swedish Geological Co. will assist in construction of equipment and field tests.

5.1.10 Hydrochemistry

Responsibility for the hydrochemistry program will be held by Dr Peter Wikberg, Department of Inorganic Chemistry at the Royal Institute of Technology, Stockholm.

5.1.11 Measurements on Large Core Samples

Responsibility for the deformation-flow coupling test on large cores samples will be Dr Nick Barton, Norwegian Geotechnical Institute, NGI. Dr Barton will also be responsible for channeling experiments on large cores using clear epoxy cast replicas of the joint surfaces, and coloured dyes. Additional channeling experiments on large core samples using a resin impregnation approach will be conducted by Prof John Gale, Fracflow Consultants, Canada.

5.1.12 In Situ Test on Fracture Deformation

Responsible for the in situ block test described in Section 4.1.4.5 will be Dr Nick Barton, Norwegian Geotechnical Institute, NGI.

5.1.13 Water Flow Validation

Responsibility for the water flow validation experiment described in section 4.1.6.2 will rest with Prof Ivars Neretnieks, Department of Chemical Engineering, the Royal Institute of Technology, Stockholm.

5.1.14 Tracer Test in the Validation Drift

Responsibility for the tracer experiment will be held by Prof Ivars Neretnieks, Royal Institute of Technology, Stockholm.

5.2 **IMPROVEMENT OF SITE ASSESSMENT METHODS AND CONCEPTS**

5.2.1 Development of High Resolution and Directional Radar

Principal investigator will be Dr Olle Olsson, Swedish Geological Co., Sweden.

5.2.2 Improvement of Techniques for High Resolution Borehole Seismics

Principal investigator will be Dr Calin Cosma, Vibrometric Oy, Finland.

5.2.3 Fracture Network Modelling

Principal investigator will be Dr Michael Norgett, Harwell Laboratory, United Kingdom.

5.2.4 Channeling Experiments

Principal investigators will be Prof Ivars Neretnieks, Department of Chemical Engineering, Royal Institute of Technology, Sweden.

5.2.5 Estimation of Fracture Length and Aperture from Single Fracture Packer Tests

Principal investigator will be Dr Thomas Doe, Golder Associates, Berkeley, USA.

5.3 **SEALING OF FRACTURED ROCK**

The overall coordination will be accomplished by the Stripa Project manager. The principal investigator will be Prof Roland Pusch, Swedish Geological Co., Sweden. The principal investigator will organize and conduct the work in cooperation with the Stripa project management and an ad hoc group

consisting of representatives from the participating countries.

6 SUMMARIZED TIME SCHEDULE

FRACTURE FLOW AND NUCLIDE TRANSPORT	1986	1987	1988	1989	1990	1991
<u>Site Characterization and Validation</u>						
Stage I - Preliminary site characterization						
Drilling	—					
Core logging and fracture mapping	—					
Geophysical single hole logging	—					
Measurements on small core samples		—				
Rock stresses		—				
Borehole radar	—					
Borehole seismics		—				
Hydraulic investigations		—	—			
Hydrochemistry		—	—			
Stage II - Preliminary prediction			—			
Stage III - Detailed characterization and preliminary validation						
Drilling and excavation			—			
Core logging and fracture mapping			—			
Geophysical single hole logging			—			
Measurements on large core samples		—	—			
In situ test of fracture deform			—			
Borehole radar			—			
Borehole seismics			—			

**GROUNDWATER FLOW PATH
SEALING**

Sealing of fractured rock

Stage I -
State of the art survey

Stage II -
Determination of
sealing properties

Stage III -
Determination of
long-term stability

Stage IV -
Field pilot tests

Stage V -
Large scale sealing test,
planning stage

	1986	1987	1988	1989	1990	1991
Stage I - State of the art survey	—					
Stage II - Determination of sealing properties		—				
Stage III - Determination of long-term stability		—				
Stage IV - Field pilot tests			—			
Stage V - Large scale sealing test, planning stage			—			

7 SUMMARIZED COSTS7.1 EXPERIMENTAL COSTS

All costs are given in MSEK, price level January, 1986

FRACTURE FLOW AND NUCLIDE TRANSPORT	1986	1987	1988	1989	1990	1991	Total
<u>Site Characterization and Validation</u>							
Stage I - Preliminary site characterization							
Drilling	1.1						1.10
Core logging and fracture mapping	0.6	0.2					0.80
Geophysical single hole logging	0.4	0.2					0.60
Measurements on core samples		0.25					0.25
Rock stresses		0.25					0.25
Borehole radar	0.4	0.7					1.10
Borehole seismics		1.3					1.30
Hydraulic investigations		1.8	0.2				2.00
Hydrochemistry		0.7	0.1				0.80
Stage II - Preliminary prediction		0.5	0.7				1.20
Stage III - Detailed characterization and preliminary validation							
Drilling and excavation			2.25				2.25
Core logging and fracture mapping			0.75				0.75
Geophysical single hole logging			0.4				0.40

Site Characterization and Validation

Continued

	1986	1987	1988	1989	1990	1991	Total
Measurements on large core samples		0.2	0.45				0.65
In situ tests of fracture deformation			1.25				1.25
Borehole radar			0.5				0.50
Borehole seismics			0.3	0.2			0.50
Hydraulic investigations			0.5	1.5			2.00
Hydrochemistry				0.4			0.40
Stage IV - Detailed predictions				2.7			2.70
Stage V - Detailed evaluation							
Drift excavation and associated measurements				1.3			1.30
Water flow validation				0.2	0.3		0.50
Tracer test	0.2	0.2	2.5	2.8	1.8	0.7	8.20
Final Evaluation and Reporting						2.5	2.50
Project coordination and contingencies	0.3	0.7	0.7	0.7	0.7	0.4	3.50
TOTAL	3.0	7.0	10.6	9.8	2.8	3.6	36.80

Improvement of Site
Assessment Methods and
Concepts

Development of High
Resolution and Direc-
tional Radar

Improvement of Techniques
for High Resolution
Borehole Seismics

Fracture Network Modelling

Channeling Experiments

Estimation of Fracture
Length and Aperture
from Single ...

TOTAL

	1986	1987	1988	1989	1990	1991	Total
Development of High Resolution and Direc- tional Radar	1.0	2.2	1.5				4.70
Improvement of Techniques for High Resolution Borehole Seismics	0.63	0.74	0.94	0.63	0.03	0.03	3.00
Fracture Network Modelling	0.6	1.2	1.2	1.2	1.2	0.6	6.00
Channeling Experiments	0.04	3.38	2.34	0.64			6.40
Estimation of Fracture Length and Aperture from Single ...	0.2	0.4	0.2				0.80
TOTAL	2.47	7.92	6.18	2.47	1.23	0.63	20.90

**GROUNDWATER FLOW PATH
SEALING**

Sealing of Fractured
Rock

Stage I - State of the art

Stage II - Determination
of sealing properties

Stage III - Determination
of long term stability

Stage IV - Field pilot
tests

Stage V - Large scale
sealing test,
planning stage

TOTAL

	1986	1987	1988	1989	1990	1991	Total
Stage I - State of the art	1.5						1.50
Stage II - Determination of sealing properties		2.0	0.5				2.50
Stage III - Determination of long term stability		1.0	1.0				2.00
Stage IV - Field pilot tests			0.8				0.80
Stage V - Large scale sealing test, planning stage			0.2				0.20
TOTAL	1.5	3.0	2.5				7.00

7.2 TOTAL COSTS

Below please find a summary of the total costs for the third phase of the Stripa Project. The costs for "other investigations", 20 MSEK is included as a result of previous correspondence between the JTC-members and the project management. A decision on the allocation of this funding should be taken by the JTC during 1988. The annual distribution of the 20 MSEK is tentative.

All costs are given in MSEK and in price level January 1986.

	1986	1987	1988	1989	1990	1991	Total
Project Management	0.6	1.2	1.2	1.2	1.2	0.6	6.00
Mine Operations	2.1	4.2	4.2	4.2	4.2	2.1	21.00
Site Characterization and Validation	3.0	6.8	10.6	10.3	2.5	3.6	36.80
Improvement of Site Assess ...	2.47	8.22	5.88	2.47	1.23	0.63	20.90
Sealing of Fractured Rock	1.5	4.5	1.0	-	-	-	7.00
Other Investigations	-	-	3.0	7.0	7.0	3.0	20.00
TOTAL	9.67	24.92	25.88	25.17	16.13	9.93	111.70