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ATTACHMENT 2

# Unsaturated Fractured Rock Characterization Methods and Data Sets at the Apache Leap Tuff Site

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Project Monitor: Thomas J. Nicholson
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PROGRESS REPORT

NRC-04-86-114

# UNSATURATED FLOW AND TRANSPORT THROUGH FRACTURED ROCK RELATED TO HIGH-LEVEL WASTE REPOSITORIES

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April 1, 1989

# LABORATORY ANALYSIS OF FLUID FLOW AND SOLUTE TRANSPORT THROUGH A VARIABLY SATURATED FRACTURE EMBEDDED IN POROUS TUFF

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# VAM2D – Variably Saturated Analysis Model in Two Dimensions

Version 5.0 With Hysteresis and Chained Decay Transport

Documentation and User's Guide

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**NRC FIN D2505**

Attachment

# intraval

## PROGRESS REPORT

## 3

November 1988 – February 1989

INTRAVAL — An International Project to Study
Validation of Geosphere Transport Models

# INTRAVAL

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

Twentyone organisations – Parties – from twelve countries participate in INTRAVAL. The Project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant. It has set up a Project Secretariate in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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## Introduction

Since 1981 conceptual and mathematical models for radionuclide and groundwater transport in the geosphere have been evaluated in the international co-operation projects INTRACOIN, HYDROCOIN, and now also INTRAVAL, managed by the Swedish Nuclear Power Inspectorate (SKI).

The INTRAVAL project was started in October 1987. The purpose of the study is to increase the understanding how various geophysical, geohydrological and geochemical phenomena of importance for the radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose. This is being done with a systematic use of information from laboratory and field experiments as well as from natural analogue studies.

Seventeen test cases have so far been included in the study. A Pilot Group has been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases. Several of cases are based on international experimental programmes, such as the Stripa Project, the Alligator Rivers Project and the Poços de Caldas Project.

It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for. To support this interaction and for the development of a strategy for the systematic application of the experiences and knowledge gained from the test cases, a special committee, the Validation Overview and Integration Committee (VOIC), has been set up within the study.

The documentation of the laboratory and many of the field experiments are now available and the Project Teams have started to produce their first modelling results. The test cases dealing with natural analogue studies and a synthetic data base are being defined and developed. A number of new test cases concerning radionuclide migration in salt formations have been included in the INTRAVAL study. For these test cases, the documentation and background material are expected to be developed and defined during the spring of 1989.

During the period covered by this progress report, the second INTRAVAL workshop was held in Tucson, Arizona. In conjunction with this workshop, VOIC met to examine the test cases as well as to discuss a framework for model validation. A meeting between the Project Teams interested in Test Case 5 based on the tracer experiments at the Finnsjön research area in Sweden was also convened during the week of the workshop.

## The Second INTRAVAL Workshop and the Third INTRAVAL Coordinating Group Meeting

The second INTRAVAL workshop and the third Coordinating Group meeting were held in Tucson, Arizona, USA, on the 14th through 18th of November 1988 with the U.S. Nuclear Regulatory Commission acting as host.

The discussions at the workshop focussed on new information on the experiments and the progress of the modelling work since the last workshop. Proposals for new test cases, a synthetic data base and laboratory and field experiments dealing with flow and transport in salt formations, were also presented at the workshop.

The afternoon of April 18th was devoted to the Coordinating Group meeting. It was then decided to include four new test cases in the study. Formally adopted were one test case dealing with a synthetic data base and three test cases related to radionuclide migration in salt formations. A complete list of the currently adopted INTRAVAL test cases is presented in Table 1. A questionnaire regarding intentions of the project teams to participate in the evaluation of various test cases were circulated at the meeting. The responses are presented in Appendix 3.

In conjunction with these meetings, the University of Arizona/U.S. NRC organised a field trip to the Apache Leap Tuff Site near Superior, Arizona, where the experimental work underlying Test Case 11 is being performed.

## Validation Overview and Integration Committee (VOIC)

A Validation Overview and Integration Committee (VOIC) for the development of a strategy for the systematic application of experiences and knowledge gained from the various INTRAVAL test cases has been set up by the Coordinating Group.

The members of VOIC are: Thomas Nicholson, U.S. NRC (Chairman), Jesus Carrera, Universidad Politéchnica de Cataluña, Neil Chapman, British Geological Survey, David Hodgkinson, Intera-Exploration Consultants Ltd, Ivars Neretnieks, The Royal Institute of Technology, Shlomo Neuman, University of Arizona, and Chin Fu Tsang, Lawrence Berkeley Laboratories.

In the mandate for the VOIC it is stated that its purpose is to provide a means for the INTRAVAL project to investigate the broad issues related to demonstrating the validity concepts, theories and models used in the performance assessment of repositories, and to provide for a continuing technical overview which will allow for ongoing adjustments and improvements to the selected test cases. Furthermore, the objectives of the VOIC are:

— to examine the broad validation issues associated with demonstrating the validity of theories and models used in the performance assessment of repositories through synthesis and integration of the experiences and knowledge gained from each of the INTRAVAL test cases, as well as to review other appropriate research studies outside of INTRAVAL; and

— to provide a technical overview function through recommendations to the INTRAVAL Coordinating Group based on the VOIC's synthesis and integration efforts of validation issues, reviews of non-INTRAVAL research studies, and ongoing reviews of the INTRAVAL test cases.

VOIC had its second meeting on November 13, 1988 in Tucson, Arizona. The topics discussed were the review of the different test cases and the formulation of a structured framework for the validation process to guide the INTRAVAL work and reporting.

At the workshop, the members of VOIC presented their ideas about the steps in the validation process that the Project Teams would need to consider in their work with the test cases. The process starts with the identification of the important processes, mechanisms, structures etc., necessary for the definition of a conceptual model. Based on this identification, the formulation of the mathematical model, the solution procedure and possibly the fitting procedure are defined. Goodness-of-fit and performance measures have to be estimated as well as sensitivity measures, i.e., how sensitive the results are according to perturbations in input data. The obtained results have to be compared to independent data or knowledge. It is also important to investigate if alternative mechanisms may give equally good fits or predictions. VOIC considered it important that the Project Teams adhered to the proposed scheme, as it would give additional insight in the INTRAVAL work towards validation.

At this second meeting it was decided to change the name of the committee from Validation Oversight and Integration Committee to Validation Overview and Integration Committee.

## Present Status of the Test Cases

### Test Case 1a

*Radionuclide migration through clay samples by diffusion and advection, based on laboratory experiments performed at Harwell, U.K. (Pilot Group leader: David Lever, Harwell Laboratory)*

This test case is concerned with the validation of models that describe the permeation, diffusion and dispersion of radionuclides through clay. A set of transient and steady state tracer experiments have been performed both parallel and perpendicular to the bedding of the clay sample. The clay, London clay, is a marine deposit. The particle size analyses indicate that approximately 60% consists of 'clay' size material (<2 µm), while the remainder is of 'silt' grade (2-75 µm). An example of the experimental setup is shown in Figures 1-3.

The length scale of the experiments are up to a few centimetres and the duration is up to a few months. The solutes used are deuteriated water, iodine, strontium and caesium. Data from experiments with elements with more complicated sorption behaviour will also be available in the future.

The transport rate parameters, like porosity, permeability, diffusivity and dispersivity, have been estimated from measured breakthrough curves. In addition, there are a number of complementary experiments available, such as small angle neutron scattering (SANS) and consolidation experiments, giving information about size, shape and distribution of the pores, as well as the dependence of the properties on the conditions under which the experiments are carried out.

The Project Team from GSF presented results from their modelling work. They have used a one-dimensional porous medium model with homogeneous and isotropic matrix. The governing transport mechanisms are advection-diffusion, whereas, matrix diffusion, sorption and decay were disregarded. The simulation of the through-diffusion experiments with iodine gave a diffusivity coefficient of $8 \cdot 10^{-11}$ $m^2 \cdot s^{-1}$. The raw data of the permeation experiments with iodine show a ratio between the total flux out of the sample and the convective flux that is larger than 1. This overshoot could not be explained with the model used.

The Project Team from UPC presented preliminary results based on a conceptual model including molecular diffusion, dispersion, advection, and diffusion into dead-end pores. Both the clay samples and the reservoirs have been modelled. Including the reservoirs in the model makes the formulation of the boundary conditions less sensitive. All experiments were modelled both with and without matrix diffusion. The analyses of the indiffusion experiments showed that the porosity varied between the different samples. This could also be seen in the raw data. The large variation between samples make it difficult to interpret the results of several experiments together. The through diffusion experiments could be fitted rather well, except in some cases for which the fitted parameters gave no sense. For the permeation experiments, different results were obtained depending on how the flux to concentration transformation was made. In the future, alternative conceptual models will be considered and a systematic sensitivity and error analysis will be performed.

The Coordinating Group expressed the need to accelerate the work with this test case (1a) so that it can act as a pathfinder for other test cases.

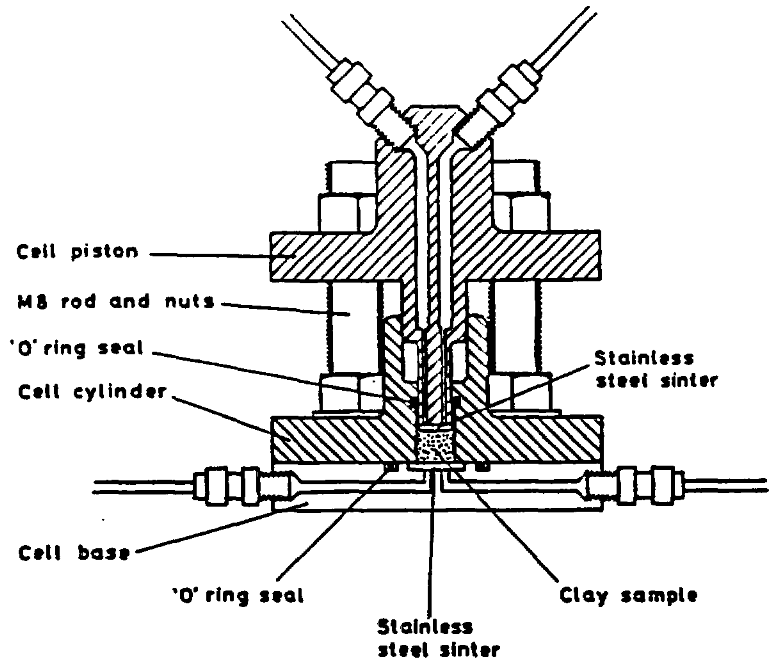



Figure 1. Experimental setup for vertical through-diffusion experiments (Test Case 1a).

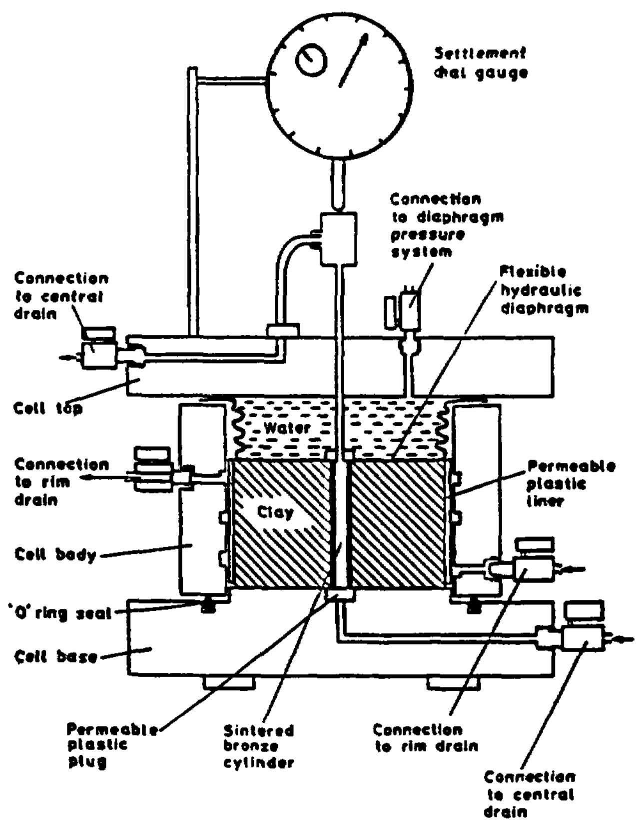



Figure 2. Experimental arrangement for horizontal through-diffusion experiments (Test Case 1a).

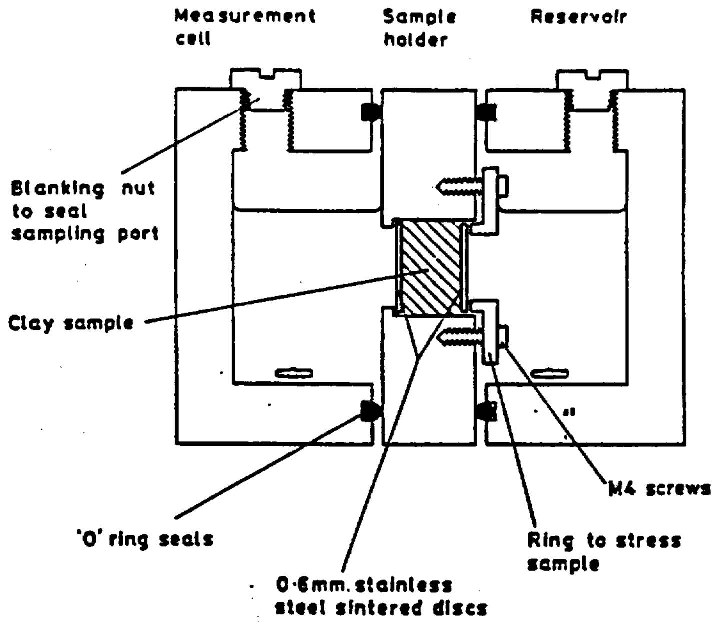



Figure 3. Experimental setup for permeation experiments (Test Case 1a).

**Test Case 1b**

*Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland. (Pilot Group leader: Jörg Hadermann, PSI)*

This test case addresses important phenomena in radionuclide transport in the geosphere, such as retardation by sorption and possible matrix diffusion, dispersion and geometry of water flow zones for various types of crystalline rocks. Water containing tracers is at high pressure forced to flow through rock cores of granite or gneiss with the dimensions in the range of centimetres. The experimental setup is shown in Figure 4.

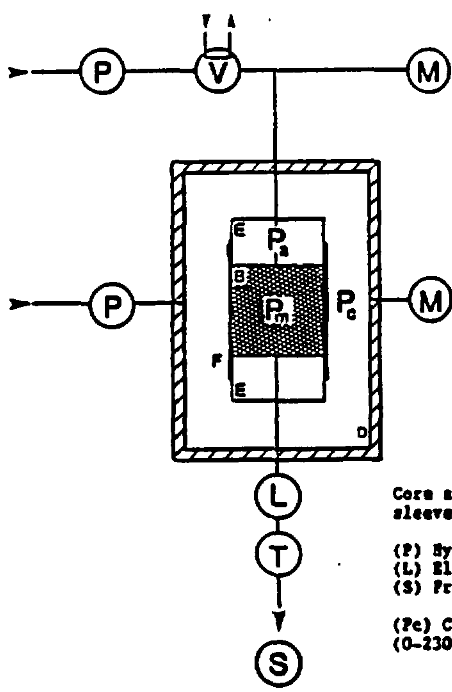
Measured quantities are chemical composition of infiltrating liquid, mineral composition of cores, hydraulic conductivities as a function of pressure, porosities, breakthrough curves (uranium, demineralised water, iodine), and batch adsorption and desorption isotherms (uranium). Moreover, alpha-autoradiographs are available.

In addition to these experiments, new infiltration experiments with other cores and more tracers such as, iodine, uranine, bromide, sodium, and strontium will be performed. Data from these experiments will be available within a year.

Since the last workshop, the Pilot Group has evaluated breakthrough curves for uranium with four different one-dimensional conceptual models, considering both equivalent porous medium and dual porosity medium models. An advective-dispersive model with linear sorption and three independent fracture families with different retardations (retardation factors 70, 400, and 2000) but equal dispersivity (0.012 m) reproduced both the peak value and the long tail. The different retardations in the pathways could possibly be explained by variations of the mineralogy phases, e.g. of the quartz content. On the other hand, one fracture family and nonlinear sorption did not reproduce the breakthrough curve. The model for a dual porosity medium accounting for advection-dispersion in water carrying zones, matrix diffusion, and linear sorption gave a relatively good fit, with a longitudinal dispersivity of 0.016 m and an effective diffusivity of $8 \cdot 10^{-14}$ $m^2 \cdot s^{-1}$. Nonlinear sorption included in this last model gave also a good fit. The system is, however, very sensitive to parameter variations. Increasing the effective diffusivity sixteen times gives a totally different result. The result is also very sensitive to changes in the longitudinal dispersivity. The main conclusion from these modelling attempts is that incorporation of matrix diffusion seems necessary to describe the long tail.

A partly contradicting conclusion was drawn from very preliminary modelling results from the VTT Project Team. A generalised Taylor dispersion analysis with four fracture families with different water flow rates but the same characteristic fracture width (5 mm), linear retardation (retardation factor 100), and disregarding matrix diffusion, gave a relatively good fit also for the tail.

In both these analyses presented at the workshop, a multiple path approach had been applied. Although it is easy to conceive a sample containing multiple paths, and the experimental data in a qualitative way support such an interpretation, there are no data to quantify the properties of the individual paths. The number of free parameters therefore increases in proportion to the number of paths assumed.




Core assembly with (B) core sample, (E) end pieces, (F) flexible sleeve

(P) Hydraulic pumps, (M) Manometers, (V) Injection valve, (L) Electrical conductivity probe, (T) Droplet counter, (S) Fraction/droplet sampler, (D) Pressure vessel

(Pc) Confining pressure (0-60 MPa), (Pa) Infiltration pressure (0-230 MPa), (Pm) Pore pressure

**Figure 4. Schematic diagram of pressure infiltration apparatus (Test Case 1b).**

## Test Case 2

***Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH. (Pilot Group leader: Tryggve Eriksen, KTH)***

This test case is based on laboratory experiments and describes radionuclide migration of nonsorbing, moderately sorbing and strongly sorbing tracers in single natural fissures in granite drill cores. It addresses important phenomena in radionuclide transport in the geosphere, such as retardation, matrix diffusion, dispersion, channelling, channel structure, and fracture properties.

Granite drill cores, each with a natural fissure running parallel to the axis were used in the experiment. The sizes of the cores were 0.04-0.2 m in diameter and 0.08-0.3 m in length. The experimental setup is shown in Figure 5.

The tracers were injected either as a step function or as a pulse. Breakthrough curves for nonsorbing (tritiated water, iodine, bromide, and lignosulphonates), moderately sorbing (caesium and strontium), and strongly sorbing (europium, neptunium, plutonium, americium, and technetium) tracers were recorded. Complementary sorption data are available for moderately sorbing tracers. The distribution of strongly sorbing tracers on the fracture surface is also available. For europium-152 most of the tracer was found on the fracture surface near the inlet, although small amounts broke through.

The Project Team from PNL evaluated this test case with a number of different conceptual models: porous medium, fracture flow, including matrix diffusion (analytically and with the numerical CRACK model), triple porous medium (three fluxes with their own characteristics), and a vein model (one-dimensional tube including matrix diffusion). The parameters in the different model approaches were fitted to all data points and to a selected number of points at the early or later part of the breakthrough curves. The effect of experimental measurement errors on the parameter fitting process was estimated in terms of constant errors and variable errors (percent). The conclusion drawn was that the porous medium model did not reproduce the breakthrough curves, whereas the other models gave rather good fits for some parameter sets. This modelling work will be continued. One approach foreseen is to constrain one parameter outside the expected region to estimate the sensitivity to this parameter.

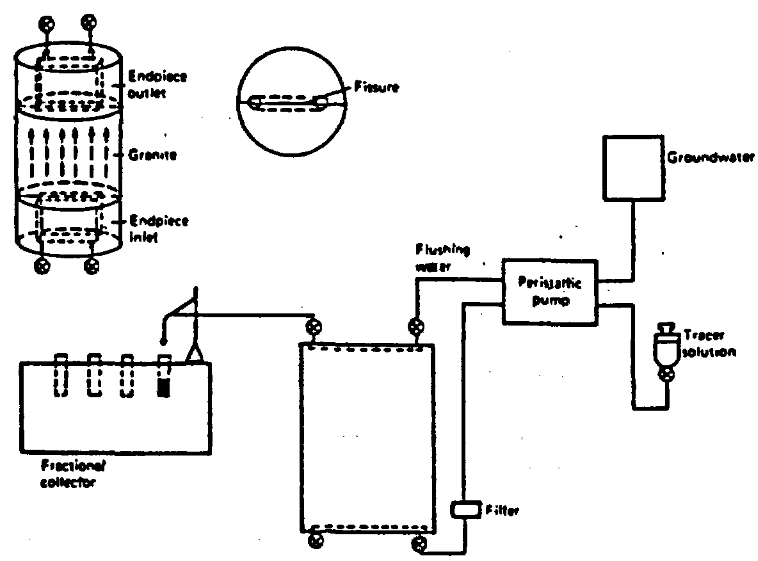



Figure 5. Experimental setup (Test Case 2).

### Test Case 3

*Tracer tests in a deep basalt flow top performed at the Hanford Reservation, Washington, USA. (Pilot Group leader: Charles Cole, PNL)*

This test case involves a recirculating tracer tests in two boreholes about 17 m apart in a deep basalt flow top, about 1000 m below ground level. The INTRAVAL efforts will be to identify additional measurements and testing procedures to distinguish between and validate various conceptual models, such as homogeneous or heterogeneous porous media flow, fracture flow, and dispersion.

The data base available is very large and includes flow rates, breakthrough curves (iodine and potassium thiocyanate), pump test data, geometry of the site, water chemistry, core data, temperature versus depth, etc. The basalt flow top is expected to be rubbly rather than fractured. The path length in the rock is relatively short compared to the depth as well as to the dispersion length.

The project team from JAERI presented model calculations with a two-dimensional analysis assuming that the flux from the flow top into the adjacent layers is negligible. Furthermore, the aquifer was treated as a homogeneous and porous medium. The groundwater flow field was determined analytically, whereas the tracer transport was solved with a finite element method with a grid based on the stream lines. Breakthrough curves both for iodine and potassium thiocyanate were evaluated. The best fitting, obtained by trial and error, of one breakthrough curve for iodine (relative concentration) and one for potassium thiocyanate (absolute concentration) gave the following range of the evaluated parameters: Darcy flow rate 0.0031 $m^3 \cdot m^{-2} \cdot s^{-1}$, longitudinal dispersivity 0.28-0.30 m and transverse dispersivity 0.01-0.2 m. To get good fits it was necessary to assume a 60% recovery of the tracers. In sensitivity estimations it was concluded that the curve fitting was not very sensitive to the transverse dispersivity. The dispersion in the piping could be important but has not been incorporated in this modelling. A detailed plan of the pipe work is being drawn up by the Pilot Group so that the amount of dispersion that occurs within it can be estimated.

The porous medium approach has been adopted also by the project team from PNC. They used an integrated finite difference code to solve the mathematical equations with a two-dimensional curve linear mesh. The longitudinal dispersivity was estimated to be around 0.5 m from one tests with iodine. In a sensitivity analysis the transverse dispersivity was shown to have only minor influence on the breakthrough results. The team concluded that the porous medium approach seems to reproduce the breakthrough curves, if full recovery is not assumed.

### Test Case 4

*Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiment performed within the International Stripa Project. (Pilot Group leader: Ivars Neretnieks, KTH)*

This test case is based on 3-D tracer tests performed in the Stripa mine in Sweden. The main purpose of this experiment is to study longitudinal and transverse dispersion in fractured rock, determine flow porosity, study channelling, and obtain data for model verification or modification. The experiment forms part of the international Stripa Project.

An experimental drift was excavated in the old iron-ore mine in Stripa, Sweden. The whole ceiling and upper part of the walls were covered with about 350 plastic sheets (2 $m^2$ each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations, 10-55 m above the test site. The location of the injection holes are shown in Figure 6.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressure and flow rates, hydrostatic pressure, diffusivity, and sorption data.

The results of the water flow measurements demonstrate extreme spatial variability. 2/3 of the drift is dry, one sheet carries 10% of the water and twelve sheets carry 50%. The flow rate into the drift does not correlate well with the fracture density. However, there is a correlation between the flow rate and the local number of fracture intersections. The longest breakthrough time was 26 months from the farthest injection point. After completion of the experiment, it was noted that one of the tracers had moved about 150 m parallel to the drift over a three year period.

The project team from Intera-ECL presented some preliminary ideas about development of improved conceptual models for transport in saturated fractured rocks. The hypothesis is that the rock mass acts as a self-similar system by virtue of the hydraulic discontinuities at a number of different length scales. The fundamental point is that the physical processes involved in the experiment are well understood, whereas the unknown quantities are the geometries of the flow and diffusion paths. Thus, in the present approach the geometry is treated as a parameter and the rock mass is assumed to be a hydraulic medium of fractional dimensionality. The first modelling step will be to analyse tracer arrival times in a systematic way.

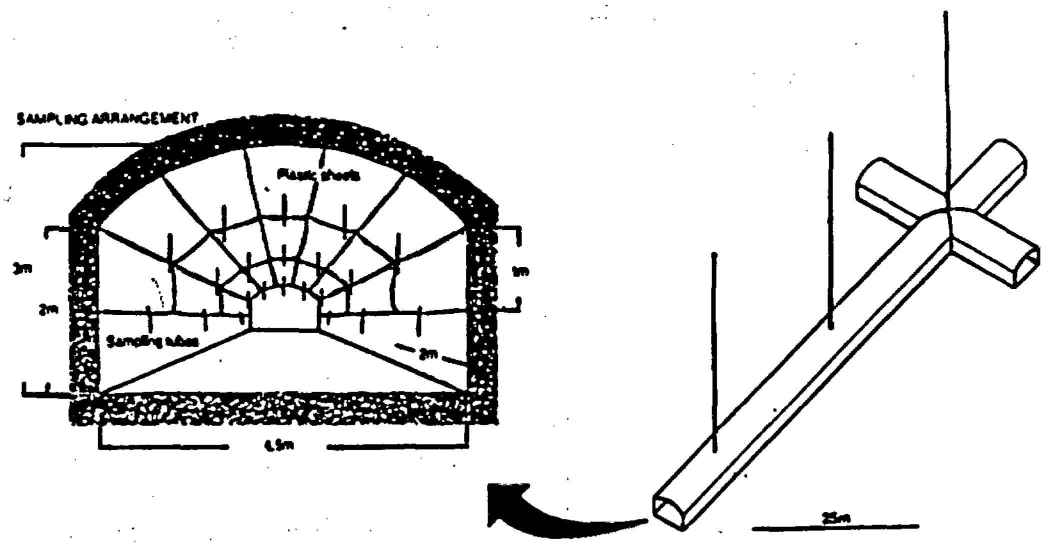



Figure 6. The experimental drift. The location of the tracer injection holes is indicated (Test Case 4).

### Test Case 5

*Tracer experiments in a fracture zone at the Finnsjön research area, Sweden. (Pilot Group leader: Peter Andersson, Swedish Geological Co)*

This test case concerns tracer experiments in a fracture zone in crystalline bedrock at the Finnsjön research area in Sweden. The rate at which radionuclides in groundwater can migrate through the rock is mainly dependent on the fracture system, as the flow through the intact rock matrix is very low. The experiment is designed for studying migration over large distances. Three different types of experiments are planned or have been performed: a radially converging tracer experiment (completed), a dipole experiment (planned) and a natural gradient tracer experiment (planned).

The fracture zone is about 100 m wide, but most of the flow appears to take place in three sub zones. Tracers will be injected in all evaluated conductive zones.

The parameters to be evaluated during this test programme are hydraulic conductivity in fractures, flow porosity, dispersivity, fracture volume, heterogeneity, interconnections between highly conductive parts, matrix diffusion and sorption.

Radially converging tracer experiments were made during the summer 1988. Water was pumped from one bore hole and tracers were injected in three boreholes at three different padded off sections of the fractured zone. A conceptual model of the experiment is shown in Figure 7. The dipole experiments are planned to start in May 1989.

The INTRAVAL participants have been invited to perform pre-test calculations for the radially converging experiment. As a response, calculations of the water flow time and the tracer flux have been performed by the Project Team from VTT. Mean flow times were calculated using reported hydrological data. The water flow was assumed to be concentrated in channels in a fracture. The actual tortuous channels in three dimensions were flattened and straightened to give a two-dimensional channel network in a fracture plane. The aperture as well as the widths of the channel may vary strongly along the channel length. The aperture variation was taken into account and a mean effective width of each channel was defined. The tracer transport was modelled as convection and diffusion of tracer in the flat fracture channel. The calculated results gave a much longer release time than the field measurements, whereas the height of the breakthrough curve was reproduced rather well.

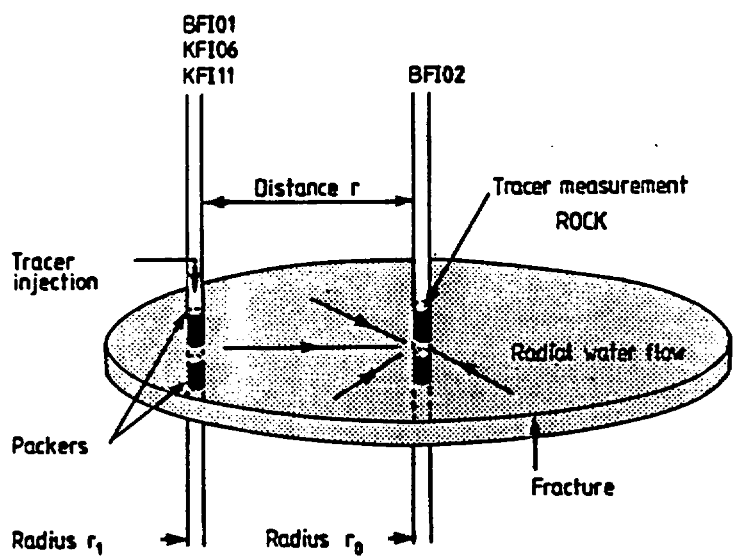



Figure 7. Conceptual model of the radially converging tracer experiment (Test Case 5).

**Test Case 6**

*Synthetic data base, based on single fracture migration experiments in Grimsel Rock laboratory in Switzerland.(Pilot Group leader: R. Codell, U.S. NRC)*

It was decided at the Coordinating group meeting to include a test case based on a synthetic data base. A working group appointed earlier has started to develop such a test case during the summer and autumn of 1988. They had two meetings during the summer.

The objectives with this exercise are to improve the understanding of identified problems, such as spatial and temporal variability, boundary conditions, competing processes, measurement scale, sampling density, and sampling location. The synthetic data base will be based on a single-fracture migration experiment in Grimsel Rock Laboratory, Switzerland. A series of flow calculations have been performed starting with the regional scale and ending with detailed flow simulations in a fracture plane. The code development for detailed flow predictions is nearly complete and has been run on some test problems. The complete package will be made available in the beginning of 1989. A second part considering nonconservative and diffusing tracers will be delivered later.

### Test Case 7a

*Redox-front and radionuclide movements in an open pit uranium mine. Natural analogue studies at Poços de Caldas, Brazil. (Pilot Group leader: Ivars Neretnieks, KTH)*

This test case is based on one of two sub-projects in a natural analogue study performed at Poços de Caldas, Minas Gerais, Brazil. It is concerned with evaluation of the transport and speciation of natural radionuclides and rare earth elements in a fissured flow system in crystalline rock under both oxidising and reducing conditions. The phenomena observed are large scale redox-front movements due to the influx of oxygenated water and its reduction by ferrous minerals in the rock, uranium mobilisation and reprecipitation, large scale channelling, as well as matrix diffusion over long times and distances.

The redox front is very sharp and can be clearly seen because of the color of ferrous and ferric minerals being different. The secondary uranium mineralisation is found around the fractures and at the moving redox fronts, see Figure 8.

The data collection will not be completed until October 1989 and a well defined test case is foreseen to be available late 1989.

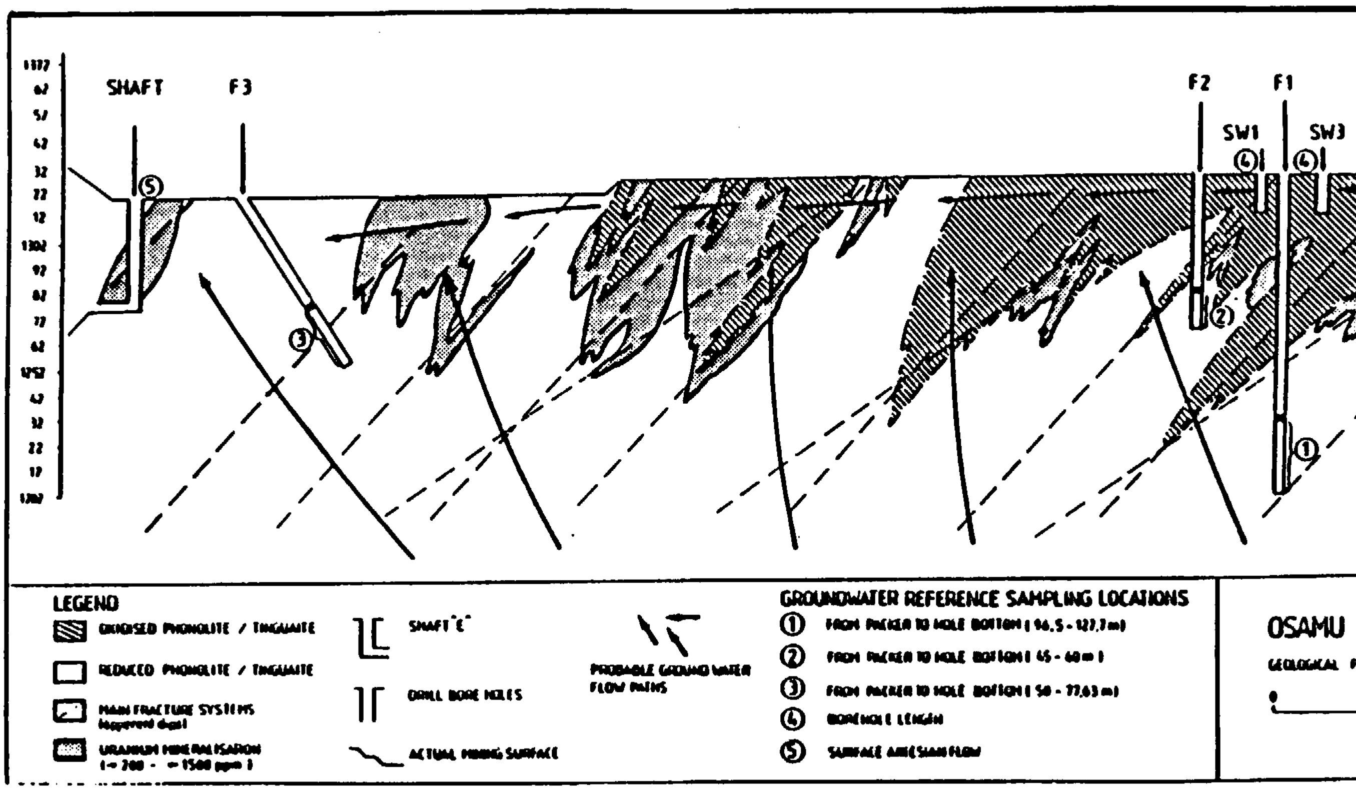



Figure 8. An example of a cross section from Osamu Utsumi mine at Poços de Caldas (Test Case 7a).

**Test Case 7b**

*Morro do Ferro colloid migration studies. Natural analogue studies at Poços de Caldas, Brazil. (Pilot Group leader: Neil Chapman, BGS)*

This test case is based on the second subproject of the natural analogue study at Poços de Caldas. Minas Gerais, in Brazil. It is concerned with colloid formation and mobility in natural ground water and the role of colloids in element transport.

The main aims are to study the content and characteristics of colloids in groundwater and to determine their role in transporting thorium, radium and rare earth elements. It is proposed to monitor seasonal changes in colloid concentration. The data are expected to become available in October, 1989. They will consist of geochemical analyses taken four times a year at five sampling points.

The primary objective is to make some assessment of colloid transport mechanisms. At present there are apparently not many models in existence dealing specifically with colloids. However, this test case could stimulate their development. The Pilot Group presented some thoughts on the development procedure for the colloid model. A model for colloid transport could consider a large number of phenomena, but it was pointed out that the model could also be a simple approach. A number of phenomena which could be included were identified, such as radionuclide complexes of colloidal size and 'pseudo-colloids', filtration of particles with various size distributions in complex pore or channel morphology, radionuclide sorption and desorption onto rocks and colloids, colloid sorption or desorption onto rocks, the chemical stability of colloids in groundwater, kinetics of radionuclide transfer and colloid stability, dispersion of particles of various sizes, and matrix diffusion of colloids of certain sizes.

**Test Case 8**

*Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia. (Pilot Group leader: Peter Duerden, ANSTO)*

This test case deals with the natural analogue studies in the Alligator Rivers region of the Northern Territory of Australia. A comprehensive experimental and modelling programme has been set up and the work will be aimed at supporting modelling studies.

The uranium deposits of the Alligator Rivers region occur near the base of Lower Proterozoic (Cahill Formation) schists. They are located in zones of chloritisation within the schists and are adjacent to lenses of massive dolomite. The Koongarra uranium mineralisation occurs in two distinct ore bodies separated by a barren gap.

The objective of the Alligator River Analogue Project, ARAP, is to assist in the long term prediction of the transport rate of radionuclides through the geosphere. The topics dealt with are the evaluation of significant processes in the radionuclide transport as well as the establishment of a radiochemical data base.

The hydrogeological data base comprises data from mineralogical and uranium assay logs from a large number of boreholes. The data base contains hydrogeological data from drawdown/recovery and pressure tests. Aquifer tests have also been made to support the characterisation of the flow system in the bedrock. Additional boreholes and tests are proposed. A data base with general hydrochemical data exists. More data will be collected for uranium and thorium decay series, colloids, fission products, as well as for transuranic nuclides. A schematic picture of the location of the sampling wells at the Koongarra deposit is shown in Figure 9.

A sub-project in the ARAP deals with the hydrology. Major efforts have been directed towards studying the general water movement in the area, as well as characterisation of faults and fractures. The system is very anisotropic and heterogeneous which has been clearly observed in drawdown aquifer tests. The major path for the water flow is in fractures. The annual fluctuation of the water table is 17 metres and depends on the precipitation which amounts to about 1700 millimetres annually.

Since the INTRAVAL workshop in Barcelona in April 1988, the Pilot Group has performed modelling using two models, a simplistic open system technique based on saleeite crystal data and a model including retardation in two different solid phases. The main purpose with the first exercise is to date the crystals and extrapolate the time scale for the formation of a zone of dispersed uranium in the weathered zone. Simplified extrapolation of the crystal ages over the total uranium deposit area yields a time scale of one million years for the formation of the dispersion zone. Limitations of the previously used transport models indicate that there might be a need of inclusion of retardation in two different solid phases in the modelling to describe the results of radiochemical analysis of isolated rock mineral phases. The Pilot Group has used a one-dimensional advection model for two mineral phases, amorphous and crystalline iron oxides, considering advection but not hydrodynamic dispersion.

The geochemical aspects of the Alligator Rivers Analogue project were presented at the workshop with the aim to give a general overview of the tools that are available. The computer programmes used in the study are EQ3 for aqueous speciation and solubility calculations and EQ6 for chemical mass transfer. Input parameters for the calculations are measured total concentrations of dissolved elements, temperature, pressure, oxidation state and measured pH-values. The data bases and the computer programmes employed have earlier been validated for economic geohydrology purposes and were then found to yield consistent results. The main purpose of the geochemical modelling is to increase the understanding of why and how the different uranium zones were formed.

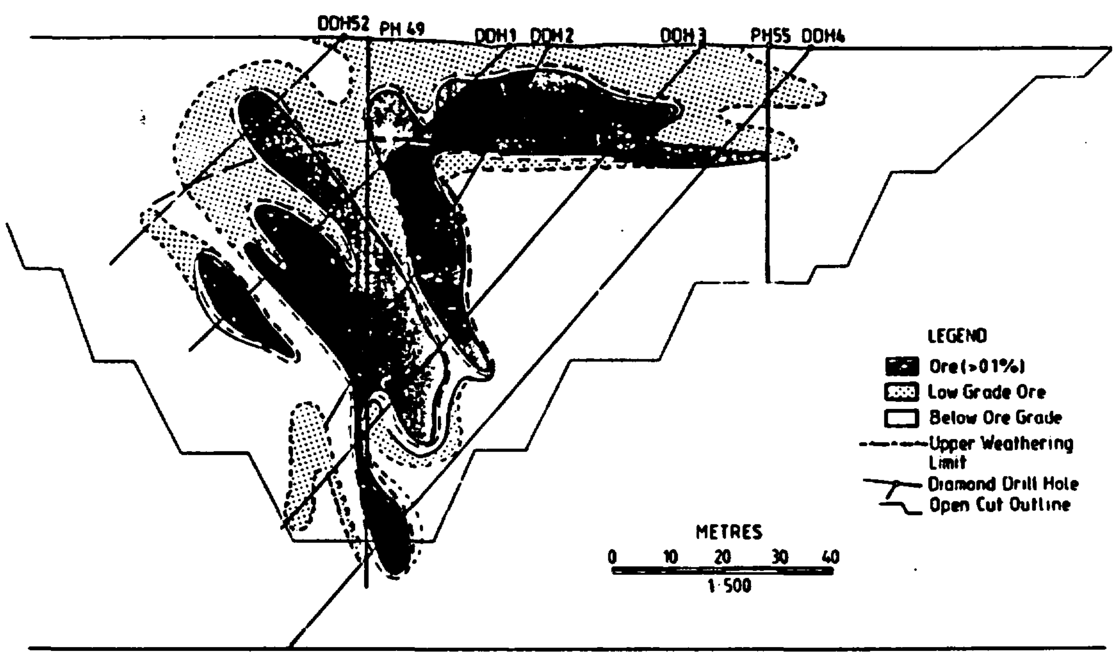



Figure 9. Cross section showing the dispersed zone at Kongarra deposit (Test Case 8).

**Test Case 9**

*Radionuclide migration in a block of crystalline rock performed at AECL, Canada. (Pilot Group leader: Berge Gureghian, OWTD)*

The purpose with this test case is to calibrate mathematical models for certain relevant fracture transport parameters against laboratory experiments using a block of granite containing a single fracture. The experiment is carried out by AECL at Whiteshell in co-operation with U.S. DOE.

The measurements are performed in a natural fracture in a pink granite block of the size 91.5 x 86.5 x 49.0 cm (length x width x height). An inlet reservoir is designed to produce a uniform hydraulic gradient and a uniform inlet tracer concentration across the entire width of the fracture. The outlet reservoir is divided into five compartments, which are sampled in sequence to give breakthrough curves for each compartment, see Figure 10. The tracers used are uranine, iodine and caesium.

The documentation of this test case has been revised during the autumn and the background information has not yet been made available in a retrievable form for the INTRAVAL participants.

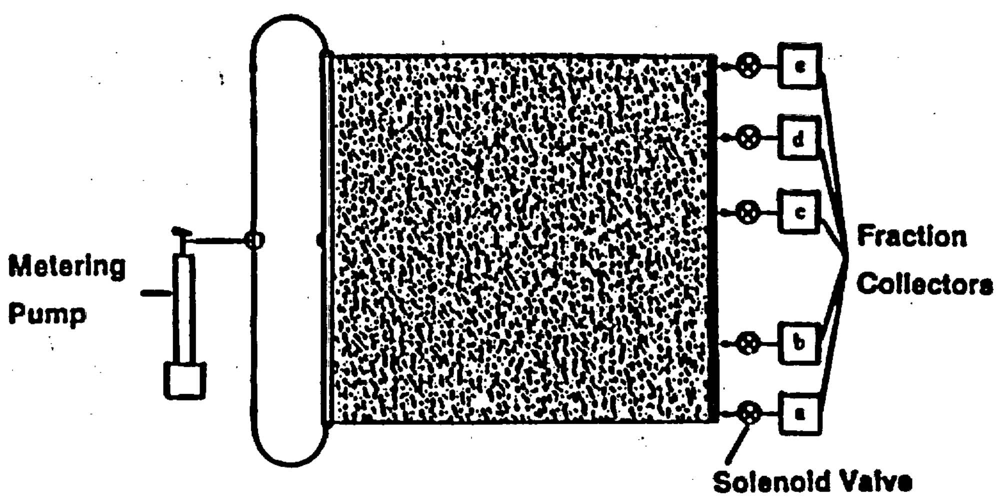



Figure 10. Schematic plan view of the arrangement of the inlet and outlet reservoirs on the large block (Test Case 9).

**Test Case 10**

*Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil, performed within a U.S. NRC trench study at Las Cruces, New Mexico. (Pilot Group leader: Thomas Nicholson, U.S. NRC)*

This test case is based on infiltration and redistribution experiments in near-surface unsaturated soils under relatively low flow conditions. The experimental location is in New Mexico, USA, 40 km northeast of Las Cruces. The main objective with the test case is to test stochastic flow and transport theories by comparing model results with measured flow and transport parameters.

A trench 16.5 m long, 4.8 m wide and 6.0 m deep has been dug in undisturbed soil, see Figure 11. Water containing tracers, tritium or bromide, has been applied at two different rates 1.76 cm/day and 0.5 cm/day. The movements of water below soil surface have been monitored with neutron probes and tensiometers, The movements of water below soil surface have been monitored with neutron probes and tensiometers, and also by visual observation on the trench wall adjacent to the irrigated area. Soil solute samples were taken to determine the movement of the tracers. It was found that bromide moves faster than tritium, this is likely to be due to anion exclusion. In addition to the trench experiments complimentary experiments have been performed in the laboratory and in large columns (lysimeters).

Different groups analysing the U.S. NRC funded Las Cruces project have used different approaches to model the experiments. MIT has developed a stochastic approach to unsaturated flow and transport modelling. The goals with this work are to understand and quantify predominant large-scale processes and to predict large-scale bulk behaviour from small scale measurements. In the MIT approach, not only the expectancy value of the output variable (e.g. moisture content) is calculated, but also its variance.

PNL performed two-dimensional deterministic modelling of the wetting front using the finite element code UNSAT2. It turned out to be difficult to predict the movement of the front with realistic parameters. However, with a higher initial saturation than observed in the field a good prediction was obtained. At PNL predictions have also been performed using the finite difference code UNSAT-H for one-dimensional calculations and the finite difference code TROUGH for two-dimensional calculations to predict infiltration profiles. The obtained profiles developed faster than was observed in the field and did not seem to be very sensitive to changes in infiltration rates.

A contractor of Sandia National Laboratory used TROUGH to make two-dimensional predictions of the wetting front movements in four homogeneous layers equivalent to the top four layers. They got good agreement with the observed field data. They also made one-dimensional analytical predictions of the travel time of the wetting front, assuming nine layers with individual data sets. These predictions turned out reasonably well.

The New Mexico State University performed crude two-dimensional estimates of the wetting front. The model results showed a reasonable fit with the field measurements obtained seven days after the start of the wetting event. The results indicated that up to 40% of the water may be coming in from the third dimension, not considered in the model.

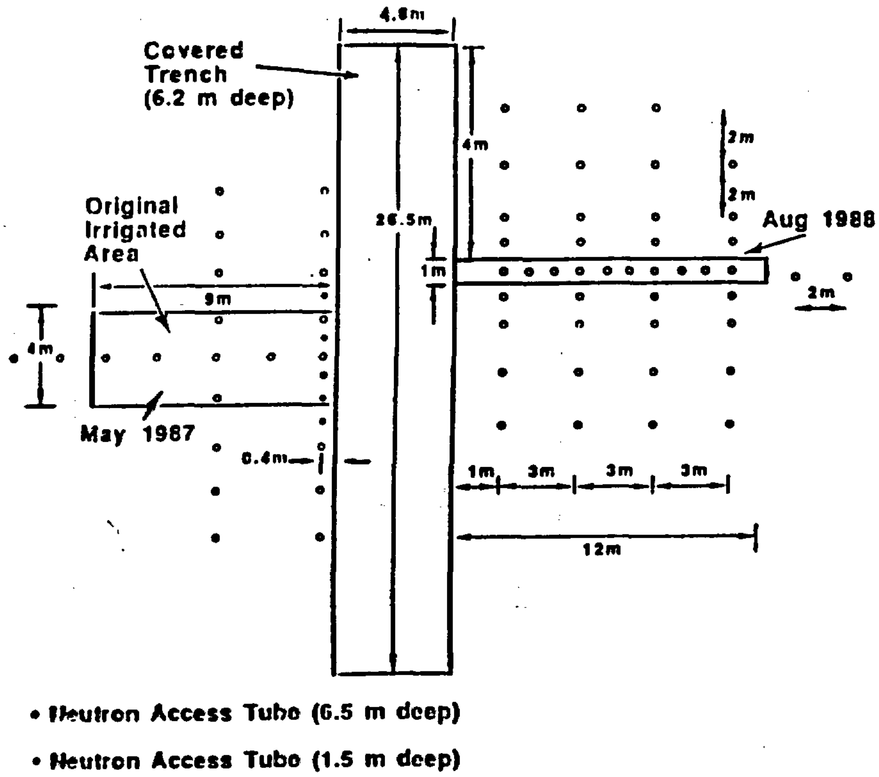



Figure 11. Top view of the trench with irrigated areas (Test Case 10).

**Test Case 11**

*Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap tuff site near Superior, Arizona. (Pilot Group leader: Thomas Nicholson, U.S. NRC)*

This test case is based on field experiments with the aim to investigate the flow and transport system in the unsaturated zone of partially welded, fractured tuff at the Apache Leap Tuff Site located near Superior, Arizona, USA.

Nine inclined boreholes have been installed in three rows with three boreholes per row, see Figure 12. The boreholes within a row are echelon at 10 m intervals. The rows are 5 m apart. The surface of the site has been covered with a plastic sheet to reduce natural infiltration and evaporation. The rock is a multi-porosity medium with common and super-conducting fractures as well as small and large pores and vugs. Experiments in the boreholes include interval testing for temperature as a function of depth, water content and borehole air flow rates. Also, pneumatic properties are tested in packed-off sections. Back-up laboratory experiments are performed at the University of Arizona. The parameters measured are the physical rock properties, hydraulic diffusivity and moisture characteristic curve. From these the relative hydraulic conductivity, the saturated hydraulic conductivity and the specific water capacity of the rock are derived.

Heat experiments on tuff cores have been performed, and it is also planned to do field heater experiments in the future.

Modelling of the laboratory and field experiments have been performed at the University of Arizona. The water redistribution in the matrix after injection was simulated in one and two dimensions. It could be concluded from these simulations that the water will move about half a meter in the matrix in 100 hours. The fractures have not yet been considered. The core heating experiments were simulated with the finite difference code TROUGH to study the two phase flow of liquid and vapor. The project team concluded, however, that this problem needs further thoughts.

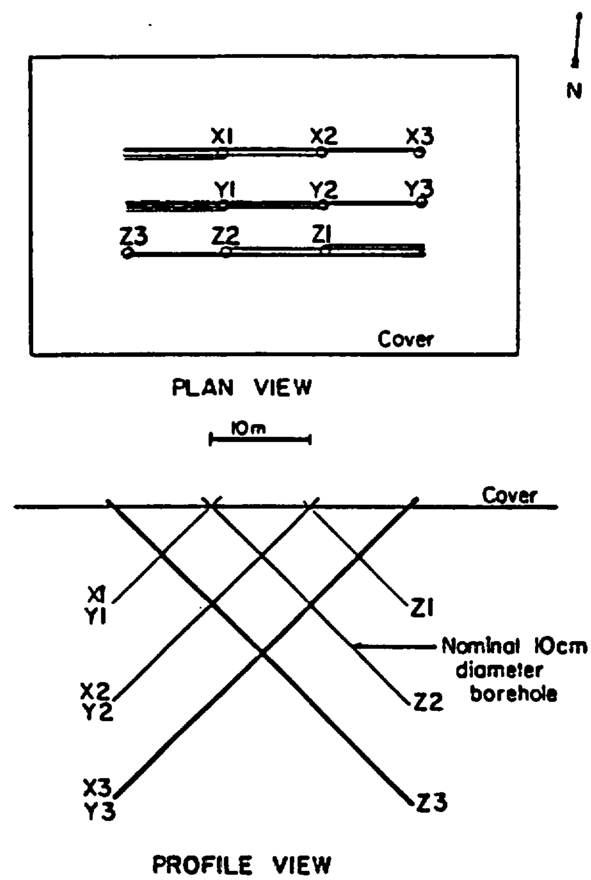



Figure 12. Bore hole configuration at Apache Leap Tuff Site (Test Case 11).

### Test Case 12

*Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site performed by the Nevada Nuclear Waste Storage Investigation Project of the U.S. DOE. (Pilot Group leader: Dwight Hoxie, USGS)*

This test case is based on the so called G-Tunnel experiments performed at the G-Tunnel Underground Facility at the Nevada Test Site, located about 110 km north of Las Vegas, Nevada, USA. The experiment is designed for model validation in respect of short-term effects as well as long-term effects.

The experimental setup consists of pairs of horizontal boreholes in nonwelded as well as in fractured welded tuff. The boreholes will be 10 m in length and 10 cm in diameter. One of the pair of the boreholes will be drilled using air as drilling fluid and the other will be drilled using water. Gas phase tracers will be injected into the drilling fluids to test for cross-hole hydrologic connections. Monitored values will be drilling fluid losses, inflow and outflow temperatures, as well as inflow and outflow tracer concentrations. A schematic plan of a pair of boreholes instrumented for long-term monitoring is shown in Figure 13. The physical and hydrological properties of the rock matrix will be measured in laboratory. At the onset (November 1988) the first borehole was drilled with air as drilling fluid.

Preliminary models have been developed to simulate the hydrological effects, produced by short-term water invasion into a highly idealised representation of a partially saturated, fractured, welded tuff. The model geometry consisted of a single vertical homogeneous rock-matrix column of rectangular cross-section bounded on all sides by vertical fractures whose properties were assumed to be uniform. The codes used are VS2D and TROUGH. The transient simulations consisted of imposing a positive head of 20 m of water at the top of the fracture-column system for time periods that ranged from several minutes to one hour. The saturation fronts were calculated to descend along the fractures at rates that were gravitationally controlled and depended principally on fracture aperture. Two phase-flow was not considered.

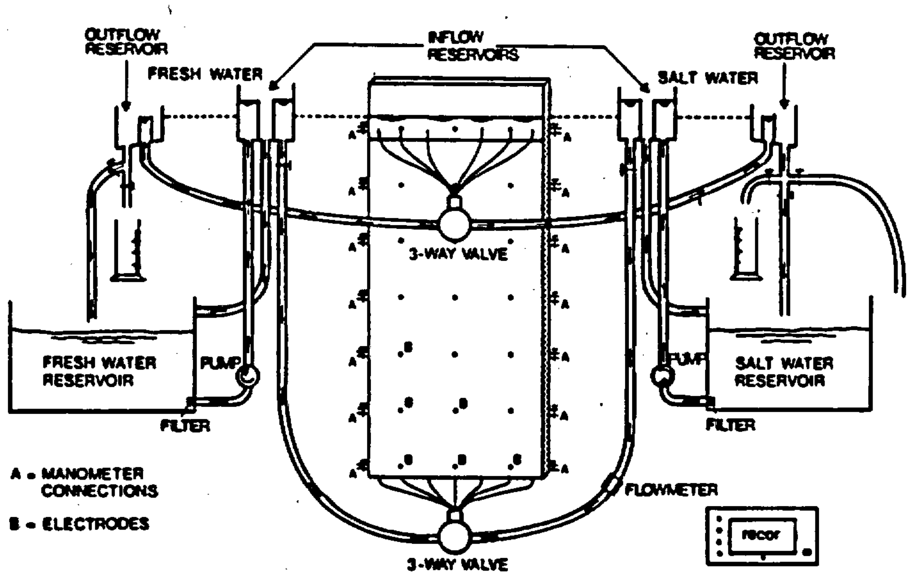



Figure 13. Schematic plan of bore hole pair instrumented for long-term monitoring (Test Case 12).

## Test Cases Related to Radionuclide Migration in Salt Formations

The working group appointed at the INTRAVAL meeting in Barcelona in April 1988 for the development of test cases related to disposal in salt formations proposed three new test cases, one laboratory experiment performed at RIVM in the Netherlands and two field experiments made at the Gorleben site in the Federal Republic of Germany. In addition one experiment performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA was proposed by Dr. William Lee and coworkers at the University of California, Berkeley. At the Coordinating Group meeting it was decided to adopt the laboratory experiment and the two Gorleben experiments and to leave the decision about the WIPP experiment until the next meeting in June, 1989.

**Test Case 13**

*Experimental study of brine transport in porous media performed at RIVM, the Netherlands. (Pilot Group Leader: Majid. Hassanizadeh, RIVM)*

This test case deals with flow and mass transport at high salt concentration situations. The objectives are to investigate the relevant processes in brine transport in porous media and also to investigate the validity of transport models based on Darcy's and Fick's laws for flow and mass transport in high concentration situations. The pressure head and the salt concentration are monitored at different locations in a two-dimensional column with the internal dimensions of 0.6 x 0.01 x 1.25 m (length x width x height), filled with a porous medium consisting of glass beads. The experimental setup is shown in Figure 14.

Two sets of experiments are carried out, one at low salt concentrations to estimate porosity, permeability and dispersivity of the porous medium, and another at high concentrations to provide data about the concentration and pressure distribution along the column.

The Pilot Group has been simulating preliminary results from low salt concentration experiments using the finite element code METROPOL developed at RIVM. These simulations predict the results of the experiments rather well. The modelling of preliminary results from experiments with high salt concentration are currently in progress.

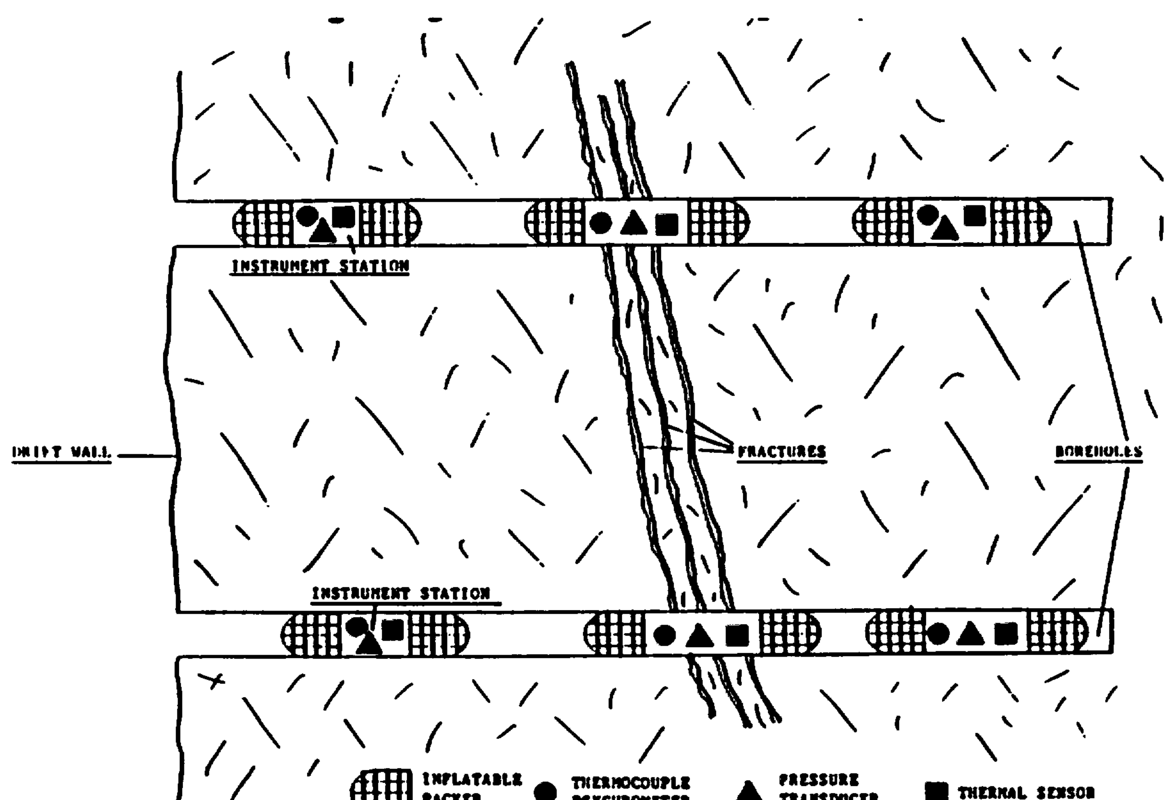



Figure 14. The experimental setup (Test Case 13).

**Test Case 14a-b**

*Groundwater flow in the vicinity of the Gorleben salt dome, the Federal Republic of Germany. (Pilot Group Leader: Klaus Schelkes, BGR)*

This test case is based on two experiments performed in similar geological environment but at different time and space scales: Pumping test in highly saline groundwater (Test Case 14a) and Saline groundwater movements in an erosional channel crossing the salt dome (Test Case 14b). The working documents for these test cases will be prepared during spring 1989.

The Gorleben salt dome is located in the northern part of Lower Saxony, the Federal Republic of Germany. Hydrological investigations have been conducted in an area of about 300 km around the dome to study the aquifer system in the sediments above the dome. Subglacial erosion channels crosses the dome at some places. The groundwater get more saline with depth, especially above the dome. During the geological and hydrological survey programmes large quantities of data have been acquired and stored.

For Test Case 14a a part of the area will be selected where a long term pumping test was carried out. The duration of the pumping test was three weeks with six additional weeks of observation. In addition, data from a short term pump test with the duration of 24 hours, performed prior to the long term test, are also available. The parameters observed during the tests were e.g. electrical conductivity logs in observation wells and flow meter logs.

The second test case, Test Case 14b, concerns flow in one of the subglacial erosion channels crossing the salt dome. The area to be modelled is about 2-3 km x 15 km. The possible validation aspects are to describe the present regional groundwater flow situation and thereafter to start with fresh water and try to extrapolate the present situation regarding salinity variations. At a later stage of the INTRAVAL project, transport calculation based on a density dependent flow system could be included, using information regarding carbon-14 concentrations in water samples.

## Meeting Concerning INTRAVAL Test Case 5

An extra informal meeting devoted to Test Case 5, Tracer experiments at the Finnsjön Site, Sweden, was held during the INTRAVAL workshop in Tucson, Arizona.

Current status of the experimental programme at the Finnsjön Site was presented by the pilot group leader Peter Andersson, and specific questions from the modellers in the project teams were answered. Minutes from this meeting and from the previous experimentalist-modeller meeting held in June 1988 have been sent out to Project Teams interested in Test Case 5. To other INTRAVAL participants the minutes will be distributed from the secretariat on special request.

## Alligator Rivers Analogue Project, Modelling Workshop

The ARAP second modelling workshop was held on November 21-22, 1988, at the University of Arizona in Tucson, USA. The meeting was arranged in connection with the INTRAVAL workshop, and all INTRAVAL participants were invited to the ARAP workshop. The possibility of having ARAP workshops in connection to INTRAVAL meetings also in the future was discussed. No date for the next ARAP meeting was decided, however, since time schedules for the field work at Koongarra, and availability of key persons in ARAP subprojects were uncertain.

The experimental activities at the Koongarra site and the modelling work made since the last workshop were presented. Water sampling at different depths in several of the wells have been made. Seven new wells have been drilled and water samples will be taken at 13-15 m depth and 22-25 m depth. Porosity measurements and possibly also geological measurements of samples from the drillcores from these new wells will be made. Sorption measurements with rock materials and water from the new wells are also planned. Other performed or planned geochemical experimental activities are: sampling and characterisation of colloids, study of the alteration of chlorite, and sequential extraction of solids in order to study inclusions.

A hydrology programme aimed at investigating the hydrological situation at Koongarra is under way. A general physical evaluation of Koongarra has been made and six aquifer drawdown tests have been performed and analysed preliminarily. Additional aquifer tests and well pumping will be made. The analysis of the hydrological model for Koongarra will be finished by spring 1990.

A study of the weathering history at Koongarra is in progress. A literature survey has been made and morphological studies and possibly some sampling at the site that could shed more light on the geological history of Koongarra will be considered.

A multiphase transport model for the migration of radionuclides in the weathered zone has been developed. Model calculations have been compared with a set of four data prints close to the boundary of the weathered/unweathered zone.

The migration behaviour of uranium and thorium series nuclides and the fixation mechanism of uranium are studied. The programme includes radiochemical and mineralogical measurements of samples from a set of points along the assumed migration path in the weathered zone at Koongarra.

An attempt to model nuclide production by fission and neutron capture, has been made. Predicted values of $^{129}I$, $^{99}Tc$, $^{239}Pu$ and $^{36}Cl$ are compared with measured values, and from the result information about the retardation/migration behaviour of these radionuclides is inferred.

An open system modelling approach has been used for evaluation of the time scales for uranium migration at Koongarra. The time for the growth of saleeite crystals is estimated based on results from radiochemical measurements of the crystals. From estimated times for crystal growth the rate of uranium mobility in the weathered zone is extrapolated.

Geochemical modelling is in progress with the purpose to identify the controlling reactions for formation of the uranium phosphate zone and uranium silicates. So far, only preliminary calculations with the EQ3/6 code have been made with groundwater data from earlier sampling as input. The modelling work will continue and the updated data base on groundwater composition will be used.

## Poços de Caldas Project Meeting

A modelling workshop within the Poços de Caldas project was held in Gstaad, Switzerland, January 19-20, 1989. The aim with the workshop was to integrate the modelling work carried out within the Poços de Caldas project.

The four main project goals, i.e. validation of thermodynamic codes and data bases, colloid transport, geochemical transport across redox fronts, and hydrothermal effects, were discussed in terms of required modelling input, data requirements, the need of additional experimental activities and field work. The outcome of the meeting from the viewpoint of INTRAVAL Test Case 7 is summarised below.

Concerning the geochemical code validation, it was decided to define four types of Poços de Caldas' groundwater, representing among other things, different redox conditions in terms of major element composition. Different modelling teams will use geochemical codes and try to predict the concentration of trace elements in these Poços de Caldas' groundwaters. The next step will be to compare the predicted concentrations with the trace element concentrations measured in water samples from the site. The results will be presented and discussed at the next Poços de Caldas modelling workshop, planned to be held in October 1989.

It was concluded that it was not possible within the time frame for the Poços de Caldas Project to do any modelling of the radionuclide transport by colloids. The main effort should instead be put into increasing the understanding of the colloid chemistry, such as the formation and stability of colloids and the interaction of colloids, radionuclides and mineral surfaces.

Geochemical transport across redox fronts was divided into three modelling tasks: the movement of the redox front, the movement of uranium across the front and the movement of other elements across the front. Mineralogical data, trace element concentrations, and natural series disequilibrium data from the open pit redox fronts, as well as the chemistry of the four Poços de Caldas' groundwaters, will be available for interpretation and modelling. Information about erosion mechanisms and erosion rates will also be included in the data set.

As regards INTRAVAL Test Case 7 it was stated that a data set will be compiled and distributed after the next Poços de Caldas modelling workshop at the end of 1989.

## Information about HYDROCOIN

The Level 1 report has been published. The Level 2 report will shortly be sent out for approval by the Coordinating Group and is estimated to be published during the spring 1989. Work has started on drafts of the Level 3 report and the Summary report. These are foreseen to be published before the end of 1989.

## Time Schedule

The INTRAVAL study is scheduled to last for three years starting in October 1987, with an option for an additional three year period.

The main work with preparation of background documents for the test cases, based on laboratory experiments and field experiments, is now essentially completed with exception of some complementary, requested information and documentation for recently adopted test cases.

The third workshop and fourth Coordinating Group meeting will be held in Helsinki, Finland, during the week of June 12th to 16th, 1989. A fourth workshop and fifth Coordinating Group meeting are preliminary foreseen to take place early in 1990.

Table 1. INTRAVAL Test Cases.

| | |
|---|---|
| 1a | Radionuclide migration through clay samples by diffusion and advection based on laboratory experiments performed at Harwell, U.K. |
| 1b | Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland. |
| 2 | Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH. |
| 3 | Tracer tests in a deep basalt flow top performed at the Hanford reservation, Washington, USA. |
| 4 | Flow and tracer experiments in crystalline rock base on the Stripa 3-D experiment performed within the International Stripa Project. |
| 5 | Tracer experiments in a fracture zone at the Finnsjön research area, Sweden. |
| 6 | Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland. |
| 7a | Redox-front and radionuclide movements in an open pit uranium mine. Natural analogue studies at Poços de Caldas (Minas Gerais), Brazil. |
| 7b | Morro do Ferro colloid migration studies. Natural analogue studies at Poços de Caldas (Minas Gerais), Brazil. |
| 8 | Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia. |
| 9 | Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Canada. |
| 10 | Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study at Las Cruces, New Mexico. |
| 11 | Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site, near Superior, Arizona. |
| 12 | Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site, performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE. |
| 13 | Experimental study of brine transport in porous media performed at RIVM, the Netherlands. |
| 14a | Pumping test in highly saline groundwater performed at the Gorleben site. |
| 14b | Saline groundwater movements in an erosional channel crossing the salt dome at the Gorleben site. |

# APPENDIX 1

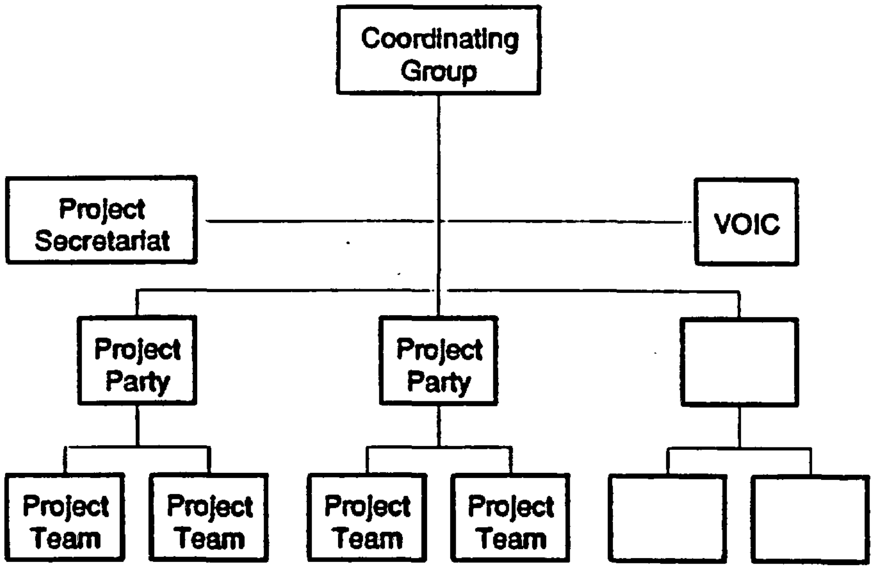
## Intraval Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Power Inspectorate (SKI) acts as Managing Participant. The Coordinating Group member from the Managing Participant acts as chairman. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty s Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). Kemakta Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expences etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.




| | |
|---|---|
| **Managing Participant:** | SKI |
| **Coordinating Group** | |
| Chairman: | A. Larsson, SKI |
| Vice chairman: | T. Nicholson, US NRC |
| Secretary: | K. Andersson, SKI |
| **Principal Investigator:** | Kemakta Consultants Co. |
| **Project Secretariat:** | K. Andersson, SKI |
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# APPENDIX 2

## Intraval Test Cases

### TEST CASE 1a

*Radionuclide migration through clay samples by diffusion and advection based on laboratory experiments performed at Harwell. U.K.*

#### Introduction

This test case is concerned with the validation of models that describe the permeation, diffusion and dispersion of radionuclides through clay samples. The behaviour of the tracers in the pore water and the adjacent solid phase is to be described. The experiments are performed at Harwell.

#### General description

Four sets of experiments have been carried out on iodine, deuterium, strontium and caesium. The four experiments are in-diffusion, vertical through-diffusion, horizontal through diffusion and permeation. The length scales of the experiments are up to a few centimetres and the duration is up to a few months. Schematic descriptions of the equipment are shown in the main report, Figure 1-3.

In the in-diffusion experiments, the tracer is allowed to diffuse into the sample from two sides. The amount of tracer that has diffused into the sample at different times is subsequently measured and this gives an indication of the porosity and the diffusion coefficient.

In the vertical through-diffusion experiments the tracer diffuses only from one side of the sample. The core in situ used in the experiments was approximately vertical and the design is such that the diffusion takes place parallel to the axis of the core. The breakthrough into the low concentration side is monitored, and the breakthrough curve gives information about the porosity and the vertical diffusion coefficient.

In the horizontal through-diffusion experiments diffusion takes place in a direction that was horizontal when the sample was in situ. A core is taken from the axis of the sample, and then the nuclide is allowed to diffuse radially outwards from the centre of the sample. This configuration means that the diffusion is one- dimensional. Information on the porosity and the horizontal diffusion coefficient is obtained from these experiments.

The permeation experiments are similar to the through-diffusion experiments but the flow is superimposed on the diffusion. The experiments give information on the permeability, porosity and dispersivity.

Summary of available data from experiments with clay:

- breakthrough curves from through-diffusion into low concentration reservoirs,
- results from in-diffusion experiments,
- breakthrough curves from permeation experiments,
- porosities and pore structures,
- complementary experiments giving the moisture content in the samples, information about the pores, permeability as a function of stress etc.

## TEST CASE 1b

*Uranium migration in crystalline bore cores based on laboratory experiments performed at PSI, Switzerland.*

### Introduction

The aim of this test case is to characterise hydraulic and tracer transport properties of small samples of crystalline rock. The experiments were performed at PSI, Switzerland.

### General description

Samples of crystalline rock (granite, gneiss) originating from various depths were taken from the deep NAGRA drillings in northern Switzerland. They differ in mineralogical characterisation, especially the extent of alteration. The cores had a diameter of 4.6 cm and were between 0.8 cm and 5.0 cm long. The cylindrical rock samples were placed in a pressure apparatus. A schematic description of the equipment is shown in the main report, Figure 4. Hydraulic pumps were used to build up an isostatic confining pressure for simulation of the lithostatic pressure. A variable axial hydraulic pressure gradient over the sample allowed for infiltration of tracer solution.

As infiltration fluid a natural granitic groundwater from Bad Säckingen was used, and as tracer distilled water and $^{233}U$. The tracer was injected and sampled during a period that for different runs varied between 180 and 350 hours. At the outlet the bulk water flow, the electrical conductivity and the uranium concentration was measured.

After terminating the uranium infiltration experiments the sample was taken out of the autoclave and cut into slices of about 1 mm thickness. The resulting surfaces were then autoradiographed to yield information on flow paths and sorption sites.

### Previous modelling results

The results from four uranium infiltration experiments have been interpreted in a previous modelling exercise. These four samples include gneiss with a micro-fracture parallel to the sample axis, and three granites (originating at two different depths) with no obvious flow paths detected at a first inspection. The model takes into account advective transport in planar fractures or linear veins, hydrodynamic dispersion which results from the network structure of these zones, sorption on their surfaces, matrix diffusion into the adjacent pore space with stagnant water and sorption within these pores. The following conclusions were drawn: No ad-hoc adjustment of absolute magnitudes of flow is necessary. The best fit seems to discriminate between the two geometries considered for water conducting zones. The result is in accordance with a qualitative inspection of alpha-autoradiographies. The same holds true for the extracted dispersivities. Also the other parameters extracted are within the ranges expected from literature studies. This is especially the case for independently measured matrix sorption distribution constants for crushed granite. Measurements on two samples from the same location yield information on the variability of parameters.

### Summary of available data:

- chemical composition of infiltrating liquid,
- mineral composition of cores,
- hydraulic conductivities as a function of pressure,
- porosities,
- uranium(VI)-breakthrough curves,
- uranium(VI) sorption data on crushed material,
- results from alpha-autoradiography of surfaces of slices.

## TEST CASE 2

*Radionuclide migration in single natural fissures in granite based on laboratory experiments performed at KTH, Sweden.*

### Introduction

This test case describes radionuclide migration in single fissures in granite. The experiments have been performed at the Department of Nuclear Chemistry, Royal Institute of Technology, Stockholm, Sweden. The experiments address important phenomena in radionuclide transport in the geosphere such as retardation, matrix diffusion, dispersion, channelling, channel structure and fracture properties.

### General description

Granite drill cores, taken from the Stripa mine were used in the experiments. Each had a natural fissure running parallel to its axis. The cylindrical surfaces of the drill cores were sealed with a coat of urethane lacquer to prevent any water leaving the rock except through the outlet end of the fissure. The granite cylinder was thereafter mounted between two plexiglass end plates containing shallow inlet and outlet channels slightly wider than the fissure. The experimental setup is shown in the main report, Figure 5.

### Nonsorbing and moderately sorbing tracers

Tests with the nonsorbing tracers tritiated water and lignosulphonate ions and the moderately sorbing ions strontium and caesium were performed in a 30 cm long drill core with a diameter of 20 cm. Tests with the nonsorbing tracers tritiated water, iodine, bromide and lignosulphonate ions and the moderately sorbing tracers strontium and caesium were performed in two cores with a diameter of 10 cm and a length of 18.5 and 27 cm respectively.

Artificial groundwater with a tracer was fed to the inlet channel. At low flow rates, flushing water was simultaneously fed through the outlet channel to reduce the time delay due to the channel volume of the end piece. The effluent was continuously fed to a fractional collector for analysis of the tracer concentrations. The tracers were introduced either as a step up or as a step up followed by a step down, after a suitable amount of tracers had been introduced (normally about 15 minutes duration).

### Previous modelling results

The results from the experiments have been interpreted in previous modelling exercises. The different models tested take into account advection, dispersion, diffusion into the rock matrix, and sorption on the fissure surface and on the micro-fissures inside the rock matrix. For the second mechanism one of the models considers hydrodynamic dispersion while the other model assumes channelling dispersion. The time delays in the inlet and outlet channels are also included in the models.

Experimental breakthrough curves for tritiated water and the lignosulphonate ion in the 30 cm long drillcore are available. The dispersion characteristics and water residence time were determined from these runs with nonsorbing tracers.

Breakthrough curves for strontium and caesium with a 15 minutes long injection pulse in the same 30 cm long drillcore are available together with model fits. The model includes channelling dispersion, sorption on the fissure surface, diffusion into the rock matrix and sorption on the inner surfaces in the rock matrix. The values of the matrix diffusion coefficient used in the model were taken from independent laboratory experiments. The volume equilibrium constants giving the fits were in accordance with results from independent batch sorption measurements, while the values of the surface equilibrium constants differed from the values obtained by batch sorption experiments on crushed granite.

The experimental data from tracer tests with the nonsorbing ions in the 18.5 cm and 27 cm long drillcores were fitted using a hydrodynamic dispersion-diffusion model. The experiments with lignosulphonate ion in the 18.5 cm long core were also evaluated using a channelling dispersion-diffusion model.

The parameter values obtained from the runs with the nonsorbing tracers were used when evaluating the runs with sorbing tracers. A model including advection, longitudinal dispersion, sorption onto the rock surface, diffusion into the rock matrix and sorption within the rock matrix was used.

The values of the surface sorption coefficient and the product of the effective diffusivity in the rock matrix and the matrix sorption coefficient giving the best fit to the experimental data are higher than was found in independent laboratory experiments both when using the hydrodynamic dispersion model and the channelling dispersion model. The fit with the hydrodynamic dispersion model gives a slightly smaller surface sorption coefficient and a higher interaction with the rock matrix than the fit using the channelling dispersion model.

Summary of available data:

- flow rates and breakthrough curves,
- distribution coefficients for $^{85}Sr$ and $^{134}Cs$ on crushed granite,
- porosity of the Stripa granite,
- the diffusivity of iodine and tritiated water in granite.

**Actinides**

Before each experiment artificial groundwater was pumped for 2 to 3 days through the drillcore to equilibriate the fissure surface. The waterflow was characterised by feeding a solution of nonsorbing lignosulphonate in artificial ground water to the inlet channel. Flushing water was simultaneously fed through the outlet channel to reduce the time delay due to the channel volume. The tracer was added as a pulse of suitable duration (normally 15 minutes), and synthetic groundwater was then pumped through the fissure. The effluent was continuously fed to a fraction collector for analysis of the tracer concentration.

The radionuclides studied ($^{152}Eu(III)$, $^{235}Np(V)$, $^{237}Pu(IV)$, $^{241}Am(III)$, $^{99}Tc(VII)$ and $^{99}Tc(IV)$) were fed to the fissure by the same technique as described previously. After several hundred fissure volumes of water had been pumped through the fissure, the drillcore was cracked open and the tracer distribution on the fissure surfaces measured. Each experiment generated effluent concentration versus time curves for the lignosulphonate ion and the radionuclides as well as the radionuclide distribution on the fissure surfaces.

When performing the tracer tests it was found that a small fraction (less than a few percent) of the total activity of $^{152}Eu$, $^{235}Np$, $^{241}Am$ and $^{99}Tc(IV)$ was transported through the fissure with nearly the same velocity as water. Inserting a 0.21 μm filter between the tracer solution reservoir and the inlet channel greatly reduced the fast moving fraction, indicating that the activity was carried by particulate matter.

**The previous evaluation**

The mechanisms included in the evaluation of the experiments were advection, dispersion and sorption onto the fissure surfaces.

The americium breakthrough curve for the first small fraction that was transported with nearly the same velocity as water is available, as well as the activity distribution on the fissure surface after the tracer test with $^{241}Am$. The water residence time and the ratio fissure surface area to fissure volume was determined from the experiments with nonsorbing tracer. These results combined with either the breakthrough curve for the radionuclide or the radionuclide distribution on the fissure surface were used to determine the radionuclide retardation in the fissure.

The value of the obtained retardation factor was used to calculate an area-specific distribution coefficient and a volume specific distribution coefficient. This latter value was compared to sorption data on crushed material reported in the literature. It was found that the results were in agreement within less than one order of magnitude, with the results from the flow experiments in all cases being higher.

Summary of available data:

- breakthrough curves for LS and the radionuclides.
- radionuclide distribution on the fissure surfaces.
- flow rates.
- distribution coefficients.

## TEST CASE 3

*Tracer tests in a deep basalt flow top, performed at the Hanford reservation, Washington, USA.*

### Introduction

This test case is concerned with the validation of important conceptual model issues such as homogeneous or heterogeneous porous media flow, fracture flow and dispersion. Data from two-well (injection/withdrawal) tracer experiments performed in the McCoy Canyon basalt flow top at the Hanford Site will be used to address these issues.

### Background

Two recirculating nonreactive, pulse-injection, ground water tracer experiments have been performed at the DC-7/8 site on the Hanford reservation, Figure 3.1, to determine effective thickness (i.e., effective porosity times aquifer thickness) and longitudinal dispersivity. The wells (DC-7 and DC-8) are 55 ft (16.7 m) apart and the horizon selected for the tracer testing is in the McCoy Canyon flow top between 3422 and 3459 ft (1043 and 1055 m) below land surface.

The first test was performed with an $^{131}I$ tracer by Science Applications, Inc., (SAI) in December 1979. It was initially analysed by a two-point match based on time-to-peak and time-to-half-peak concentrations and it was reanalysed by L. W. Gelhar utilising type-curves based on the general theory for longitudinal dispersion in nonuniform flow along streamlines. The two different techniques produced results for effective thickness and longitudinal dispersivity that were less than 1/2 an order of magnitude different. The type-curve analysis is considered to be more accurate.

The second test utilised KSCN and was performed by Rockwell in January 1982. The major differences between the two tests were the tracers and the details regarding the recirculation. In the first test by SAI the flow rate varied between 2.0-3.5 gal/min (7.5-13.0 l/min) and only about 2/3 of the water pumped from DC-7 was reinjected into DC-8. In the second test a constant rate of 1 gal/min (3.8 l/min) was maintained and all of the water produced at DC-7 was reinjected at DC-8.

Summary of available data:

- flow rates,
- breakthrough curves (I, KSCN),
- geometry of the site,
- pump test data,
- steady state pressure and hydraulic head,
- core data,
- geologic and geophysical logs.

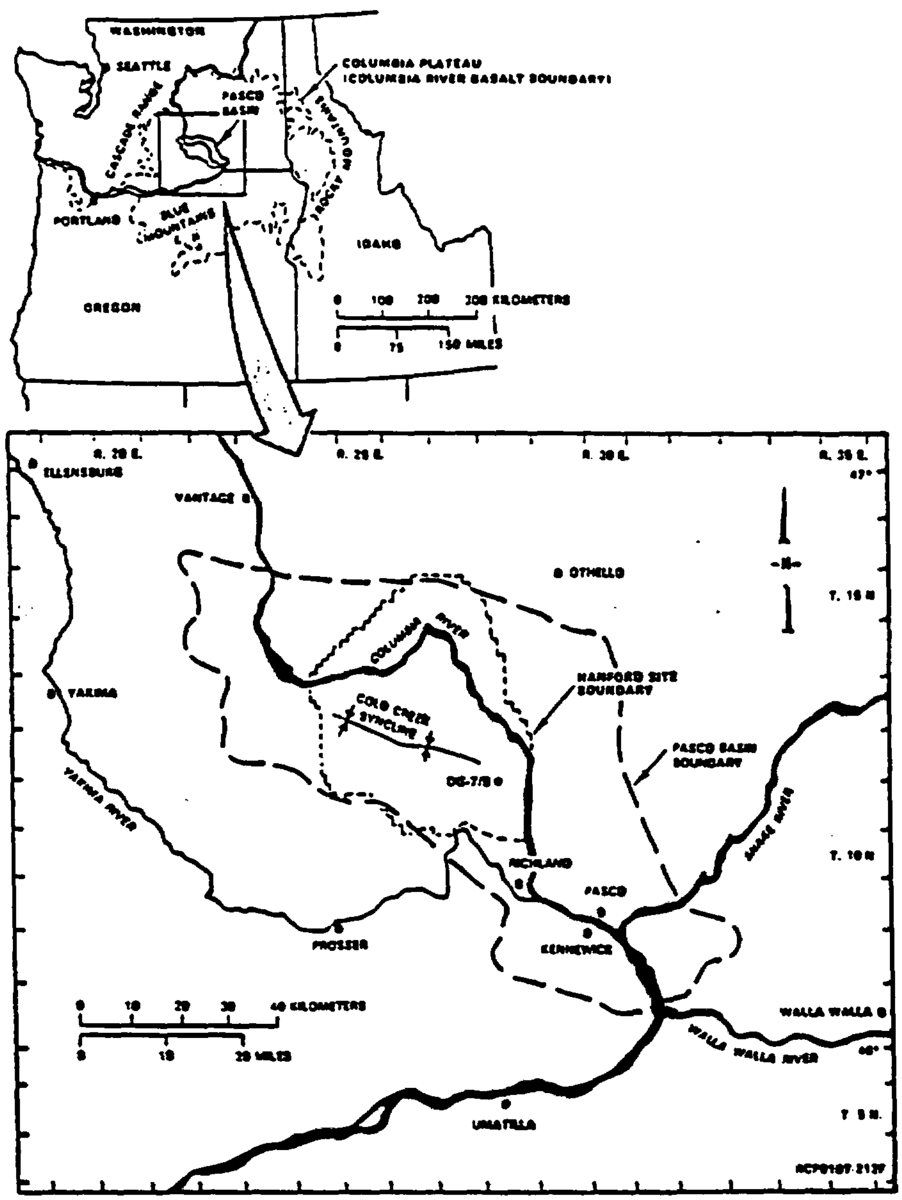


**Figure 3.1 Location of the Columbia Plateau, Hanford Site, and the DC-7/8 Test Site.**

## TEST CASE 4

*Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiment performed within the international Stripa Project*

### Introduction

This test case is based on the 3-D tracer test performed in the Stripa mine in Sweden. The experiment was performed within the OECD/NEA international Stripa project. The main purpose of this experiment was to investigate the spatial distribution of water flow paths in a larger block of rock. This experiment gives an opportunity to validate geosphere transport models in terms of dispersion, channelling and geometrical factors when water is flowing in a fractured crystalline rock over distances up to 50 m.

### Experimental description

In the Stripa mine at 360 m below the ground, a drift was excavated. The drift is 75 m long and has two side arms with a length of 12.5 m each. Three vertical holes for injection of tracers have been drilled upwards with lengths of 70 m.

The ceiling and large parts of the walls in the drift were covered with plastic sheets, each sheet with an area of about 2 $m^2$. A total number of about 350 sheets served as sampling areas for water emerging into the upper part of the test drift. The sampling arrangements completely covered a surface area of 700 $m^2$. The spatial distribution of water flow path ways could thus be obtained.

Injection of conservative tracers were carried out from a total number of 9 separate high permeability zones within the three vertical holes, each zone about 2.5 m in length. The injection zones were located between 10 and 55 m above the test site. The tracers were injected continuously for nearly two years. The injections were carried out with a 'constant' over pressure, approximately 10-15 % above the natural pressure. The concentrations of the injected tracers were between 1 000 and 2 000 ppm, and the different flow rates varied from 1 to 20 ml/h. The following tracers were injected: Uranine, Eosin blueish, Eosin yellowish, Phloxine B, Rose Bengal, Elbenyl Brilliant Flavine, Duasyn Acid Green, Bromide and Iodide.

### Results

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring shows that water does not flow uniformly in the rock over the scale considered (700 $m^2$), but seems to be localised to wet areas with large dry areas in between. Measurable amounts of water emerged into 113 of the 350 sampling areas. Out of these 'wet' sampling areas 10 % gave more than 50 % of the total water inflow.

After 6 months of injection, tracers from at least 5 injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves have been obtained. Each curve is based on typically more than 1 000 individual measurements. The tracer tests have been interpreted with various models including different mechanisms which may give similar results. The models tested are advection-dispersion and advection-channelling, with matrix diffusion effects included. Also a fracture network model has been tested.

Summary of available data:

- water flow rates,
- tracer concentration in water to test site,
- rock characteristics and fracture data,
- water chemistry,
- injection pressures and injection flowrates,
- hydrostatic pressures,

— daily logs, diffusivity and sorption data.

## TEST CASE 5

*Tracer tests in a fracture zone at the Finnsjön research area, Sweden.*

### Introduction

This test case is based on tracer tests in a fracture zone at the Finnsjön research area in Sweden. The aim of the tracer tests is to investigate the transport properties in a highly conductive rock over distances up to about 400 m. In a validation sense, results from this experiment will be valuable because of the long migration distances involved. Other validation aspects are: retardation, matrix diffusion, dispersion and geometrical factors.

### General description

The tracer experiments includes three runs in different geometries in order to determine or estimate important transport parameters in the major sub-horizontal fracture zone (zone 2) at the Brändan area in Finnsjön study site. The first tracer test, with radially converging flow geometry, started in early summer 1988. The two other tests planned are a dipole experiment and a natural gradient tracer experiment. The dipole tests will be started in May 1989.

In the radially converging test one borehole (BFi2) was pumped in a packed-off interval enclosing Zone 2. When steady state conditions prevailed continuous injection of conservative tracers was carried out within 2 to 3 packed-off sections in each of the boreholes Fi6, Fi11 and BFi1, see Figure 5.1 and 5.2.

Summary of available data:

A lot of background information such as geological data, hydrological, data geochemical data and geophysical data from investigations of the Brändan area are available. Data available from the radially converging tests are:

— tracer breakthrough curves,
— head difference between injection and sampling section,
— geometrical data,
— time correction factors,
— pumping and injection flow rates.

In addition to this laboratory measured porosities and matrix diffusivities are available.

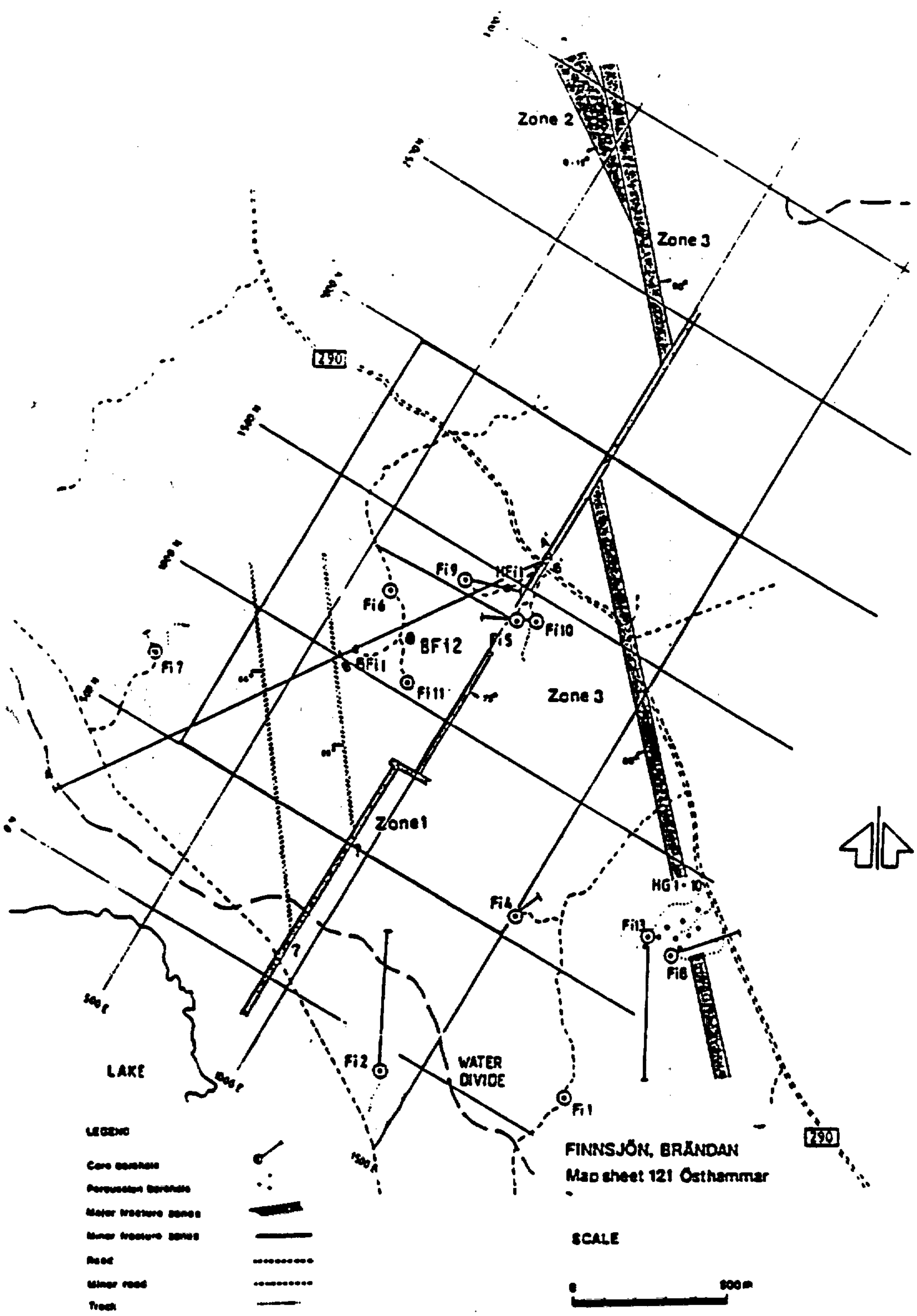


Figure 5.1 Borehole location in the Brändan area.

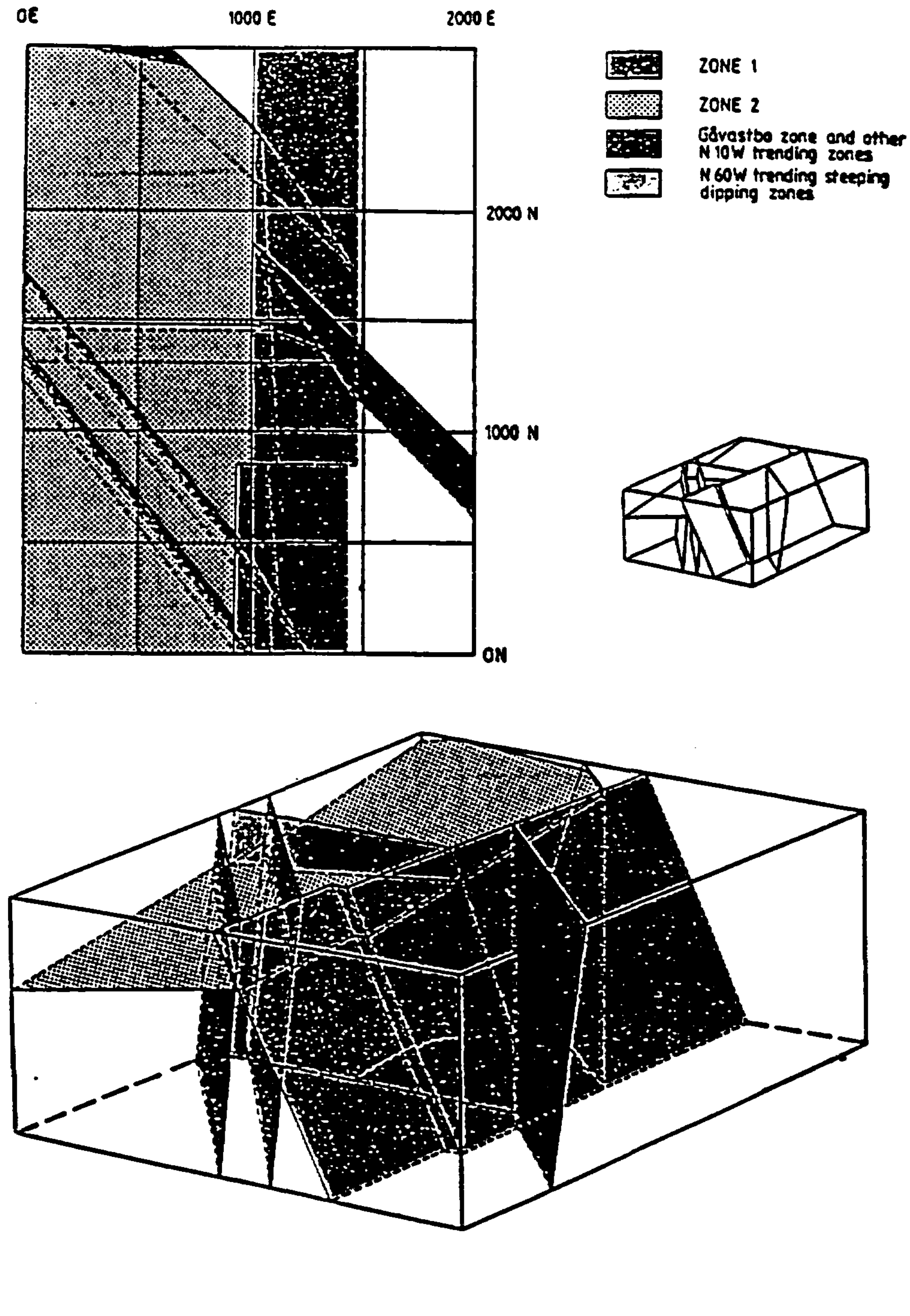


**Figure 5.2** Cross section through the Brändan area showing Zone 2. The location of the profile is shown in Figure 5.1.

## TEST CASE 7a and 7b

*Natural analogue studies at Poços de Caldas, Minas Gerais, Brazil.*

### Introduction

Test case 7 is a natural analogue study based on an investigation performed at Poços de Caldas, Minas Gerais, Brazil. The project started in May 1986 and is planned to last three years. The project involves two subprojects;

1) evaluation of the transport and speciation of natural radionuclides and rare-earth elements in a fissure flow system in crystalline rock under both oxidising and reducing conditions

2) colloid formation and mobility in natural groundwaters and the role of colloids in element transport.

For the INTRAVAL study two test cases have been defined, Test case 7a concerning the redox-front and radionuclide movement in the open pit uranium mine and test case 7b based on the movement of colloids.

Two sites are available for the study:

— Osamu Utsumi Mine (C-09 Uranium Mine; U with subordinate Th and rare-earth elements) where Project 1 will be located,

— Morro do Ferro (U, Th, rare-earth elements) where Project 2 will be located.

The programme of study at Poços de Caldas is projected to take three years. The first year was dedicated to a feasibility study of the C-09 uranium mine involving drilling, sampling, and scoping analysis of selected important samples. The second year was mainly be devoted to Morro do Ferro together with some supplementary sampling at the C-09 mine, and to the main programme of groundwater and rock analysis. The third year will be concerned with the compilation, interpretation and reporting of the data.

### General description

The Poços de Caldas region consist principally of alkalic intrusive rocks and is generally anomalous with respect to uranium, thorium and the rare-earth elements. These elements show pronounced chemical similarities to neptunium, plutonium and americium/curium respectively.

The open pit uranium mine (Osamu Utsumi) is at present several hundreds of meters wide, nearly 1 km long and more than hundred meters deep in places. The bedrock is crystalline and consists mainly of phonolites and nepheline syenites. The rock matrix is porous with a porosity of 4-20%. The hydraulic conductivity of the matrix is an order of magnitude lower than that of the overall rock including fractures. The deeper portions of the rock are strongly reducing while the upper portions has become oxidised by oxygen carried by infiltrating rain water. The redox front is very sharp. In association with fractures and fracture zones, which have higher permeability than the rock matrix itself, 'fingers' of oxidised rock are extending much further downward than the average depth of the front. Pitchblende modules with typical sizes between 0.5-1 cm and nearly spherical in shape, are found in many places just below the redox front in the reduced rock.

The basic geology of Morro do Ferro is a fractured volcanic complex containing a massive magnetite dyke system with surrounding magnetite-rich breccia. The whole system has been extensively altered both by hydrothermal activity and weathering processes. The upper tens of metres are a lateritic soil composed of kaolinite, illite, gibbsite, and accessory minerals including jarosite and magnetite.

The water table is a subdued reflection of the topography. At the top of the hill the water table is at least 80 m below the surface fluctuating by at least 20 m between the wet and dry seasons.

High concentrations of Th and REE (rare earth-elements) can be observed in organic-rich surface and unsaturated zone waters. Humic compounds seems to be the predominant complexants in these waters; Th, REE's, Fe and Mn are present mostly as colloids. Interaction of these species with the rocks are responsible for low concentrations of Th/REE and DOC (dissolved organic carbon) in the groundwaters.

The chemistry of the groundwater in four reference zones is being monitored to establish a basic data set and any seasonal variability. Colloidal material is being extracted from these reference waters and characterised for composition, size and Th/REE content. Simple hydraulic testing is being performed to establish the properties of the rock, and a simple conservative tracer test is being considered to calibrate an existing 2-D flow model for the system.

### Current status and available data

A very large amount of data has been collected from the open pit uranium mine. A complete dataset will, however, not be available until late 1989. At present the dataset includes:

- detailed maps of the vertical walls showing the location of the redox front and the concentration profiles of uranium,
- substantial information on rock chemistry, mineralogy, petrography, physical properties, uranium series disequilibria,
- the chemistry of waters at different depths in the boreholes
- hydraulic conductivities measured in the boreholes and in the rock matrix,
- porosities and diffusivities in the rock matrix,
- content of colloids and their composition,
- information on microbiological activity,
- infiltration rates,
- results from some geochemical modelling and from hydraulic modelling of groundwater flow patterns and velocities in the area of the mine prior to excavation as well as with the mine in its present state.

## TEST CASE 8

*Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia*

### Introduction

This test case deals with the analogue studies in the Alligator Rivers region of the Northern Territory of Australia commenced in 1981. The work that has been carried out can be divided into four broad categories:

- radionuclide distribution in rock samples and rock fractures,
- the role of groundwater and colloids in radionuclide transport,
- the production and dispersion of the fission products $^{129}I$ and $^{99}Tc$, and transuranics $^{239}Pu$,
- development of modelling codes and evaluation of the Koongarra site for modelling studies.

A comprehensive experimental and modelling program has been agreed to by the participants (ANSTO, JAERI, PNC, SKI, HMIP/DoE and U.S. NRC) of the NEA/OECD co-ordinated project which will continue the earlier work carried out in the US NRC funded project. The work will be aimed of supporting modelling studies. An initial task of the project will be the establishment of a comprehensive data base and the provision of sectional contour representations of the data.

### General description

The uranium deposits of the Alligator Rivers region occur near the base of Lower Proterozoic (Cahill Formation) schists. They are located in zones of chloritisation within the schists and are adjacent to lenses of massive dolomite.

The Koongarra uranium mineralization occurs in two distinct ore bodies separated by a barren gap. Both bodies consist of primary zones containing uraninite veins within a zone of steeply-dipping, sheared quartz-chlorite schists of the lower member of the Cahill Formation, which is adjacent to a steeply-dipping reverse fault that brings the schists into contact with the Kombolgie sandstone. In the No 1 ore body, which is the subject of this study, secondary mineralisation is present in the weathered schists from near the surface down to the base of weathering at a depth of 25-30 m, and forms a tongue-like fan of ore grade material extending down-slope for about 80 m. There is little indication of secondary mineralisation in the No 2 ore body where the primary zone is intersected in unweathered rock from 50 m to at least 250 m below the surface.

The Koongarra ore zone has been extensively explored, but as yet Australian Government policy has restricted its development as a uranium mine.

### Geologic data

The geological data available is based on the mineralogical and uranium assay logs of 140 percussion holes and 107 drill cores in the immediate vicinity of the uranium deposit, together with data on over 300 backhoe pits and auger holes, geophysical surveys and geologic maps of surface exposures. The drill core material and pulp from the percussion holes is stored at the site and is available for examination. This material has been the subject of an extensive measurement program which studied the distribution of uranium and thorium series radionuclides in the region of the ore body. A computer data base is presently being established.

### Hydrogeologic data

The study region, in common with much of northern Australia, has a monsoonal climate with almost all the rainfall occurring in a wet season between November and March.

General migration of groundwater is from the north, at the foot of a prominent south facing escarpment, towards the south through the ore deposit with natural groundwater discharge taking place by evapotranspiration and direct discharge into a stream in the southern part of the site during the wet season. Rainfall records have been kept for the last 17 years and water levels in 61 wells have been monitored for various periods up to 7 years in duration since 1971.

Hydrogeologic characterisation of the bedrock has been obtained from 24 drawdown and recovery tests and 50 water pressure tests. Five aquifer tests have also been made to help characterise the flow system in the bedrock.

Further hydrogeologic work is in progress to help determine possible trajectories and travel times. This work is aimed at investigating whether the groundwater flow is primarily along fractures even in the highly weathered zone, and what is the general depth of transition between matrix flow and fracture flow. Connections, if any, between groundwater in the bedrock and groundwater in the surficial deposits will also be investigated. Further wells will be drilled for additional groundwater sampling and aquifer tests.

### Hydrochemical data

A base body of general hydrochemical data exists. Analyses for various radionuclides have been made. These radionuclides include $^{238}U$, $^{234}U$, $^{226}Ra$, $^{222}Rn$, $^{232}Th$, $^{230}Th$, $^{129}I$, $^{99}Tc$, $^{36}Cl$, $^{14}C$ and $^{3}H$. A number of stable nuclides have also been determined. Further work in isotope hydrochemistry and additional complete chemical analyses of water within and around the ore deposit are the subject of the proposed project.

### Previous modelling

Three hydrodynamical modelling methods have been developed to determine the migration time of uranium in the secondary mineralisation region. The effects of linear, equilibrium sorption is described by a constant retardation factor. The model is one-dimensional with a constant groundwater velocity. The hydrodynamic dispersion is not considered. The second model is based on the spatial gradient of uranium and activity ratios $^{234}U/^{238}U$, $^{230}Th/^{234}U$.

A modified version of the open system model, which was set up to interpret data from the Northern Territory uranium deposits, has been developed for Koongarra. The mathematical framework of the model is based on the measured results of authogenic and allogenic changes in the ratios of uranium isotopes and some of their daughter products, e.g. thorium.

## TEST CASE 9

*Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Whiteshell, Canada.*

### Introduction

This test case is based on laboratory experiments on migration of tracers in a single fracture in a large block of granite. The experiments were performed at AECL, Canada, and the aim was to calibrate relevant fracture transport parameters and transport model(s). The experiments address important phenomena in radionuclide transport in the geosphere such as sorption, dispersion, channelling, matrix diffusion and fracture properties.

### General description

The granite block (length 91.5 cm, width 86.5 cm, height 49.0 cm) contains a single natural fracture. The fracture aperture was estimated from the volume of water required to completely fill the fracture to be approximately 800 µm. The block was positioned so that the fracture was approximately horizontal. The outside surface of the block, as well as the edges of the fracture on the long sides, were coated with a silicone-based rubber to avoid evaporation of the transport solution through the porous matrix. Inlet and outlet reservoirs were attached to the short sides of the block covering the fracture where it intersects these surfaces of the block. This way a uniform gradient was created across the entire width of the fracture. The outlet reservoir was divided into five compartments which were sampled in sequence by solenoid valves, see Figure 10 in the main report.

To determine the longitudinal dispersivity experiments with the nonsorbing tracer uranine were performed. After that runs with the tracers iodine and caesium were made. To determine the sorption of caesium on the rock, independent, static, batch-type experiments were also performed. The fracture were then opened at the flow paths were investigated with alfa-autoradiography. The fracture surface has also been examined with gamma scan.

### Previous modelling

The results from uranine experiments at high fluid flow rates were used to estimate the average value of the fracture aperture and to calibrate the longitudinal dispersivity using the FRACFLO code. The estimated dispersivity together with a matrix diffusivity and surface sorption coefficient for caesium was used to estimate the breakthrough of caesium. The predicted breakthrough curves were then compared with the experimental breakthrough curves.

Summary of available data:

- — flow rates in the experiments,
- — rock porosity and density,
- — rock and groundwater composition,
- — caesium sorption data,
- — breakthrough curves for nonsorbing uranine,
- — breakthrough curves for caesium and iodine.

## TEST CASE 10

*Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study at Las Cruces, New Mexico.*

### Introduction

This test case are foreseen to give the opportunity to validate parameters and models relevant for radionuclide transport in unsaturated soils. The experimental location is the New Mexico State University College Ranch, 40 km north-east of Las Cruces, New Mexico, USA.

### General Description

The field site is on a basin slope of a mountain. The geologic features, geomorphic surfaces, soil series and vegetation types found in the area around the field test are typical of many areas of southern New Mexico and are similar to arid and semiarid areas of the southwestern United States.

The climate in the region is characterized by an abundance of sunshine and low relative humidity. Average annual precipitation is 23 cm with about 50 % of the rainfall occurring between July 1st and September 30th.

A trench 16.5 m long, 48 m wide and 6.0 m deep has been dug in the undisturbed soil. Two irrigated areas measuring 4x9 m and 1x12 m respectively are adjacent to the trench. In the first test water containing a conservative tracer, tritium, has been applied at a controlled rate of 1.76 cm/day on the surface of one side of the trench. The movement of water below the soil surface has been monitored with neutron probes and tensiometers as well as by visual observations of the water movement on the trench wall. In a second test, water containing tritium and bromide has been applied at a controlled rate of 0.5 cm/day on the surface on the other side of the trench. The irrigated area in the second test is only 1 m wide, this test will therefore be used to study the lateral spreading of the wetting front.

### Parameters evaluated

The parameters measured or evaluated are hydraulic conductivity values, characteristic curves for the range of saturation to field water contents, specific water capacity, soil property parameters, moisture content or moisture profiles as a function of time, tension data and visual observation of wetting front advances.

In addition to the field experiment, laboratory column tests can be used to define transport parameters, such as Peclet number and dispersion coefficients.

## TEST CASE 11

*Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site near Superior, Arizona.*

### Introduction

This test case deals with transport in unsaturated fractured rock. The experimental location is the Apache Leap Tuff Experimental Area in non-welded to welded tuff near Superior, Arizona, USA. The purpose with the test case is to validate parameters and models relevant for radionuclide transport in fractured unsaturated media against data sets.

### General Description

Nine inclined boreholes have been installed in three rows of three boreholes per row. The boreholes within a row are echelon at 10 m intervals. The rows are 5 m apart. The surface of the site has been covered with a plastic sheet to reduce natural infiltration and evaporation. The experiments in the boreholes include interval testing for temperature, water content and saturated hydraulic conductivity. Also, pneumatic properties are tested on intervals.

### Parameters evaluated

The parameters measured or evaluated are hydraulic diffusivity, moisture characteristic, hydraulic conductivity, specific water capacity, soil property parameters, saturated hydraulic conductivity, physical properties, borehole temperatures, borehole water contents and borehole air flow rates.

Many of the borehole analyses are repetitively measured during different seasons. All the moisture-dependent hydraulic parameters are measured at three meter intervals.

Additional experiments in an abandoned road tunnel and in a mine haulage tunnel located nearby will also provide important data. Comparison of parameters between sites should allow models developed at one site to be verified at another.

## TEST CASE 12

*Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE.*

### Introduction

This test case deals with near-field effects in partially saturated Tuffaceous rocks produced by propagating transient disturbances. The experimental location, the G-Tunnel Underground Facility, Nevada Test Site, is located about 110 km north of Las Vegas, Nevada, USA.

### General Description

The objectives with the tests are to:

- — Obtain rock-matrix and fracture-system calibration data for partially saturated welded and non-welded tuffaceous rocks,
- — Predict hydrologic system flux and velocity fields in response to imposed time and spatially variable disturbances,
- — Predict system long-term recovery and reequilibration following disturbance termination,
- — Compare model predictions with experimental field data collected during both the short-term transient and long-term recovery periods.

The field-experimental design consists of continuously coring pairs of horizontal boreholes into both non-welded tuff and into fractured, welded tuff. The boreholes will be about 10 m in length and 10 cm in diameter with a separation of about 6 m. The core with a diameter of about 6 cm will be encased in plastic as coring proceeds in order to minimize drilling-fluid contact with the core. One of each pair of boreholes will be drilled and cored using air as drilling fluid and the other will be drilled and cored using water.

**Data to be measured**

The borehole logging consists of caliper logs, TV camera logs and neutron moisture meter logs. At the completion of the logging each borehole will be instrumented. The dry-cored boreholes will be instrumented first in order to monitor any crosshole effects caused by the drilling of the wet-cored boreholes. Instrument stations will be placed in all four boreholes and will remain in place until the isolated areas of the boreholes have reached equilibration. Each instrument station will consist of pressure transducer, thermal sensor and thermocouple psychrometer. Gas-phase tracers will be injected into the water and air drilling fluids in order to test for cross-hole hydrologic connections. Fracture zones and unfractured matrix will be isolated and instrumented. Interconnecting fractures will be instrumented if they are encountered.

Laboratory techniques will be used to determine the effects of drilling fluids on the hydrologic condition of the core samples. Laboratory experiments will be used to measure or evaluate bulk density, grain density, porosity, water content, water potential, water characteristic curves, saturated and unsaturated hydraulic conductivity, imbibition, heat capacity and thermal conductivity.

The effects of capillary hysteresis will be investigated in a suite of complementary imbibition and moisture-release experiments. These will also provide an independent set of transient data set.

**Previous modelling**

Preliminary models have been constructed to simulate the hydrologic effects produced by short-term water invasion into a highly idealized representation of partially saturated, fractured, welded tuff.

**TEST CASE 13**

*Experimental study of brine transport in porous media performed at RIVM, the Netherlands.*

**Introduction**

This test case describes flow and mass transport in high-concentration situations. This is of importance for studies related to radioactive waste disposal in deep geological formations where high concentrations of dissolved salts are encountered in the host rock or in overlaying aquifers.

**General description**

The experimental set-up is a column; 0.6 m long, 0.01 m wide and 1.25 m high, filled with glass beads, see Figure 13 in the main report. Fluid can be circulated through the bed. The pressure head along the bed can be monitored by nine sets of manometers and three electric pressure transducers. The salt concentration of the fluid can be measured at sixteen points by electrodes. Two sets of experiments will be performed; one set at low salt concentrations to measure porosity, permeability and dispersivity of the porous media and another set at high salt concentrations to record the salt mass fraction and pressure along the bed.

**Previous modelling**

Preliminary low-concentration experiments have been used to test the code METROPOL code developed in RIVM. The code predicts these results rather satisfactorily. Very preliminary results from high-concentration experiments have also been used to test the code. It, however, appears the the boundary conditions employed in the simulations strongly dictate the outcome of the calculations.

# APPENDIX 3

Below the intentions of the Project Teams to participate in the evaluation of various test cases are summarised. The list refers to a preliminary questionaire circulated among the participants at the INTRAVAL workshop in Tucson, November 1988.

| Project Teams | TEST CASE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a | 1b | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| DEMT | x | x | | | | x | x | | x | | | | | x | |
| AECL | | x | x | | x | x | | x | | x | | | | | |
| ANSTO | x | | | | | | | x | x | | | | | | |
| BGR | | | | | | | | | | | | | | x | x |
| PTB | | | | | | | | | | | | | | x | |
| EDM | | x | | x | | x | x | | | x | | | | x | |
| UPC | x | x | | x | | x | x | | x | | | | | x | x |
| GRS | x | | | | | | | | | | | | | x | x |
| GSF | x | | | x | | | | | | | | | | x | x |
| BGS | x | x | | | | | | x | | | | | | | |
| AES | | x | x | | | x | | x | | x | | | | | |
| VTT | | x | x | | | x | | | | x | | | | | |
| JAERI | x | x | x | x | x | x | x | | x | x | x | | | | |
| CRIEPI | | | | | | | | | | | | | | | |
| Hazama Gumi | | x | | | x | x | | | | x | | | | | |
| PSI | x | x | x | | | | x | | | x | | | | | |

| Project Teams | TEST CASE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a | 1b | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| RIVM | x | | | | | | | | x | | | | | x | x |
| PNL | | | | | | | | | | | x | | | | |
| MIT | | | | | | | | | | | x | | | | |
| SNL | x | x | x | | | | x | | x | | x | x | | | |
| TBEG | | | | | | | | | | | x | | | | |
| UAZ | | | | | | x | | | | | | x | | | |
| NRPB | x | x | x | | x | x | | x | x | | | | | | |
| HSK | x | x | x | | x | | | | | x | | | | | |
| PNC | x | x | x | x | x | x | | x | x | x | | | | | |
| KTH/SKB | | x | x | | x | x | | x | | | | | | | |
| KTH/SKI | | | | | x | x | | | | x | | | | | |
| HARWELL | x | x | | | | | | | x | | | | | | |
| Intera-ECL | | | | | x | x | | x | | | | | | | |
| PASS | x | x | x | x | | x | x | | x | x | x | x | x | | |
| OWTD | | x | | | | | | | | x | x | | | | |
| NNWSI | x | | | x | x | x | x | | | x | | x | | | |
| USNRC | | | | | | | x | | x | | x | x | x | | |
| State of Nevada | | | | | | | x | | | | | | x | | |
| Yugoslavia | | x | | | | | | | | | | | | | |
| Sum: | 16 | 19 | 11 | 7 | 10 | 16 | 10 | 8 | 11 | 13 | 8 | 5 | 3 | 8 | 5 |

**INTRAVAL Parties:**

Agence Nationale pour le Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/Physikalisch-Technische Bundesanstalt (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire (France), Empresa Nacional de Residuos Radioactivos S.A. (Spain), Gesellschaft für Reaktorsicherheit (Federal Republic of Germany), Gesellschaft für Strahlen- und Umweltforschung (Federal Republic of Germany), Her Majesty's Inspectorate of Pollution (United Kingdom), Industrial Power Company Ltd. (Finland), Japan Atomic Energy Research Institute (Japan), Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Switzerland), National Institute of Public Health and Environmental Hygiene (The Netherlands), National Radiological Protection Board (United Kingdom), Nuclear Safety Inspectorate (Switzerland), Power Reactor and Nuclear Fuel Development Corporation (Japan), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy (United States), U.S. Nuclear Regulatory Commission (United States).

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