PEER 17 - INTRAVAL (Progress Reports 5 - 10)

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PROGRESS REPORT

5

November 1989 – April 1990

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

INTRAVAL Progress Report No. 5, 1990

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.

Twentytwo 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 and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was initiated in October 1987. A first phase of the study will be finalised in the autumn 1990. SKI has initiated discussions among the participating organisations about the possible contents of a second three year period. A decision about the continuation will be taken at the INTRAVAL Coordinating Group meeting in October 1990.

The purpose of the study is to increase the understanding of 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 by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process.

Seventeen test cases have so far been included in the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project, the Alligator Rivers Project, and the Poços de Caldas Project.

A Pilot Group has been appointed for each of the test cases. The responsibilities of the Pilot Groups are to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations.

A pronounced policy of the INTRAVAL study is to support interaction between modelers and experimentalists in order to gain reassurance that experimental data are properly understood and that experiences of the modelers regarding the type of data needed from the experimentalists are accounted for. In order to support this interaction and to develop 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.

Since the issue of the previous Progress Report, the fourth INTRAVAL workshop and the fifth Coordinating Group meeting were held during the week February 5th to 10th, 1990 in Las Vegas, United States of America. During the workshop a number of oral presentations were given about work performed with the test cases. The final documentation of the first phase was also initialised and six working groups responsible for the technical content in technical reports foreseen to be published were appointed. The time scale for the final documentation of the first phase of INTRAVAL were agreed upon. VOIC had two meetings and some other working groups used the opportunity to arrange meetings.

The Fourth INTRAVAL Workshop and the Fifth Coordinating Group Meeting

The fourth INTRAVAL Workshop and the fifth Coordinating Group meeting were held in Las Vegas, Nevada, USA, on the 5th through 10th of February 1990 with the U.S. Department of Energy acting as host. In conjunction with the meetings an excursion to the Nevada Test Site was organised. The discussions at the workshop focussed on new modelling results achieved since the last workshop. Quite some time was also spent to organise the finalisation and documentation of the first Phase of INTRAVAL. In addition, the initialisation of a second Phase of INTRAVAL was discussed and proposed test cases for the second Phase were presented.

The Coordinating Group meeting was held on the 10th of February 1990. The Coordinating Group recommended a second Phase of INTRAVAL. The final decision on this matter will be taken at the next meeting in October 1990. The Swedish Nuclear Power Inspectorate will send out an invitation for participation in the INTRAVAL Phase 2 to the Organisations before the summer. The next INTRAVAL workshop and Coordinating Group meeting will be held in Cologne, The Federal Republic of Germany, in October 1990.

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 (now Intera-Exploration Consultants Ltd), Peter Glasbergen, National Institute of Public Health and Environmental Protection, 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.

The charter for VOIC states that the purpose of the committee is to provide a means for the INTRAVAL Project to investigate the broad issues related to demonstrating the validity of concepts, theories and models used in the performance assessment of repositories, and to provide for a continuing technical overview which will allow for adjustments and improvements to the selected test cases. The work within VOIC has been focussed on formulating how the term validation could be interpreted in the INTRAVAL context and what processes of relevance to radionuclide transport modelling in the performance assessment of radioactive waste repositories could be addressed by the different test cases. VOIC also specified the goals of INTRAVAL as 'ensuring that models are available and validated to each of the set of crucial processes that control the flow and transport in the geosphere'.

VOIC has suggested that the process of validation may be described as follows:

1. *Understanding and Research*
Without proper understanding of the processes and system structures involved, there could be no validation. On the other hand, one can say that a thorough understanding represents the major part of validation.

2. *Comparison of Theory and Modelling Calculations with Experiments*
This is to study how well we are able to predict or simulate experimental results quantitatively. Any discrepancy may be due to parameter uncertainties, statistical nature of the system or lack of understanding. The last case requires further effort in item 1. Care should be taken to avoid curve fitting without the proper understanding and confirmatory results.

3. *Peer Review and Public Scrutiny*
It is important to have our work published in the open literature, both to receive the benefits of anonymous technical review and to open it to public scrutiny. A study

whose results are in the open literature, examined by and maybe used by the general scientific community over long periods of time has a much better chance of being correct.

Almost by definition one can never validate a computer code without complementing the statement with further qualifying phrases. Thus, in VOIC's view, a certified code means that the code is properly verified and properly documented. It is then mathematically correct in its formulation and solution and properly documented with respect to function, accuracy, guidelines about the required discretisation, and ranges of applicability. A model, including the conceptualisation and the computer code, can be validated either with respect to (a) a process or (b) a site-specific system. For (a), a process is first identified (e.g. buoyancy driven flow) and the conceptualised (e.g. as temperature-dependent density and viscosity) and coding is performed on this conceptualisation. The model is then applied to an appropriate experiment and its results compared with measurements. If the calculations compare well with the experiment with due consideration given to parameter uncertainties etc., we can say that the model is validated with respect to this specific process. For (b), a site-specific system may be composed of a number of processes and structures, which form the building blocks of the system. Once the building blocks are identified, a model or group of models may be used to simulate and compare with field observations. If successful, the group of models is said to be validated with respect to this particular site, within a range of applications determined by the range of field observations studied.

Hence, there is no such thing as a validated model in the generic sense. However, we can say that 'a model is validated with respect to a given process', or that 'a model or group of models are validated with respect to a given site'. Ranges of applicability should always be included in such statements. The decision if a model is valid is not made only by those using the model. The model is valid in a given case if the user has applied it correctly and can convince another knowledgeable person or group of persons of this. In the end the scientific community will decide the validity of models and whether they are correctly used in the right context.

In the process of defining INTRAVAL Phase 2, VOIC has given assistance and advice to the INTRAVAL Secretariat and the Coordinating Group concerning the outline of the continuation. Phase 2 should be based on on-going and well documented field experiments. The study should be more directed to validation strategy and performance assessment considering the accomplishments of Phase 1. It is also suggested that various key issues, such as scale dependence, heterogeneity, and coupled processes, are highlighted.

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 Laboratory, U.K. (Pilot Group Leader: D. Lever, Harwell Laboratory)

Experimental Setup and Scales

Experiments to study solute (iodide, deuterium and tritium) migration through intact samples of clay, from one borehole at a depth 28–34 meters below ground level, have been performed at Harwell Laboratory in U.K. A set of transient and steady-state tracer experiments have been performed, both parallel and perpendicular to the bedding of clay samples (vertical through-diffusion, horizontal through-diffusion, in-diffusion, and dispersion experiment). The length scale, of the experiments are up to a few centimeters and their durations are up to a few months. The data available are breakthrough curves from the through-diffusion and from the hydrodynamic dispersion experiments, as well as the amount of tracer that have diffused into the samples in the in-diffusion experiments. In addition, results are available from complementary experiments such as moisture content and porosity, size and distribution of the porosity, and hydraulic conductivity as a function of stress.

Analyses by the Project Teams

The Project Team from SNL has defined a validation strategy which has been tested on this case. The method could briefly be described in terms of a number of steps including choice of conceptual model, identification of validation issues and design of experiments to assess these. It also contained a proposed scheme for invalidation of the model by comparing the "best fit" model breakthrough curve. The model is not acceptable if a systematic error of correlation in the residual is observed. Two models of diffusion in clay has been tested on this test case, one two-dimensional single porosity model and one two-dimensional dual porosity model. The single porosity model was tested earlier and was found to be invalid. Probability distribution function representing the uncertainty in parameters were obtained, mainly by reviewing available literature, and a number of Monte Carlo simulations were undertaken.

The transport equation was solved with the finite difference code SWIFT-II. The model structure was then tested by comparing the 'best fit' model breakthrough curve with the experimental breakthrough curve in terms of residual in time values for different levels of concentration. The residual plot was judged to be acceptable if a semivariogram did not show a trend but nugget.

The method was applied on through-diffusion experiments with iodide on two different samples. The test showed a trend in the semivariogram for one of the samples (INT8I), implying that the model structure was invalid, whereas for the other sample (INT9I) the model was acceptable as the semivariogram showed nugget. During the discussion it was concluded that the applied test did not filter out constant errors.

The Project Team from RIVM used both an analytical model and the finite element code METROPOL to simulate the experiments. The results from the analytical model was checked against results obtained from METROPOL and gave equal results. The total porosity was evaluated analytically from equilibrium results of the in-diffusion experiments. The total porosity for deuterium varied between 0.47 and 0.48 in different samples, whereas the variation for iodide was between 0.14 and 0.24. The evaluated porosity for deuterium was in good agreement with porosity values obtained from oven-drying. The difference in porosity for iodide and deuterium could probably be explained by the existence of micropores accessible to deuterium but not to iodide. The effective diffusivity determined analytically from the steady state part of the through-diffusion breakthrough curves was found to vary between $7.2 \cdot 10^{-11}$ and $8.6 \cdot 10^{-11}$ $m^2 \cdot s^{-1}$ for deuterium in different samples. For iodide the effective diffusivity varies between $2.8 \cdot 10^{-11}$ and $3.9 \cdot 10^{-11}$ $m^2 \cdot s^{-1}$. Using these values to predict the transient part of the in-diffusion and through-diffusion experiments with METROPOL no good agreement between calculated and experimental results was obtained. In the case of through-diffusion, there is no agreement between experimental and calculated results even at extended times, i.e. at equilibrium where the porosity and diffusion coefficients were evaluated. A curve-fitting exercise evolved in such a way that different values of the porosity and diffusion coefficients had to be selected for the in-diffusion and the through-diffusion experiments. For iodide different values had to be selected for the different samples. The introduction of matrix diffusion in the conceptual model gave a better agreement between calculated and experimental results. A preliminary unique set of parameters for the two tracers was selected. The total porosity was estimated at 0.474 from oven-drying and in-diffusion experiment with deuterium, and the macro porosity was estimated at 0.14. The effective diffusivity and the matrix diffusivity were estimated at $7.7 \cdot 10^{-11}$ and $1.1 \cdot 10^{-5}$ $m^2 \cdot s^{-1}$ for deuterium and at $6.5 \cdot 10^{-11}$ and $2.0 \cdot 10^{-7}$ $m^2 \cdot s^{-1}$ for iodide from in-diffusion experiments. The through-diffusion experiments could be simulated with satisfactory agreement with the experimental results if the above presented parameter values were employed. The permeation experiments has not yet been simulated but will be.

The Project Team from UPC previously presented an analysis where three different advection-dispersion models were used to simulate the experiments: a single porosity model, a double porosity model (including matrix diffusion, and a triple porosity model (including matrix diffusion and molecular diffusion in immobile water). The main conclusion from this evaluation was, however, that all data could be explained with a simple model. More complex models could be used but their parameters could not be estimated reliably. This indicates that the validity of the simple model or the need for more complex ones requires calibration under different conditions.

As an approach to designing experiments that can distinguish between different models, the following methodology was adopted: A suitable experiment is proposed. The proposed experiment is simulated with one model, then the other model is attempted to fit both the experimental data and the simulated data. If this can be done, then the proposed experiment cannot be used to distinguish between the two models, whereas if it cannot be done adequately then the proposed experiment is a candidate for differentiating between the models. This is then checked further by interchanging the roles of the models in the above analysis.

The experiment is a good discriminator between the models only if it satisfies both tests. A number of possible permeation experiments with pulse injection have been tested and found to fail to distinguish between the two models according to the above described methodology.

The parameters that have been varied in these experiments are:

- the pulse duration (10 000 and 5 000 s),
- the size of the downstream reservoir (1 cm and 10 cm, which is a reduction of 50 respectively 5 times compared to the reservoir used in the experiments),
- the water flow rate (5 and 2.5 times the flow rate used in the experiments),
- the weight of the pulse experiment,
- the retardation factor.

The conclusions drawn from these tests are that it is of no value to use dual or triple porosity models to evaluate the transport of conservative (non-sorbed) tracers. For sorbed tracers (retardation factor of 10), it was possible to reproduce model data, especially if reduced weight was given to the pulse experiment. The evaluation approach is based on the assumption that all samples can be characterised by one set of parameters, although there is significant variability between different samples.

The Project Team from PNC evaluated the in-diffusion and the through-diffusion experiments with a one-dimensional model. Both separate and joint analysis of the in-diffusion and through-diffusion experiments indicates that the experiments cannot be described with a single set of porosity and diffusion coefficient values. A statistical test (least squares method) shows that the population mean values of porosity and diffusion coefficient from the through-diffusion experiment are larger than those from the in-diffusion experiments both for iodide and deuterium, with 95% significance level. Data from joint analysis (porosity from in-diffusion experiments and diffusion coefficient from through-diffusion experiments) show that all experimental points of the in-diffusion experiments for iodide fit within the estimated interval of the population mean of porosity and diffusion coefficient values, whereas, for deuterium some points fall out of the estimated region (99% confidence interval). It was also concluded that the estimations of both the porosity and the diffusion coefficients are sensitive to the method applied to evaluate them, especially with regard to the applied boundary conditions. Preliminary results from evaluation of the permeation experiments with a one-dimensional advection-dispersion model show good agreement between calculated and measured breakthrough curves, except for one experiment. Further evaluation of the permeation experiments is needed before these results can be assessed in the conclusions of this modelling exercise.

TEST CASE 1b

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

Experimental Setup and Scales

In this experiment, performed at the Paul Scherrer Institute (PSI) in Switzerland, tracer migration in crystalline bore cores were studied. Water at high pressure was forced to flow through rock cores of granite or gneiss with a diameter of 4.6 cm and a length between 0.8 cm and 5.0 cm. The high pressure was intended to simulate the rock overburden. Tracer (uranium-233) was added to the infiltration water and the tracer concentration was measured in the water sampled at the core outlet. After the experiments the samples were sliced and the surfaces of the slices were auto-radiographed to yield information of flow paths and sorption sites. Complementary results on hydraulic conductivity versus confining pressure, and dynamic porosities of the samples are also available, as well as results from uranium adsorption/desorption experiments.

Analyses by the Project Teams

The Project Team from HARWELL has analysed the breakthrough curves from four different bore cores, three granite and one gneiss core. They compared three different one-dimensional advection-dispersion transport models, one with linear equilibrium sorption only, one considering also matrix diffusion, and one with kinetic sorption. The approach adopted was to calibrate each of the models using the first few data points on the breakthrough curve for a core, and then compare the predictions of the model with the remaining data points for that core. In each case, the number of data points was chosen so that the model was calibrated to the data points giving the initial rise and falling back to approximately half the peak output concentration. The models were calibrated automatically using a non-linear least-squares method to evaluate the parameters that gave the best fit for the selected model.

The results from the evaluation showed with considerable evidence that the model incorporating matrix diffusion was the most appropriate model to describe the transport. The model with only linear sorption tended to underestimate the initial peak of the tracer concentration curve and to overestimate the concentration. The model with kinetic sorption also overestimated the concentration, although it gave a better estimate of the peak.

The results from the model with matrix-diffusion can be used to evaluate the retardation and the dispersion length. The retardation is approximately 20 for the gneiss sample and for two of the granite samples, whereas the retardation for the third granite sample is an order of magnitude higher. The higher value for the last sample is consistent with the broader peak in the output tracer concentration curve for this sample. The dispersion length evaluated for two of the cores was in the range of $3\text{-}8 \cdot 10^{-3}$ m, which seems reasonable. The dispersion length for the two other cores were $2 \cdot 10^{-4}$ and $3 \cdot 10^{-6}$ m respectively. These values appear to be small. To investigate the role of the model parameters for the model with matrix-diffusion a sensitivity study was carried out. For each experiment, each of the parameters was varied to half and to twice its best fit value while the other parameters were kept at their best fit. From this sensitivity analysis it was shown that the model was not very sensitive to changes in the parameter describing the dispersion length, for samples showing very low values of the dispersion length. The discrepancies between the measured data and the model predictions were also examined and there appears to be some structural tendency.

The study of the test case shows that the experiments provide considerable support for the concept of rock matrix diffusion. It would, however, be desirable to have supporting evidence for the model on larger spatial and time scales. It might also be preferable to perform experiments for temperature and groundwater chemistry within ranges of direct interest for a repository.

The Project Team from ECL presented plans for complementary work on this test case to the work performed by HARWELL where non-linear sorption of uranium-233 is introduced instead of linear sorption in a one-dimensional advection-diffusion model. A number of sorption isotherms are identified in the literature, relating the density of sorbed tracer within the rock sample to the concentration of tracer dissolved in the surrounding water. Throughout this study the Project Team selected to use the Langmuir isotherm ($s = a{\cdot}c/(1+b{\cdot}c)$, where s is the density of sorbed tracer, c the concentration of tracer dissolved in groundwater, and a and b positive constants). The first aim with the study is to demonstrate that the specified equations can be solved robustly and efficiently before parameter estimations are started. The next step will be to analyse the test case.

TEST CASE 2

Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH, Sweden. (Pilot Group Leader: T. Eriksen, KTH)

Experimental Setup and Scales

This test case is based on laboratory experiments, performed at the Royal Institute of Technology, Sweden, on radionuclide migration of non-sorbed, moderately sorbed, and strongly sorbed tracers in single natural fissures in granite drill cores (0.02 – 0.04 m in diameter and 0.08 – 0.3 m in length). Synthetic groundwater was fed to the fissure inlet and tracers were either added by continuous feeding or as a pulse of suitable duration. The effluent was continuously sampled and analysed with respect to the tracer concentration.

Analysis by the Project Teams

The Project Team from OWTD presented results of their analysis of the test case using FRACFLO-VAL. This is a package including non-linear least squares techniques for parameter estimation and analytical solutions for one-dimensional advection-dispersion equation with and without matrix diffusion. The models and the estimation procedure were tested against analytical solutions with known parameter values. Reasonable fits to all experimental data were obtained.

TEST CASE 3

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

Experimental Setup and Scales

This test case involves recirculating tracer tests in two boreholes about 17 m apart in a deep basalt flow top, about 1000 m below ground level. 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 as derived from the breakthrough curves.

General Comments on Test Case 3

Test case 3 was formulated at a time when disposal in basalt was an option in the U.S. waste disposal programme. One valuable aspect of this test case then was a possibility to go back to the site and perform complementary measurements. Because of the discontinuation of the U.S. basalt programme the experimental site has subsequently been decommissioned and the possibility of complementary measurements no longer exists. Due to these reasons the interest among the INTRAVAL participants to perform further simulations of this test case is rather limited.

TEST CASE 4

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

Experimental Setup and Scales

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. 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 have been 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 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, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments.

The results of the water flow measurements demonstrated extreme spatial variability. Thus, 2/3 of the drift was dry, one sheet carried 10% of the water and twelve sheets carried 50%. The flow rate into the drift did 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.

Analysis by the Project Teams

The Project Team from SKI/KTH has analysed the water flow and the tracer transport in the Stripa 3D experiment with a discrete fracture network model. The computer code, DISCFRAC, generates the fracture network and solves the equations. The fractures were modelled as planar circular discs with a radius, orientation and transmissivity randomly and independently placed. The model parameters were estimated from geometric estimate based on mapped fractures and the observed flow distribution in the ceiling of the drift. The cumulative tracer breakthrough times were calculated assuming pipe flow in single fractures using particle tracking. The breakthrough curves from the discrete model were then fitted to the advection-dispersion model by the method of least squares to determine a Peclet number and a water residence time.

By plotting the Peclet number as a function of cumulative fractions of realisations for different transport distances it was found that at zero variance of the channel transmissivity the Peclet number increased linearly with distance. This means that the dispersion coefficient is constant which implies a Fickian dispersion behavior. As the variance of the channel transmissivity was increased, the Peclet number tended to be smaller and more constant, which implies a non-Fickian dispersion behavior. The tracer breakthrough in different defined small squares (windows) gave different Peclet numbers in the different squares due to fracture passing. At this stage, the Project Team thinks that the discrete fracture network model can explain the experiment. Parameter uncertainty may scale up to orderly advection-dispersion and extreme channeling.

TEST CASE 5

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

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the

Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometers.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} $m^2 \cdot s^{-1}$, the middle 10^{-7}–10^{-6} $m^2 \cdot s^{-1}$ and the lower 10^{-4} $m^2 \cdot s^{-1}$. The middle layer is not continuous. A fresh water salt water interface exists in the fracture zone relatively close to the upper previous layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated at 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core drilled (and some percussion drilled) boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed: a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbed tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from VTT presented their interpretation of the radially converging experiment. They used a channel model, characterised by the number of channels and the channel properties. Each channel had a transmissivity and a width, related to the channel dispersivity. The total transmissivity of Zone 2 was assumed to be the average of the sums of transmissivities measured in individual boreholes. In the present modelling, one single transport route between the injection borehole section and the pumping borehole was considered. This transport route represents the fastest connection between the injection and collection sites. It was assumed that the route was a flat channel having an aperture of about 1 mm or less and a width of 10 cm, and that the velocity in the channel varies over the width from zero to a maximum velocity over 5 cm. The analysis was performed assuming constant groundwater flow but time dependent tracer injection rates. It can be concluded that the applied simple model seems to predict the majority of the breakthrough curves rather well and also to reproduce dispersion effects over a wide range of transport routes and times by one value.

The Project Team from Intera-ECL has analysed the radially convergent tracer tests. They utilised two-dimensional flow models considering advection-dispersion. Data were available from nine continuous injection tests and three pulse injection tests. The evaluation concentrated on the pulse injection tests as they were likely to be more sensitive to the assumed fracture geometry, since both a wave-front and a wave-back had to be considered. The pulse injection tests (from borehole KFI11) showed a double pulse breakthrough which seems to be a consequence of flow path geometry. The best fit to the breakthrough curves was sought by minimising the sums of squares of the residuals over the time frame of the experiment. The breakthrough curves received, if a single fracture plane was assumed, did not agree very well with the observed breakthrough curves. The single fracture plane was then replaced by two parallel fractures connecting the packed-off sections of the boreholes. The pressure gradient was the same in both fractures, depending only on the distance between the injection and pumping hole. The two fractures, however, had different values for the dispersivity and flow. The fitted breakthrough curves took the form of two pulses but the fitted curves gave no good agreement with the experimental breakthrough curves. These results show, however, that just one or two parallel fractures are inadequate to model radially convergent tests with pulse injection. It might be worthwhile to investigate the effect of including the following components in the model: molecular diffusion, matrix diffusion, or non-integer dimensional flow paths.

The Project Team from JAERI modelled the radially convergent tracer pulse injection experiments with a variable channel aperture model. The two-dimensional steady state channel flow in single fractures of zone 2 was evaluated and the transport of non-sorbed solutes was simulated by a particle tracking technique considering local dispersion within each channel. The probability distribution of channel aperture was assumed to be lognormal. The effects of diffusion and sorption was not considered. In the groundwater flow calculations the fracture was divided by a rectangular grid into nodes with different apertures. The model domain was a quarter part of the area. In the solute transport simulations, the fracture plane was modelled as a rectangular network system. The travel time of particles in each channel was given by one-dimensional solutions, and particles coming to an intersection of the network were distributed in the outlet branches with a probability proportional to the flow rates. A preliminary comparison between calculated and experimental breakthrough curves showed that the tailing of the calculated curves were much smaller than for the experimental curves, this could be due to diffusion into dead-ends. The effects of local dispersion was not considered in the calculations. Best fit values of the mean channel aperture and the variance of the aperture density distribution were quite different for different flow paths. From these circumstances, and from the shape of the experimental breakthrough curves, it was concluded that a macroscopic anisotropy existed for the transmissivity in the fracture zone.

The Project Team from Hazama-Gumi analysed the radially convergent tracer test. The groundwater flow in the area was modelled to pass through a fracture network. The network was generated based on observed information on orientation and fracture density from vertical drill cores as well as on fracture lengths examined at the outcrops. Zone 2 was divided into three regions; upper (12 m thick), middle (40 m thick), and lower part (33 m thick). The fracture density is higher in the upper ($0.004\ m^{-2}$) and lower ($0.002\ m^{-2}$) parts than in the middle ($0.001\ m^{-2}$) part. The fracture length was set to 50 m and the water was assumed to flow symmetrically towards the pumping borehole.

A parallel plate model was used for the water flow in each fracture element. The transport analysis was carried out using the velocity field obtained from the groundwater flow analysis. The solute transport was simulated with a particle tracking method considering advection and matrix diffusion. The residence time for each particle within the fractures was determined by a probability density function. The water flow rate at the injection boreholes was varied between $1.7 \cdot 10^{-3}$ and $2.3 \cdot 10^{-2}\ m^3 \cdot s^{-1}$ and the fracture aperture was varied between $4 \cdot 10^{-4}$ and $5 \cdot 10^{-4}$ m. When matrix diffusion was considered the matrix diffusion coefficient was assumed to be $1 \cdot 10^{-9}\ m^2 \cdot s^{-1}$ and the rock porosity ranged from 0.015 to 0.03.

The results showed that multi-peak breakthrough curves are produced if matrix diffusion was not taken into account. Some of the calculated breakthrough curves considering matrix diffusion seem to agree quantitatively with the measured ones, although the total flow rates obtained in the calculations were smaller than those observed in the field. It was concluded that matrix diffusion seems to have significant influence on the solute transport.

TEST CASE 6

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland. (Pilot Group Leader: R. Codell US NRC)

This test case is patterned after a tracer migration experiment in a single fracture plane at the Grimsel Rock Laboratory in Switzerland. A highly detailed two-dimensional synthetic data set of hydraulic conductivities and other properties conditioned on the actual data from the Grimsel site has been generated. In addition, results from a number of simulated hydraulic and tracer migration experiments with the synthetic model are available. Based on these data sets, the task for the Project Teams was firstly to predict the breakthrough of a non-sorbed tracer at several simulated boreholes and tunnels (Phase I of this test case), and secondly, to include also diffusion and chemical retardation in the geosphere (Phase II of the test case).

Analysis by the Project Teams

The Project Team from USNRC presented results for a simple potential flow model with uniform properties. The model was calibrated to the 'observed data' (actually obtained from very fine grid simulations of a heterogeneous medium). Comparison between predicted breakthrough curves and 'observed' breakthrough curves showed considerable differences in arrival times. A finite difference model was also applied using transmissivities inferred from 'borehole tests' from a few boreholes. A linear variogram appeared to fit these hydraulic data best. The finite-difference model gave better results than the simple potential flow model, but the conclusion was that more data in some areas are needed.

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: I. Neretnieks, KTH)

This test case is based on one of two subprojects 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 deeper parts of the rock are found to be strongly reducing while the upper parts have become oxidised by oxygen carried by infiltrating rainwater. A redox front can be clearly seen because the colors of ferrous and ferric minerals are different. Secondary uranium mineralisation is found around the fractures and at the moving redox fronts.

Analysis by the Project Teams

The Project Team from SKB/KTH has studied the redox-front movements at Poços de Caldas. The redox-front movement was modelled with the coupled transport and chemical code CHEQMATE, that models the transport through a series of equilibrium boxes. The phenomena modelled were: the redox-front movement, feldspar to clay reactions, hydrolysis front movement, formation of uranium ore, and aqueous phase complex formation. The modelled water chemistry, mineral composition and front movements rate were then compared with field observations. Assumptions have been made concerning the water infiltration rate which is an important parameter for the rate of redox front movements, the chemistry of the infiltrating water, the dispersion length and the rock composition. Modelling the infiltration of rainwater through a one-meter column during 38 000 years resulted in a sharp drop in pe at 0.8 m and precipitation of uranium at this redox-front. In field observations it can be seen that the front is not sharp but follows fractures and fracture zones, which have higher permeability than the rock matrix itself, deeper down. Oxygen from the water in the fracture diffuses into the rock and the uranium in the rock is dissolved and diffuses out to the water in the fracture, where the concentration is lower, and is swept down the fracture and precipitates at the redox-front.

TEST CASE 7b

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

This test case is based on the second subproject of the natural analogue study at Poços de Caldas, Minas Gerais, Brazil. It is concerned with colloid formation and mobility in natural groundwater 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. The Pilot Group has pointed out that the field work has given little, if any, evidence of colloid transport of the natural tracers studied. At present it is therefore deemed unlikely that the data set can be developed for a meaningful test case for INTRAVAL.

TEST CASE 8

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

This test case deals with the natural analogue studies at the Koongarra site in the Alligator Rivers region of the Northern Territory, Australia. A comprehensive experimental and modelling programme has been set up and the main objective is to contribute to the production of reliable and realistic models of radionuclide migration within geological environments relevant to the assessment of the safety of radioactive waste repositories.

Uranium mineralisation at Koongarra occurs in two distinct but related ore bodies separated by about 100 m of barren schists. Both ore bodies strike and dip broadly parallel to the Koongarra Reverse Fault, which is the footwall to the ore zone. Primary mineralisation is largely confined to quartz-chlorite schists immediately above the fault zone. A graphitic quartz-chlorite schists forms a distinctive hanging wall unit. The more south-westerly of the two ore bodies (No. 1 ore body) has a strike length of 450 m and persists to a depth of about 100 m. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m to the east.

Analysis by the Project Teams

The Project Team from RIVM presented their proposed modelling approach for this test case. The data base will firstly be evaluated followed by three-dimensional groundwater flow modelling of No. 1 ore body and one-dimensional radionuclide migration calculations. Geochemical models is also foreseen to be used for e.g. speciation calculations.

The Project Team from ANSTO presented an approach to investigate the time signatures that might be encoded the present day shape of the secondary uranium deposit. The top 30 meters of the weathered rock, in which the major uranium mobilisation occurs, contains two distinct layers. The specific uranium distribution pattern between these layers may contain some information important for the evaluation of the time scale. The model used is a quasi-two dimensional model describing the transport in a two-dimensional vertical cross-section as transport in two one-dimensional pipes separated by an intermediate zone where no horizontal transport is considered. This zone provides transfer of material from the bottom pipe to the upper pipe, reflecting transport due to seasonal fluctuations in water table. Two approaches were applied, one based on advection-diffusion in the pipes and a second based on open-systems model. Preliminary findings are that the distribution coefficient (K_d) is 10^4 ml/g and the time scale seems to be less than 2 million years.

TEST CASE 9

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

Experimental Setup and Scales

This test case is based on laboratory experiments on migration of tracers in a single natural fracture in a large block of granite. The size of the block is 91.5 cm × 86.5 cm × 49.0 cm (length × width × height). The block was positioned so that the fracture was approximately horizontal and an inlet reservoir was designed to produce an as uniform hydraulic gradient and inlet tracer concentration as possible across the entire fracture width. The outlet reservoir was divided into five compartments, which were sampled in sequence to give breakthrough curves for each compartment. After the experiments were performed the fracture was opened and the flow paths were investigated with alpha-autography.

Analyses by the Project Teams

The Project Team from VTT has analysed the experimental data assuming five parallel isolated channels with equal width and considering advection-dispersion, matrix diffusion and sorption (depending on tracer) both on fracture walls and in the rock matrix. The number of channels corresponds to the number of sample ports. The interpretations were made with the finite element code FTRANS. The approach was to calibrate channel specific parameters from uranine (non-sorbed tracer) breakthrough curves. Tracer specific sorption and matrix diffusion coefficients have been calibrated from caesium (sorbed tracer) breakthrough curves. The performed simulations agree reasonably well with the uranine experiments. For caesium the agreement is reasonable for all channels except one. The longitudinal dispersivity in the five channels were estimated to vary between $4.0 \cdot 10^{-3}$ and $2.2 \cdot 10^{-2}$ m and the fracture aperture was estimated to vary between $4.1 \cdot 10^{-4}$ and $6.3 \cdot 10^{-4}$ m.

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: T. Nicholson, U.S. NRC)

Experimental Setup and Scales

The Las Cruces Trench experiment is setup in order to study flow and transport in unsaturated soil. A trench 16.5 m long, 4.8 m wide and 6 m deep has been dug in the undisturbed soil. Two irrigated areas measuring 4 m × 9 m (first experiment) and 1 m × 12 m (second experiment) have been arranged adjacent to the trench. Water and tracers (tritium and bromide) have been applied at a rate of 1.76 $cm \cdot day^{-1}$ to the first irrigated area and at a rate of 0.5 $cm \cdot day^{-1}$ to the second irrigated area.

The movement of the wetted zone is observed on the trench walls and by neutron tubes arranged as a grid in three cross sections parallel to the trench. In addition, permeameter tests and laboratory analyses of a set of soil samples from the test area should allow for an evaluation of the statistical distribution of the saturated hydraulic conductivity as well as the characteristic curves. The solute samplers are tensiometer cups that are connected to a vacuum line (suction lysimeter).

Analyses by the Project Teams

University of Arizona presented results from an analysis of the tritium breakthrough curves. A one-dimensional advection-dispersion model assuming steady-state flow was applied. Dispersion and retardation parameters were estimated by a fitting procedure using experimental breakthrough curves from different depths.

New Mexico State University presented a comparison of observations from the second experiment and predictions of water contents, tritium and bromide concentrations using a deterministic finite-difference code. A uniform soil model was used with a dispersion coefficient, $D = 1 + 5V\ cm^{-2} \cdot day^{-1}$, and retardation $R = 1.0$, for tritium and $R = 0.84$ for bromide. The fact that retardation was smaller than 1 for bromide was explained as due to anion exclusion. The experimental data show a large scatter both in water content and tracer concentration. This scatter is due to local heterogeneities which are not encountered for in the deterministic models where smooth profiles are obtained. The calculations performed for the tracer transport give generally too high spreading of the concentration plume and also too low peak concentrations. Apparently even lower dispersion coefficients must be used in the calculations.

The Project Team from SNL set up a homogeneous deterministic model for the system in order to explore whether such a model is valid for a truly heterogeneous system. Uncertainties in data were handled using Latin-Hypercube Sampling (LHS). The performance of the model was measured by the moisture content at a depth of 1.5 m as a function of time. They found that the physical behavior at early times was outside the range of the LHS runs, whereas at later times the physical behavior was within the range. It was commented that average performance criteria should be applied rather than pointwise ones.

Hydro Geologic Inc. presented results of simulations of the second experiment using the finite element code VAM2D. Three flow scenarios and their impact on transport predictions were evaluated. Scenario 1 corresponds to a case where no data exist and representative values from the literature have to be used. Scenario 2 illustrates a case where sufficient data are available to define average soil parameters. Scenario 3 utilises all available soil core and neutron probe data to fully define heterogeneous soil properties and initial conditions. Dispersivities and diffusion coefficient for tritium transport were taken to be 5 cm and $1\ cm^{2} \cdot day^{-1}$, respectively, for all three scenarios. The results indicate that the heterogeneous model reproduces the observed lateral spreading and irregular shape of the water content contours but overpredicts the movement and spread of the tritium tracer.

Kemakta Consultants Co./SKI presented flow and transport modelling using the integrated finite-difference codes TRUST and TRUMP. Three cases were considered: a uniform soil, an initially dry uniform soil and a nine-layer model. It was noted that the field data imply that the soil is initially dryer than the supposed residual moisture content. This was acknowledged by extrapolating the permeability and capillary pressure curves to lower saturations. The results demonstrated that a better moisture content agreement with experimental data was obtained using dryer initial conditions and that the layered description of the soil better predicts the lateral spreading of water. The calculations performed for tracer transport give too high spreading of the concentration plume indicating that lower dispersivities must be used.

PNL have performed Monte Carlo simulations of the infiltration experiments using a version of PORFLO with the objective to incorporate uncertainty in the prediction of the wetting front position. Using a nine-layer one-dimensional model all parameters were taken to have log-normal distributions truncated at the maximum and minimum observed values. It was pointed out that a low permeability layer could act as a barrier in a one-dimensional stochastic calculation, whereas in two-dimensions it was less likely to do so.

The group from MIT showed results from their effort to stochastically model the first trench experiment. Simulations with the highly non-linear effective mass balance equation, in which the moisture content depends on gradients of the potential in space and time, were compared with a deterministic model with anisotropy. They found the stochastic model to better reproduce the experimental results, especially for extended times.

The Center for Nuclear Waste Regulatory Analysis presented results from three-dimensional stochastic simulations using the BIGFLO code. This code utilises the Turning Band Method to generate realisations and an efficient implicit finite-difference numerical scheme for solving the non-linear flow equations. A model comprising a strip-source in a random stratified soil similar to the Las Cruces Trench was solved on a Cray 2 using 300 000 nodes.

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: T. Nicholson, U.S. NRC)

Experimental Setup and Scales

This test case is in fact three sets of experiments on flow and transport in unsaturated welded tuff. The experiments are supported by the US NRC. The first set of experiments are field experiments at the Apache Leap Tuff Site, the second is a set of laboratory block experiments and the third is a set of laboratory core experiments. All experiments have up to date been performed by the University of Arizona.

The dimension of the field experiment is in the order of 30 m × 30 m × 30 m. Nine inclined boreholes have been installed in three rows of three boreholes per row. This general setup will allow for a set of different experiments. At one experiment performed at the site so far, the rock adjacent to one borehole was saturated and the propagation of the wetted front was to be evaluated by measuring the moisture content in the other boreholes. However, the introduction of the moisture could not be detected in the other boreholes.

The dimension of the blocks is 20 cm × 20 cm × 50 cm (block 1) and 21 cm × 20 cm × 66 cm (block 2). Each block has a single fracture located through the center of the block. The vertical sides of the blocks are insulated whereas the top and bottom are attached to porous plates which should allow for controlled unsaturated flow through the block and the fracture. The flow rate between the upper and lower plates will be used to calculate the unsaturated transmissivity, and the water content of the fracture will be monitored using mass balance calculations.

The dimension of the core is 6.4 cm in diameter and 12.7 cm in length and it does not contain any (observable) fractures. The core was oven dried and then partially wetted with a solution of potassium iodine. The core was then coated to prevent moisture or air from leaving the core. The core ends were held at two different temperatures (70°C and 5°C) whereas the sides of the core were thermally insulated (no heat flow). The temperature and moisture distribution were measured after different times, as well as the final solute concentration (after 32 days).

The present status of the experimental programme was presented by the pilot group from the University of Arizona. Additional experiments have been performed, and further experimental work is planned.

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: D. Hoxie, USGS)

Experimental Setup

This test case deals with near-field effects, produced by propagating transient disturbances in partially saturated Tuffaceous rocks. The basic experimental design consists of continuously cored pairs of horizontal boreholes into both non-welded and fractured welded tuff. The boreholes are about 10 m in length and 10 cm in diameter with a separation of about 6 m. The core, diameter around 6 cm, is cased in plastic as the coring proceeds in order to minimise the contact between the drilling fluid and the core. One of each pair of boreholes is drilled using air as drilling fluid and the other is drilled using water. Gas phase tracers are injected into the drilling fluids to test for cross-hole hydrologic connections. Monitored values are drilling fluid losses, inflow and outflow temperatures, as well as inflow and outflow tracer concentrations. The physical and hydrological properties of the rock matrix are measured in laboratory.

The results were presented from the laboratory experiment, i.e. porosities and sorptivities, as well as the results from the field imbibition experiment.

TEST CASE 13

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

Experimental Setup

This test case deals with flow and transport at high salt concentrations. The experimental setup is a two-dimensional column with the dimensions 0.6 m × 1.25 m × 0.01 m, filled with glass beads. Fresh water and salt water is circulated through the column and the pressure head and salt concentration are measured at different locations in the column. The duration of a displacement experiment is from 2 to 5 hours.

Two sets of experiments have been carried out, one at low salt concentrations to estimate the 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.

Analyses by the Project Teams

The Project Team from GSF has restricted their work to one-dimensional advection-dispersion modelling of the experiment. The dispersion length was determined to be 0.8 mm and the porosity in different regions of the column seemed to vary between 0.35 and 0.47. They used a one-dimensional finite difference code CHET, that had been checked against the SUTRA code. The CHET code was used mainly because the calculation times were far less than for similar calculations with other available codes (SUTRA, SWIFT, CFEST). For the low concentration experiments the steepness of the breakthrough curves were predicted quite well, in contrast to the breakthrough times which gave wrong results. For the high concentration experiments both the steepness and the breakthrough times were predicted badly. The dispersion length seemed to become smaller with increasing concentration. For the time being, the dispersion length had been considered as a property of the porous medium. At rather high salt concentrations, however, an additional possible dependence on fluid properties might help to more correctly simulate the experimental breakthrough curves more correctly.

The Project Team from BGR had made two-dimensional advection-dispersion calculations. The dispersivity was estimated at $1 \cdot 10^{-3}$ m, the porosity varied between 0.40 and 0.44, and the permeability was fixed to $1.7 \cdot 10^{-10}$ m^2. The slopes of the numerically approximated breakthrough curves for the low concentration experiments agreed closely with the measured curves. For the high concentration experiments the measured curves turned out to be much steeper than the calculated curves. In the calculations, the viscosity had been constant and the density had been a linear function of mass fraction. As a parameter variation the employed finite element code SUTRA was modified to include non-linear functions of mass fraction for both the viscosity and density. However, this had only minor influence on the breakthrough curves in the lower part of the column and no influence higher up in the column. Nor did the effect of varying the transversal dispersivity between the value of the longitudinal dispersivity and zero influence the behaviour of the breakthrough curves. On the other hand, a decrease in time-step strongly affected the slopes of the breakthrough curves. The need to use smaller time-steps led to the decision to shift to one-dimensional calculations, mainly to decrease the CPU times needed. The one-dimensional calculations gave good agreement between measured and calculated breakthrough curves for the low concentration experiments. For the first 0.4 m of the column, the simulations of the high concentration experiments gave good agreement with the measured breakthrough curves only if the dispersivity were decreased to 10^{-4} m.

The Pilot Group from RIVM had earlier performed calculations with the finite element code METROPOL and obtained reasonable agreement between measured and calculated breakthrough curves in the bottom part of the column (inflow side) for low concentration experiments with the following parameter setup: porosity 0.38–0.42, permeability $1.7 \cdot 10^{-10}$ m^2, and dispersivity $5 \cdot 10^{-4}$ m. The simulations of the high concentration experiments showed much more dispersion than observed in the experiments. In parameter variations the dependence of dispersivity on concentration was investigated in advection-dispersion calculations performed with the one-dimensional computer code SPRINT. It was concluded that the linear Fickian-type relation is unable to simulate the high concentration experiments. Applying a non-linear dispersion theory, where the concentration gradient is a quadratic expression in the flux of salt, made it possible to successfully simulate all experiments.

TEST CASE 14a and b

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany. (Pilot Group Leader: K. Schelkes, BGR)

Experimental Setup and Scales

This test case is based on two experiments performed in similar geological environment in sediments above the Gorleben salt dome but on different time and space scales, a pumping test in highly saline groundwater (Test Case 14a) and movement of highly saline groundwater under natural gradient conditions in an erosional channel crossing a salt dome (Test Case 14b).

The Gorleben salt dome is located in the northern part of Lower Saxony in 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. Sub-glacial erosion channels cross the dome at some places. The groundwater gets 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 has been 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 available. The parameters observed continuously during the tests were e.g. electrical conductivity in observation wells and amount of water pumped.

Test Case 14b, concerns flow in one of the sub-glacial erosion channels crossing the salt dome. The area to be modelled is about 2–3 km × 15 km. The possible validation aspects are firstly to describe the present regional groundwater flow situation, and after that either to simulate the next thousand years or to start with fresh water and try to extrapolate the present situation regarding salinity variations. At a later stage of the INTRAVAL Project, transport calculations based on a density dependent flow system could be included, using information regarding carbon-14 concentrations in water samples.

The data sets for these Test Cases are planned to be available in spring 1990. Due to delay of disseminating data, very few or no Project Teams will have the time to perform any modelling within INTRAVAL Phase I. It has therefore been proposed to transfer this test case to the anticipated next Phase of the INTRAVAL project.

Finalisation of INTRAVAL Phase 1

In the agreement for the INTRAVAL project, a time period of three years was foreseen for the project. The possibility of an extension of the project to cover an additional three year period was however indicated.

INTRAVAL Phase 1 started in October 1987 and the first phase of the project is now close to finalisation. The last workshop and Coordinating group meeting will be held during autumn 1990.

Most of the work with the analysis of the test cases is now finalised or is in draft form. However, since some of the definitions of the cases have been completed rather late, there are some test cases that have not yet been analysed by other Team than the Pilot Group. Also, because of constraints in terms of man-power limitations, the analyses of the test cases dealing with laboratory scale experiments are more complete than the analyses of the field experiments. In particular, the natural analogue studies have not been fully utilised. During the second Phase of INTRAVAL which is now being considered, the Teams would get the opportunity and time to analyse these remaining test cases.

The achievements from the first three-period of INTRAVAL will be documented in a summary report as well as in a series of technical reports, one report for each or possibly a few closely connected test cases. In addition, a report will be prepared that describes the experiments behind the test cases in detail.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 1). An editor has been appointed for each test case. The editors will have the responsibility to compile the test case analyses provided by the Project Teams, which have worked with the test case. The report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. The technical reports are planned to be published in the spring 1991. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report is planned to be published late 1991.

Table 1. Working groups for finalisation of the technical reports.

Working group	Test cases[1]
1	1a, 1b, 2, 9
2	4, 5
3	7, 8
4	10, 11, 12
5	13
6	6

1) Too few analyses have been performed to prepare a technical report for Test Cases 3 and 14.

INTRAVAL Phase 2

Since it has been decided to start planning for the optional three year period of the INTRAVAL Project, the INTRAVAL Secretariat has began to compile background material for a decision on this matter in the INTRAVAL Coordinating Group.

The overall objectives of a Phase 2 will be similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process. This process includes several steps which can be described e.g. as follows:

1. Identification of validation aspects of relevance for the performance assessment.

2. Understanding and research. Without proper understanding of the processes and system structures involved, there could be no validation. A thorough understanding represents the major part of the validation.

3. Comparison of theory and model calculations with experiments. This is to study how well we are able to predict or simulate experimental results quantitatively. Any discrepancy may be due to parameter uncertainties, statistical nature of the system or lack of understanding. The agreement between the model results and the experiments should be consistent with the understanding of the parameter uncertainties and other statistical properties of the system.

4. Peer review and public scrutiny. It is important to have the work published in the open literature, both to receive the benefits of anonymous technical review and to open it to public scrutiny.

A model, including the conceptualisation and the computer code, can be validated either with respect to a process or a site-specific system. For a process, a process is first identified and conceptualised and coding is performed based on this conceptualisation. The model is then applied to an appropriate experiment and its results compared with measurements. If the calculations compare well with the experiment with due consideration given to parameter uncertainties etc., we can state that the model is validated with respect to this specific process. A site-specific system, on the other hand, may be composed of a number of processes and structures, that the building blocks of the system. Once the building blocks are identified, a model or group of models may be used to simulate and make comparisons with field observations. If successful, the group of models is said to be validated with respect to this particular site, within a range of applications determined by the range of field observations studied.

Although INTRAVAL has the ambition to cover both processes and site specific systems, the emphasis of the work in Phase 1 has been on the process identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the process identification issue, it appears to be a natural development to shift the focus in Phase 2 towards structure identification. This issue is more complicated than the process identification, because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for a laboratory experiment.

The selection of test cases for Phase 2 has been discussed in two ad-hoc meetings with VOIC and the Project Secretariat during the autumn of 1989. One conclusion of these meetings was that as a consequence of the shift of emphasis towards the structure identification issue, Phase 2 should deal mainly with field experiments and natural analogue studies. Information from laboratory experiments should be regarded primarily as supporting data and should not form the principal basis for autonomous test cases. Another conclusion of the meetings was that the number of test cases should be much reduced compared to Phase 1 in order to reduce the risk for dilution of effort. Test Cases proposed for Phase 2 were presented at the Workshop in Las Vegas and it was decided by the Coordinating Group that detailed write-ups should be prepared for nine experiments until the next Coordinating Group meeting, in the autumn of 1990, when decisions about Phase 2 will be taken.

Test cases proposed for INTRAVAL Phase 2

Here follows a short introduction of the test cases proposed for INTRAVAL Phase 2. Many of the proposed test cases are continuations of test cases from Phase 1, but there are also three completely new experiments.

Flow and tracer experiments in crystalline rock base on the Stripa 3D experiment, Sweden

The Stripa 3D experiment is included in Phase 1 as Test Case 4. The intention for Phase 2 is to further analyse the Stripa 3D experiment. An extended set of complementary data will become available since much additional information has been gathered on fracture statistics, hydraulic testing data as well as on water chemistry in what is called the 'site characterisation and validation' program. A new drift has been excavated near the old 3D drift and instrumented with plastic sheets and other water collection devices. Furthermore, channeling experiments in individual fractures are being performed providing data on the variability of hydraulic transmissivities and fracture apertures over 2 m lengths along 5 fractures. Tracer tests between two holes in the same fracture plane are also being performed.

Finnsjön tracer experiments, Sweden

This experiment is included in Phase 1 as Test Case 5. Of the three experiments performed so far, interference tests, radially converging tracer experiment and dipole experiment, only data from the radially converging test have been used during INTRAVAL Phase 1. For Phase 2 the coupling of all three experiments performed should be investigated. This would mean an increase in geometrical scales to distances between 150 and 1500 meters. Other objectives for INTRAVAL Phase 2 may be incorporation of existing laboratory data from core samples of the fracture zone. The data can also be used for predictions of a proposed natural gradient experiment.

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany

This experiment is included in INTRAVAL Phase 1 as Test Case 14. Unfortunately experimental data has not yet been made available and it is therefore proposed to transfer this test case into Phase 2.

Radionuclide migration in the weathered zone of the Koongarra uranium deposit, Australia

This natural analogue is included in Phase 1 as Test Case 8. The analyses of the data base from the Alligator Rivers Analogue are still in a preliminary stage and the number of project teams that have tackled this test case during Phase 1 is limited since a broad and innovative approach is needed for the analysis.

Poços de Caldas

The Poços de Caldas analogue is included in Phase 1 as Test Cases 7a (redox-front movement) and 7b (colloid transport). Since the data have not yet been made available to the Project Teams it is proposed to transfer the part concerning the redox-front movement and uranium movement to Phase 2. The part concerning colloid transport will not be continued since no evidence of colloid movement has been found in Poços de Caldas.

Las Cruces trench, USA

This experiment is included in INTRAVAL Phase 1 as Test Case 10. Since additional experiments will be performed at the site, it is proposed to include the experiments at Las Cruces Trench as a Test Case in INTRAVAL Phase 2. In Phase 2, models calibrated against data from the already performed experiments can be used to predict water flux and solute transport in the experiments to be carried out.

Apache Leap Tuff site, USA

This experiment is included in Phase 1 as Test Case 11. The Phase 2 exercise will be a continuation. Data from experiments performed at different scales, i.e core, block and field, are already available, and additional experiments of similar type will be performed.

Migration of tritium in clay at Mol, Belgium.

A piezometer nest is emplaced in a single bore hole drilled horizontally from the gallery of the Hades underground research facility at Mol, Belgium. The nest is equipped with several filters at 1 m intervals through which tritiated water is injected. An additional five piezometer nests have been installed for radionuclide injection, but these have not yet been loaded. Two of these are intended for determination of anisotropy in the clay (perpendicular and parallel to the bedding of the clay). The data from these additional tests will be made available to INTRAVAL as they arrive.

The experiment was originally designed to make in situ determinations of migration parameters for comparison with parameter values determined in the laboratory. The spatial scale of the experiments is in the order of 2 m migration distance involving about 30 m^3 of clay. The time required for an experiment is in the range of 1–4 years. The first tritium injection was carried out two years ago. The spatial scale of the complementary laboratory experiments is in the order of a few centimeters and the time scale in the order of weeks. The validation aspects of the experiments are coupled to radionuclide migration in clay and the scale dependence of the migration parameters.

Tracer experiments at the Twin Lake aquifer, Canada

The proposed test case comprises 20, 40, and 260 m natural gradient radio-tracer experiments performed in a sandy to gravel aquifer at the Twin Lake site. The experiments were performed in 1982, 1983 and 1987–1988. The longest experiment ran for about a year. The spatial separation of the measuring points are about 5 m in the flow direction and 0.5-1 m in the direction perpendicular to the flow. As a result of the 1982–1983 experiments there exists approximately half-a-million data points on the spread of iodine. A very large amount of hydrogeological and geophysical data have also been collected. New experiments are planned for the autumn 1990.

Sand and gravel aquifers will not be considered for radioactive waste disposal. In that sense, this test case is of limited relevance for validation with regard to radioactive waste disposal. However, the test case could potentially provide a set of detailed data, which could be used for validating the necessary conditions generally assumed in transport models, i.e. to answer the question whether a general transport model can predict the results of any field experiment, where there is little uncertainty in the data.

Brine Flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

Field experiments are conducted in the underground facility at the Waste Isolation Pilot Plant (WIPP) site in the southeastern New Mexico. The underground facility lies 655 m below ground surface within bedded evaporites, primary halite, of Permian Salado Formation. The WIPP, currently scheduled to open late 1990, is to be a permanent repository for low-level and transuranic wastes generated by the United States' defense programmes.

This test case is based on experiments performed to determine the nature of brine flow through bedded evaporites of the Salado Formation. The experiments are designed to provide different types of data with which to evaluate whether Darcy's law correctly describes the flow of brine through evaporites, or whether a different type of model, perhaps one involving creep-driven flow, is more appropriate. Three principal types of measurements are being made: brine-inflow rates, pore-pressures, and permeabilities, at a number of scales ranging from 4.5 cm diameter boreholes to 3 m diameter rooms. The test case is concerned with the validation of conceptualisation and models used in test interpretation and in the modelling of brine inflow to the repository. The objectives are to integrate the results of all the experiments in a comprehensive and consistent model of brine flow through evaporites.

The experimental programme is currently scheduled to continue through May 1992. In late 1990 or early 1991, the programme may expand to include gas threshold-pressure testing and tracer testing through a fractured anhydrite bed.

OECD/NEA Brochure

OECD/NEA and the Secretariat are preparing a brochure describing the INTRAVAL Project. The brochure will be printed before the upcoming autumn.

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 Inspectorate (SKI) acts as Managing Participant. 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 expenses, 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.

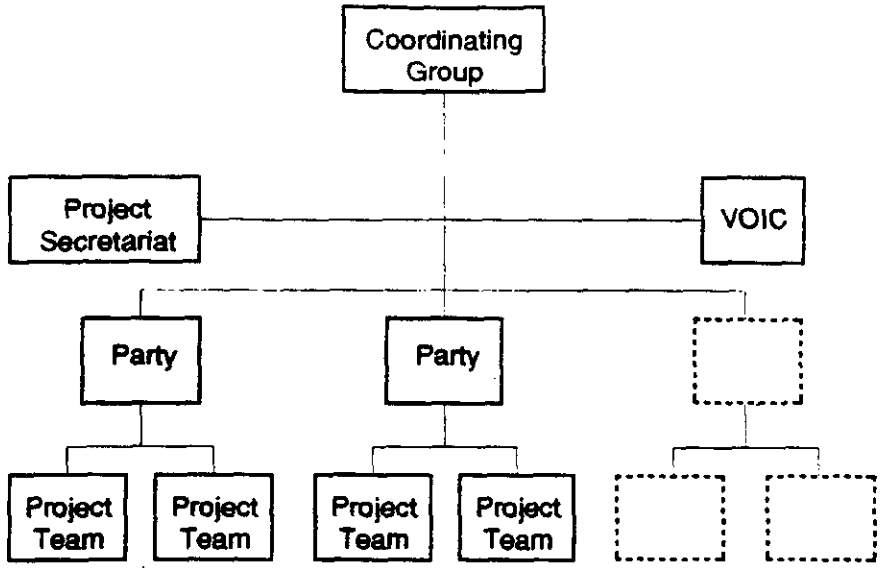

Figure 1. INTRAVAL Organisational Chart

Managing Participant:	SKI
Coordinating Group	
Chairman:	A. Larsson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	K. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	K. Andersson, SKI
	J. Andersson, SKI
	L. Dagerholt, KEMAKTA
	M. Ericsson, KEMAKTA
	B. Grundfelt, KEMAKTA
	D. Lever, HMIP/DoE, Harwell
	K. Pers, KEMAKTA
	K. Skagius, KEMAKTA
	C. Thegerström, OECD/NEA

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Swedish Nuclear Power Inspectorate, Sweden K. Andersson	(SKI)	The Royal Institute of Technology J. Andersson	(SKI/KTH)

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	Intera-Exploration Consultants Ltd. (ECL) D. Hodgkinson
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	Massachusetts Institute of Technology (MIT) L. Gelhar
	Pacific Northwest Laboratories (PNL) G. Gee
	Sandia National Laboratories (SNL) P. Davis
	Texas Bureau of Economic Geology (TBEG) TBEG, Dept of Hydrology and Water Resources B. Scanlon
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	Center for Nuclear Waste Regulatory Analysis R. Ababou	(CNWRA)
Organisation for Economic Cooperation and Development/ Nuclear Energy Agency (OECD/NEA) Member of Secretariat: C. Thegerström		
International Atomic Energy Agency (IAEA) S. Hossain (observer)		
State of Nevada L. Lehman (observer)		

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

Three sets of experiments have been carried out with iodine, deuterium and tritium as tracers. The experiments are *in-diffusion, through-diffusion* (vertical and horizontal) and hydrodynamic dispersion (vertical and horizontal). The transport direction vertical or horizontal refer to the 'in-situ' location of the sample. The length scales of the experiments are up to a few centimetres and the duration is up to a few months.

In the in-diffusion experiments, the tracer was allowed to diffuse axially into the sample from two sides. Six or seven replicate clay samples were loaded into diffusion cells (Figure 1) and both measurement cell and reservoir for each cell were filled with simulated clay water containing NaI and deuterated water.

The cells were dismantled in turn, and the amount of tracer that had diffused into each sample was determined. These data give an indication of the porosity accessed by the tracer at different times, and the diffusivity.

The vertical through-diffusion experiments were performed in the same type of cell as used in the in-diffusion experiment (Figure 1). The sample was loaded into the cell, and the reservoir was filled a simulated clay groundwater containing the tracers. The measurement cell was filled with simulated clay groundwater only. The increase in tracer concentration in the measurement cell was monitored. The breakthrough curve gives information about the porosity and the vertical diffusion coefficient.

In the horizontal diffusion experiment the sample was sealed into a large diffusion cell (Figure 2). A solution containing the tracers was circulated against one face of the sample. The other face of the sample was in contact with a solution initially free from the tracers. The increase in concentration of tracer in the encasement cell was monitored as a function of time. Information on the porosity and the horizontal diffusion coefficient is obtained from the breakthrough curves in these experiments.

For measurement of the vertical component of the hydrodynamic dispersion a high pressure stainless steel cell was used (Figure 3), and the large diffusion cell (Figure 2) was used for horizontal measurements. The experiments were carried out in a way similar to the through-diffusion experiments except that a pressure gradient was maintained over the sample. The breakthrough curve into the measurement cell gives in these experiments information on the permeability, porosity and dispersivity.

In addition to the tracer experiments hydraulic conductivity experiments have been performed. Results from these experiments are given as hydraulic conductivity as a function of effective consolidation stress. Other complementary experiments performed are:

- determination of porosity and moisture content by an oven drying technique,
- determination of size and distribution of the porosity, and of the accessibility of the pore space to deuterated water by a small angle neutron scattering (SANS) technique,
- determination of the pore size distribution by the mercury intrusion porosimetry technique,
- determination of the mineralogical content of the clay samples and of the size fractions of individual mineral phases by X-ray Diffraction analysis.

Summary of Available Data:

- breakthrough curves from through-diffusion experiments and from the hydrodynamic dispersion experiments
- porosity of the sample accessed by the tracer after different times in the in-diffusion experiments
- results from complementary experiments such as moisture content and porosity, size and distribution of the porosity, pore size distribution, hydraulic conductivity as a function of stress etc.
- experimental conditions such as sample dimensions, initial concentrations, volumes, flow rates etc.

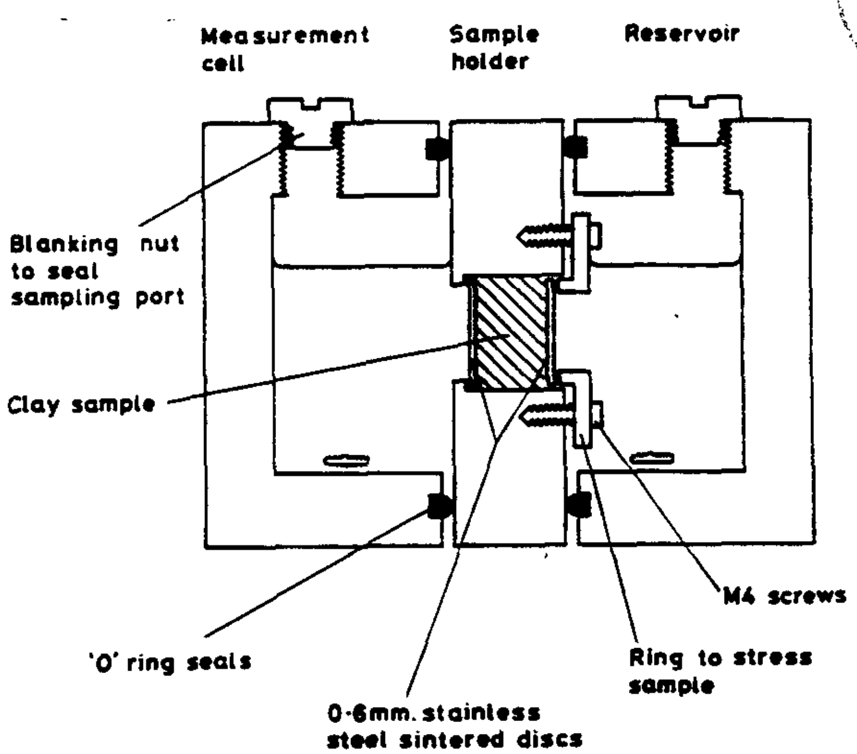


Figure 1. Diffusion cell used in the in-diffusion experiments and in the vertical through-diffusion experiments (Test Case 1a).

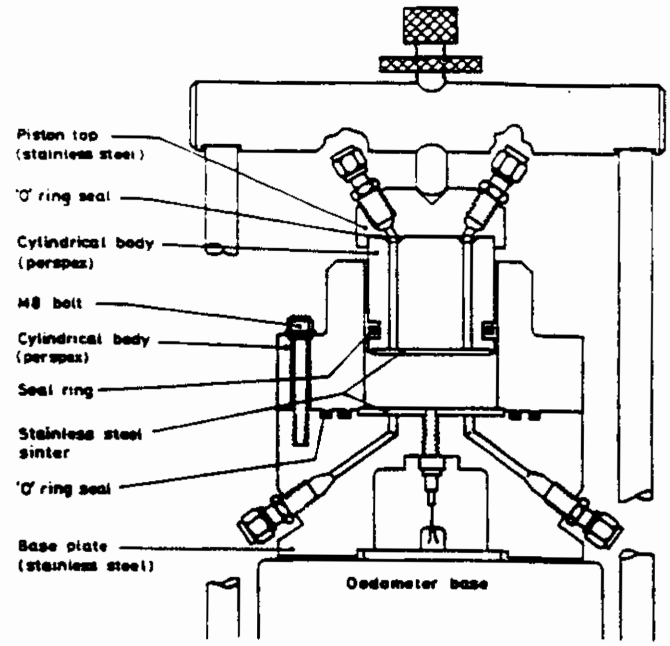


Figure 2. Large diffusion cell used in the horizontal through-diffusion experiments (Test Case 1a).

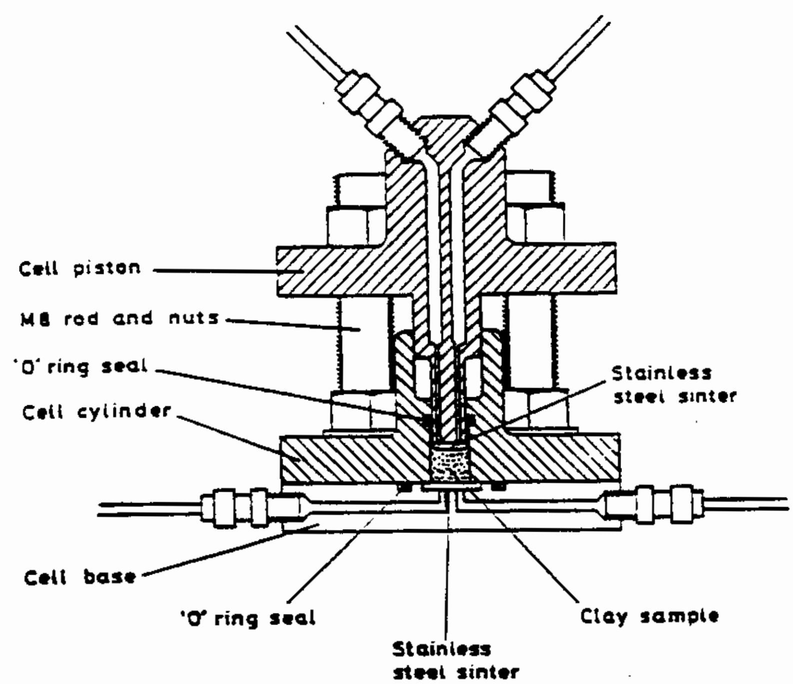


Figure 3. Cell used in the vertical permeation experiments (Test Case 1a).

TEST CASE 1b

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

Introduction

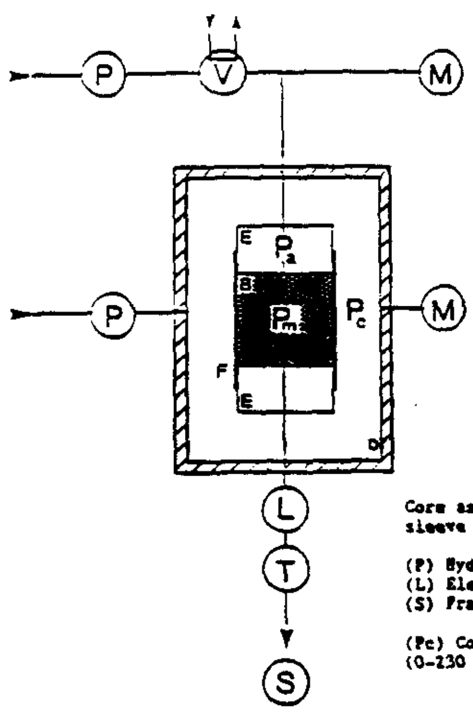
The aim of this test case is to characterise hydraulic and tracer transport properties of small samples of crystalline rock. The experiments were performed at PSI, Switzerland.

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 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



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 the pressure infiltration apparatus (Test Case 1b).

were then autoradiographed to yield information on flow paths and sorption sites.

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 Figure 5.

Non-sorbed and moderately sorbed tracers

Tests with the non-sorbed tracers tritiated water and lignosulphonate ions and the moderately sorbed ions strontium and caesium were performed in a 30 cm long drill core with a diameter of 20 cm. Tests with the non-sorbed tracers tritiated water, iodine, bromide and lignosulphonate ions and the moderately sorbed 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).

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,
— diffusivity of iodine and tritiated water in granite.

Actinides

The diameter of the drill cores used in these experiments was 40 mm and the lengths 80-105 mm. Before each experiment artificial groundwater was pumped for 2 to 3 days through the drill core to equilibrate the fissure surface. The water flow was characterised by feeding a solution of non-sorbed NaLS 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 drill core 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.

Summary of Available Data:

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

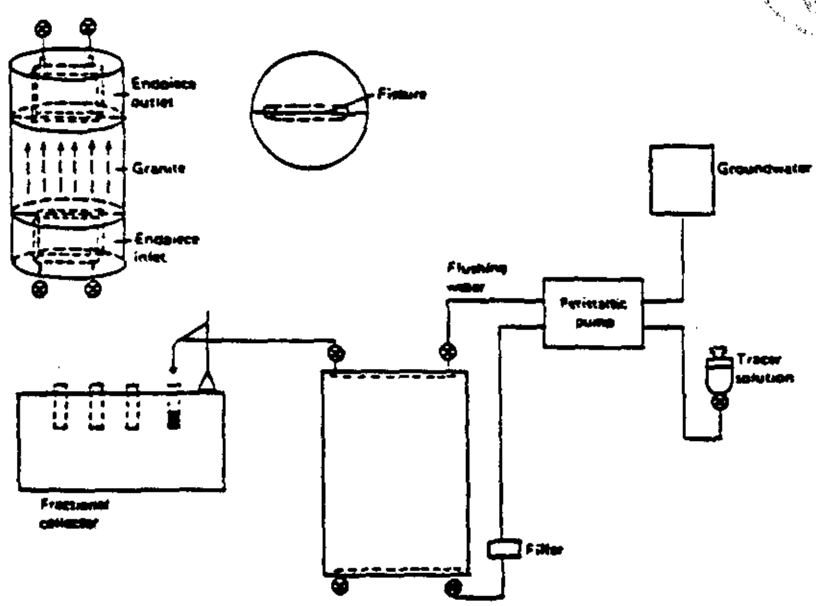


Figure 5. Experimental setup (Test Case 2).

TEST CASE 3

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

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.

General Description

Two recirculating nonreactive, pulse-injection, ground water tracer experiments have been performed at the DC-7/8 site on the Hanford reservation, Figure 6, 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 non-uniform 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 $gal \cdot min^{-1}$ (7.5-13.0 $l \cdot min^{-1}$) 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 $gal \cdot min^{-1}$ (3.8 $l \cdot min^{-1}$) 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.

TEST CASE 4

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment performed within the International Stripa Project.

Introduction

This test case is based on the three dimensional 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.

General 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

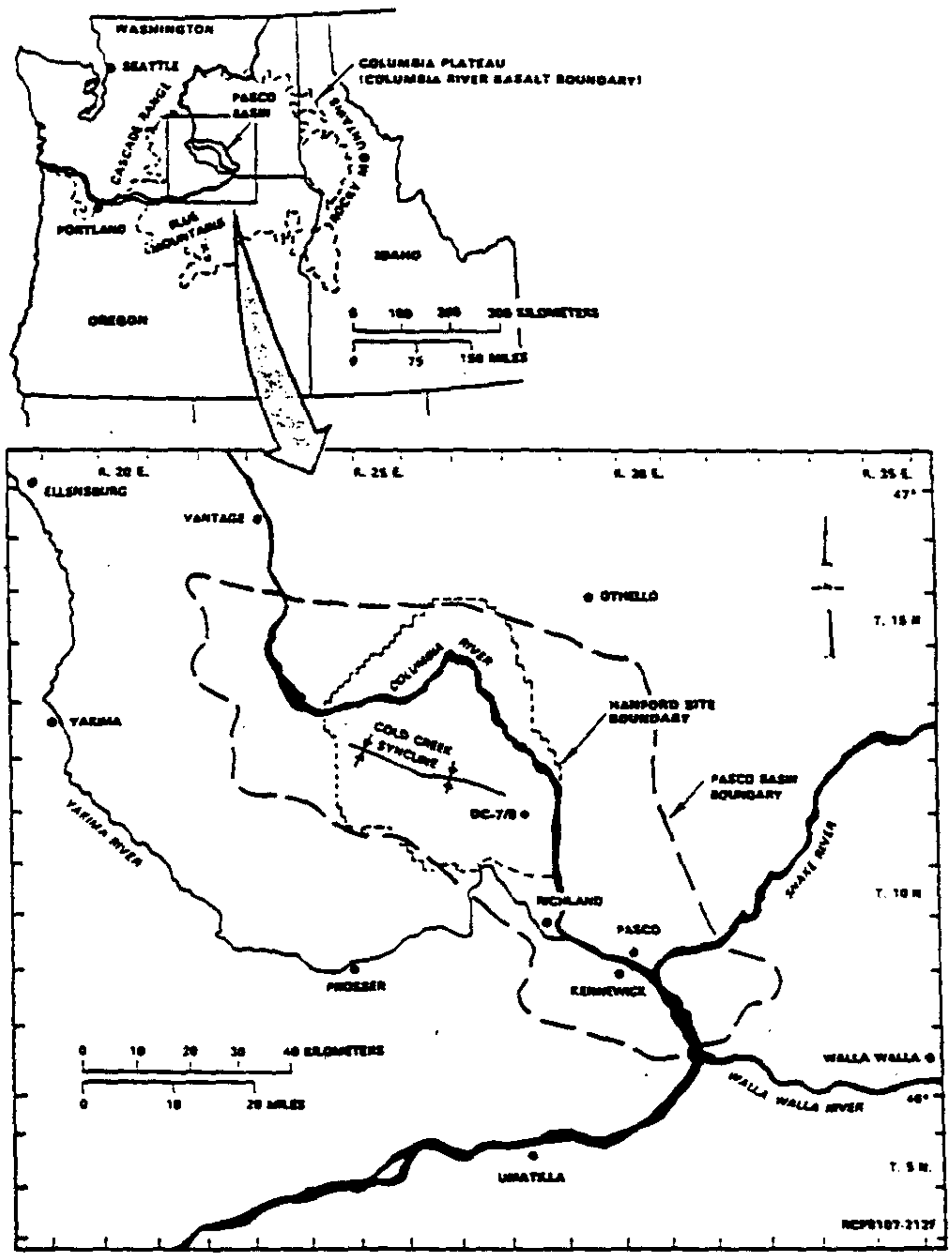


Figure 6. Location of the Columbia Plateau, Hanford Site, and the DC-7/8 Test Site (Test Case 3).

for injection of tracers have been drilled upwards with lengths of 70 m (Figure 7).

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 1000 and 2000 ppm, and the different flow rates varied from 1 to 20 $ml \cdot h^{-1}$. 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

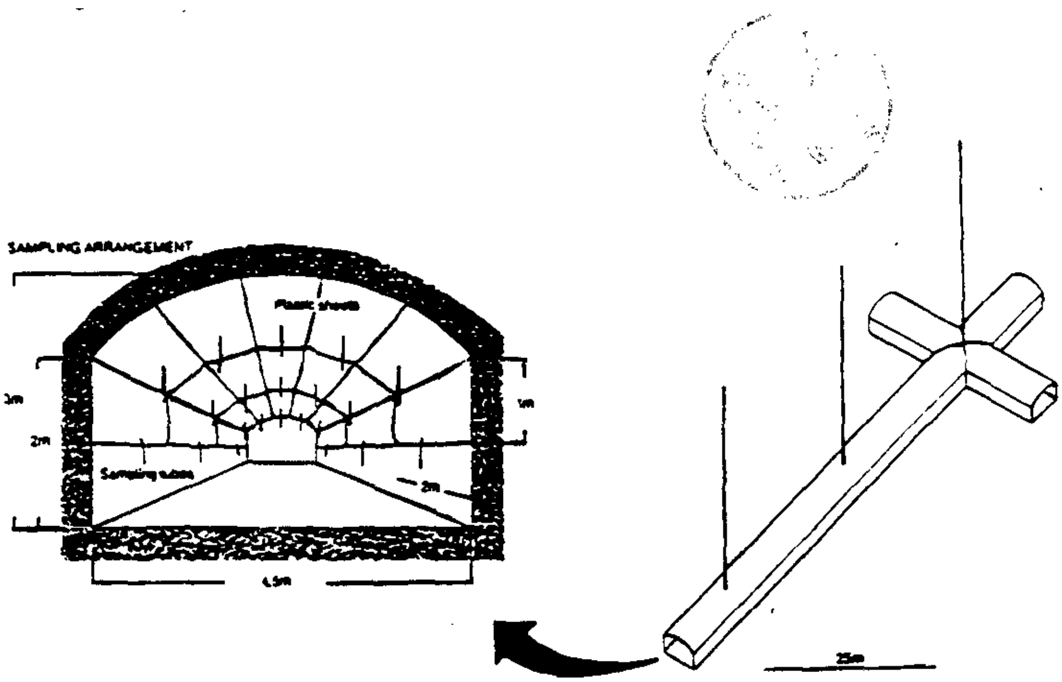


Figure 7. The experimental drift. The location of the tracer injection holes is indicated (Test Case 4).

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.

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 flow rates,
— hydrostatic pressures,
— diffusivity and sorption data
— daily logs.

TEST CASE 5

Tracer experiments 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.

So far two tests in different geometries have been performed in the major subhorizontal fracture zone (zone 2) at the Brändan area (Figures 8 and 9). The fracture zone is about 100 m wide, but most of the flow appears to take place in three subzones. The first tracer test was carried out with a radially converging flow geometry and the second with a dipole flow.

Radially Converging Test

In the radially converging test tracer injections were made in three peripheral boreholes, BFI01, KFI06 and KFI11 which are situated in different directions from the withdrawal borehole BFI02 (Figure 8).

Totally 11 tracers were injected in three packed-off intervals in each injection hole, 8 of them continuously for 5-7 weeks and 3 as pulses. The tracers used were DTPA and EDTA complexes with rare earth metals, fluorescent dyes (Uranine and Amino G Acid) and two anions (I^- and ReO_4^-).

Tracer breakthrough was registered from all nine injection intervals, with first arrivals ranging between 24-3500 hours. A detailed sampling in the withdrawal borehole indicated good hydraulic interconnections between different parts of the zone.

Summary of Available Data

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

Data available from the radially converging test are:

— tracer breakthrough curves,
— withdrawal and hydraulic head data,
— tracer concentrations in injection intervals,
— groundwater flow rates during tracer injection,
— log of events during the experiment,
— results from detailed sampling in the withdrawal hole.

In addition to this porosities and diffusivities from laboratory measurements on drill core samples are available.

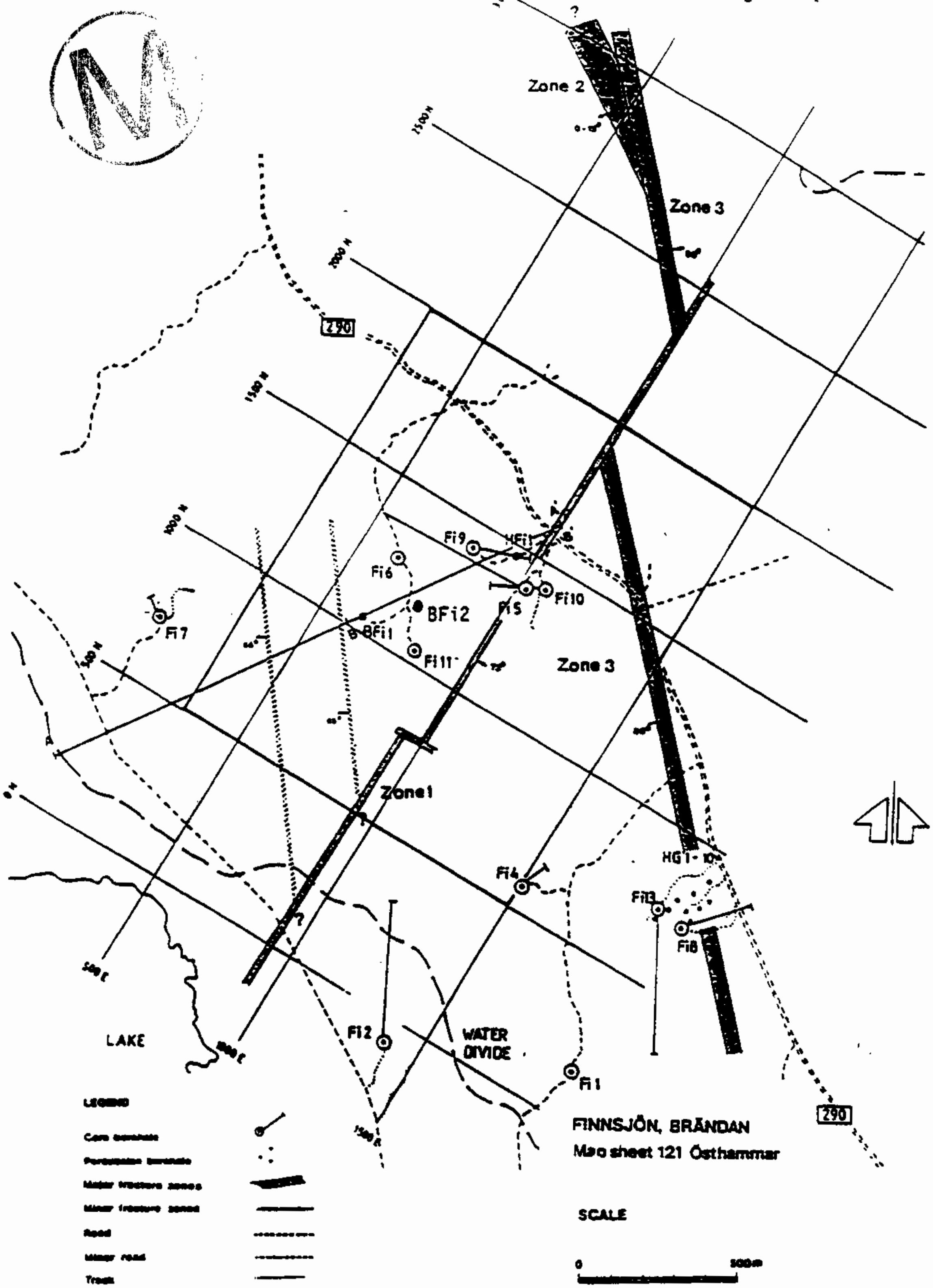


Figure 8. Borehole location in the Brändan area (Test Case 5).

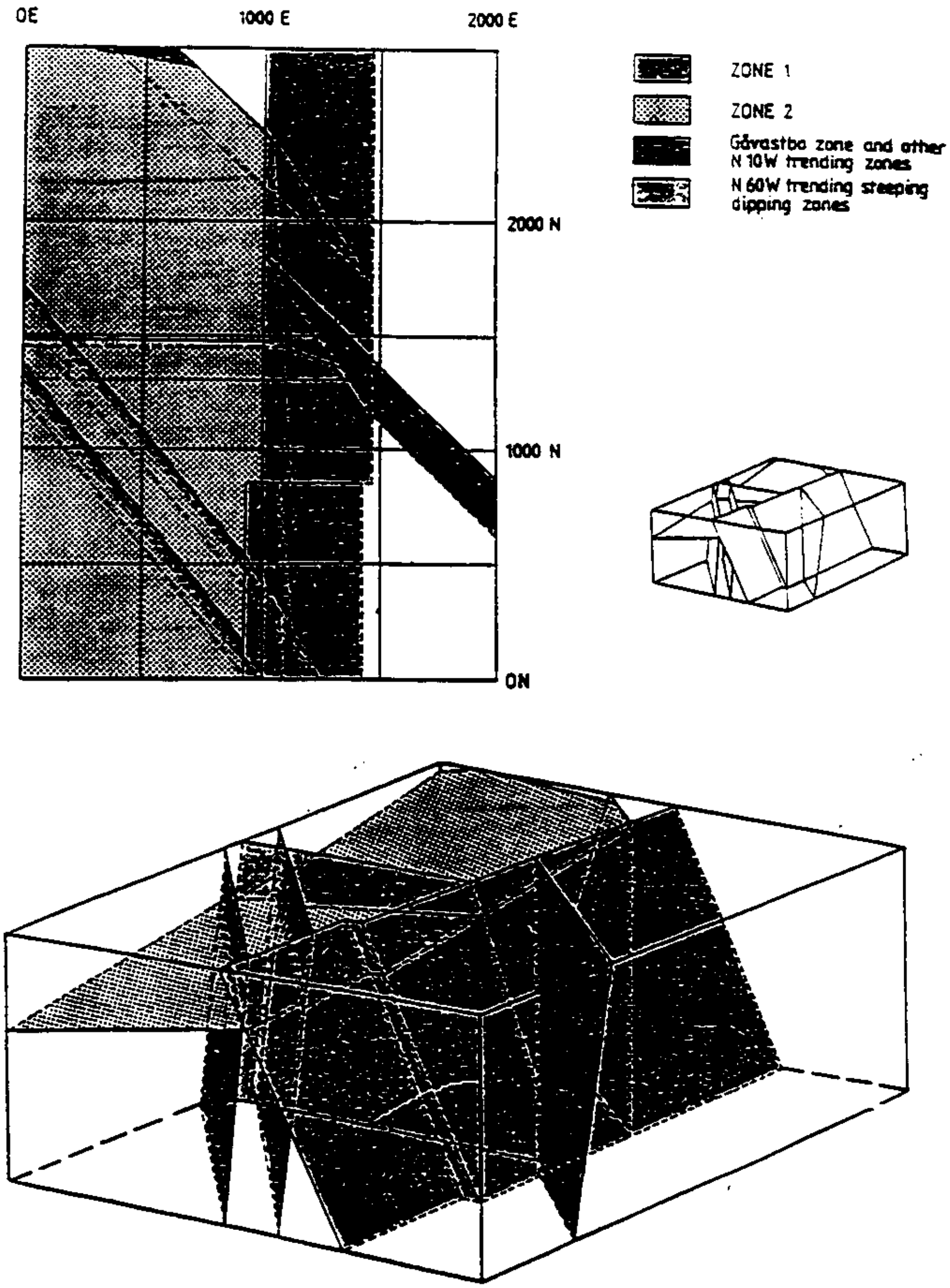


Figure 9. Cross section through the Brändan area showing Zone 2. The location of the profile is shown in Figure 8 (Test Case 5).

Dipole Experiment

The dipole experiment was performed in a recirculating flow field between the boreholes BFI01 (injection) and BFI02 (withdrawal). Only the upper highly conductive interval of zone 2 was used with injection in the same interval as in the radially converging test. Water withdrawn from BFI02 was injected again into BFI01.

Totally 20 different tracers were used, and they were injected into the system as pulses with a duration of 4-8 minutes. The tracers are non-sorbed or sorbed radioactive ions and complexes, and non-active complexes and dyes. In order to study the possible effects of matrix diffusion a macromolecular compound was also injected.

The evaluation of the dipole experiment is presently in progress. Data will be available late 1989.

TEST CASE 6

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland.

Introduction

This test case is based on a synthetic site. Geologic and hydrologic boundaries, and the mean, variance and spatial correlation scales of the model parameters are conditioned with real-world data from the Grimsel Rock Laboratory in Switzerland. The synthetic migration experiment will test the ability of groundwater flow and transport modelling strategies to interpret and characterise transport of tracers, through a large fracture zone on the bases of a sparse number of borehole hydraulic tests, dipole tracer tests and other observations. The test will also include an assessment of the uncertainty in the interpretation and ability to predict based on this uncertain interpretation.

General Description

The site is positioned in the mountainside on a scale of kilometres. Two water bodies bound the site on either side of the mountain. The plane to be studied is an essentially vertical two dimensional fracture. It has been assumed that the tunnels in the area are open to the atmosphere and the potential at their surface is therefore equal to their elevation. Simulated experimental measurements will cover a few tens of meters, and time scales of seconds to weeks.

The generation of the synthetic geosphere has been made in four steps:

— The hydraulic head on the scale of the distance between the water bodies (about 5000 m) has been generated with a finite difference computer program using a 107×47 uniform grid with spacing of 45.5 meters (coarse scale modelling). The effect of the tunnels is taken into account, and the transmissivity is assumed to be uniform throughout the grid. The hydraulic head is considered to be equal to the land or water surface elevation along the top boundaries and no-flow on the other three boundaries.

— The second scale modelling deals with an intermediate scale problem. The domain is 182 x 182 m divided into a regular finite difference grid 513 x 513. The transmissivity field is taken from a 4096 x 4096 fractal data set, based on observed data at the Grimsel site, by arithmetic averaging. Boundary conditions of the hydraulic head on the boundary of the domain are taken from the coarse scale model.

— The finest scale model is represented by a 29.9 × 22.75 m area discretised into 673×513 grid. Bore holes are modelled separately in a radial coordinate system and matched to the rectangular grid. The boundary conditions on the edges of the rectangular domain are specified by the output of the intermediate scale model. The finest level solution is used to simulate the dipole test and to calculate the steady state inflows to the experimental tunnel and boreholes.

— Borehole tests are simulated with a transient model. For the sake of computer run times, the transient hydraulic tests are performed in a grid twice as coarse 337 × 257, giving only minor differences from the finer grid results.

The Parameters Generated are:

— Steady state hydraulic head at closed bore holes.
— Transient and steady state outflow to or from open bore holes and tunnels.
— Response to transient pressure tests in all bore holes resulting from a pressure stress in one bore hole
— Dipole tracer tests between two pairs of boreholes
— Response in tunnels to bore hole tests (increased of diminished flow or appearance of tracer).

Models to include diffusion and geochemical retardation are being developed for a later stage of this test case.

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 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.

The Poços de Caldas region consists 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.

Subproject 1 has been located at the Osamu Utsumi Mine (C-09 Uranium Mine; U with subordinate Th and rare earth elements) and subproject 2 at Morro do Ferro (U, Th, rare-earth elements).

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

TEST CASE 7a

Redox front and radionuclide movement in an open pit uranium mine.

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

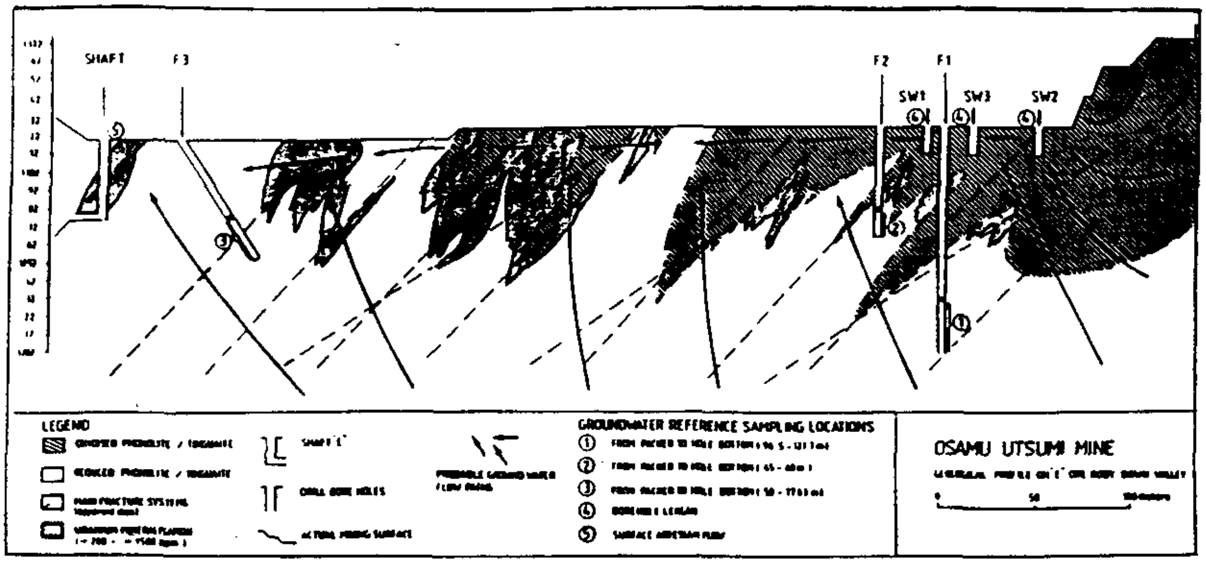


Figure 10. An example of a cross section from the Osamu Utsumi Mine, Poços de Caldas (Test Case 7a).

much further downward than the average depth of the front (Figure 10). 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.

A very large amount of data has been collected from the open pit uranium mine. A complete dataset will, however, not be available until early 1990. 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,

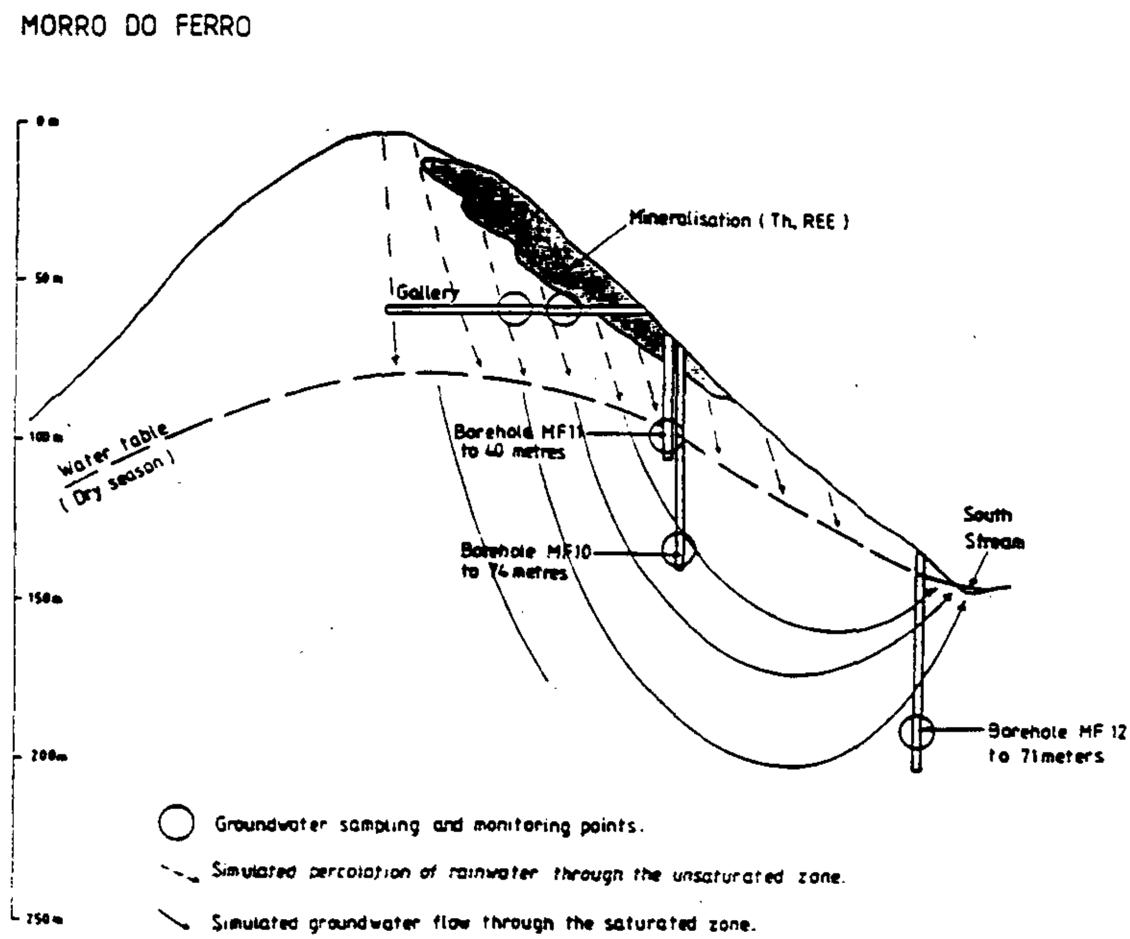


Figure 11. A schematic illustration of the Morro de Ferro site (Test Case 7b).

— 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 7b

Morro do Ferro colloid migration studies.

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 rock is extensively oxidised, but in one borehole a redox front occurs at 35 m, with pyrite occurring in the un-oxidised phonolite below it.

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 (Figure 11). In the valley bottom the water table is at or near the surface, coinciding with seepages or discrete springs.

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 has been monitored to establish a basic data set and any seasonal variability. The groundwater has been characterised regarding major and trace element content, natural series content, rare earth elements, organic chemistry, electrochemistry, etc. Colloidal material has been extracted from these reference waters and characterised for composition, size and Th/REE content. Simple hydraulic testing has been performed to establish the properties of the rock. A complete dataset will be available in the beginning of 1990.

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 (Figure 12). 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 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.

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

Data Collection Activities

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 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. These new data would generally be of a higher quality than much of the previous data that was obtained under other conditions and primarily for other purposes (potential for mining).

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 in progress.

A study of the geomorphology of the area is being made to try to obtain a general idea of the geological and hydrogeological history of the site. Important components to understand are formation of the escarpment, onset of the weathering, influences of erosion/deposition of loose materials, effects of glaciation i.e., changes in sea-level and in climate and precipitation.

TEST CASE 9

Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, 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 ad-

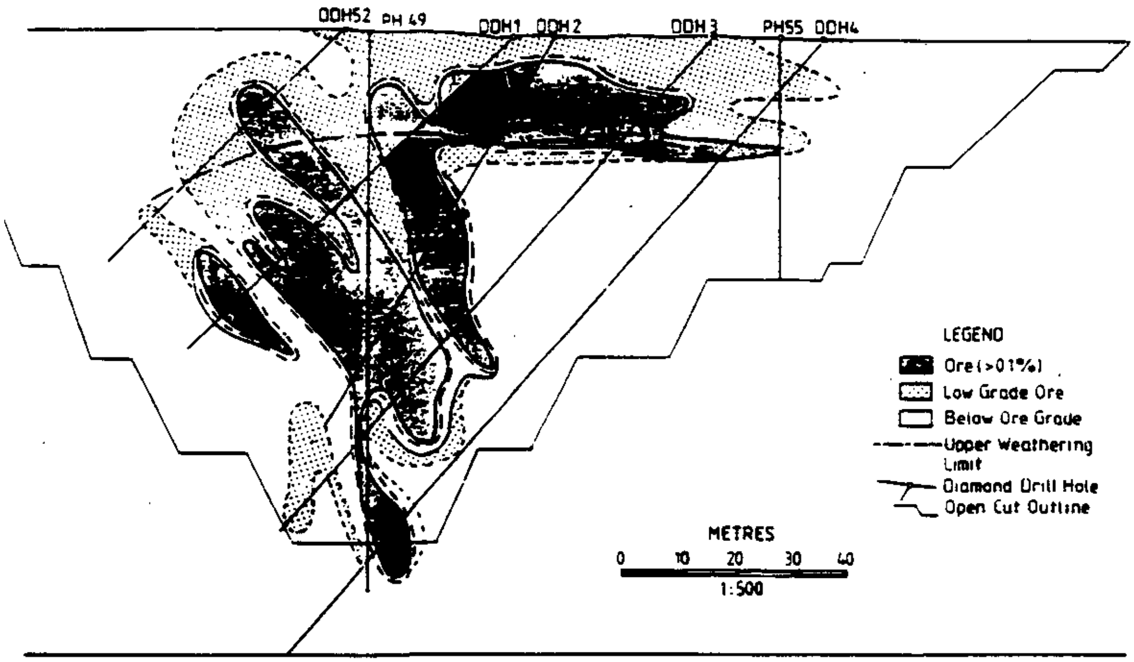


Figure 12. Cross section showing the dispersed zone at the Kongarra deposit (Test Case 8).

dress 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 13.

To determine the longitudinal dispersivity experiments with the non-sorbed 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 was then opened and the flow paths were investigated with alfa-autoradiography. The fracture surface has also been examined with gamma scan.

Summary of Available Data:

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

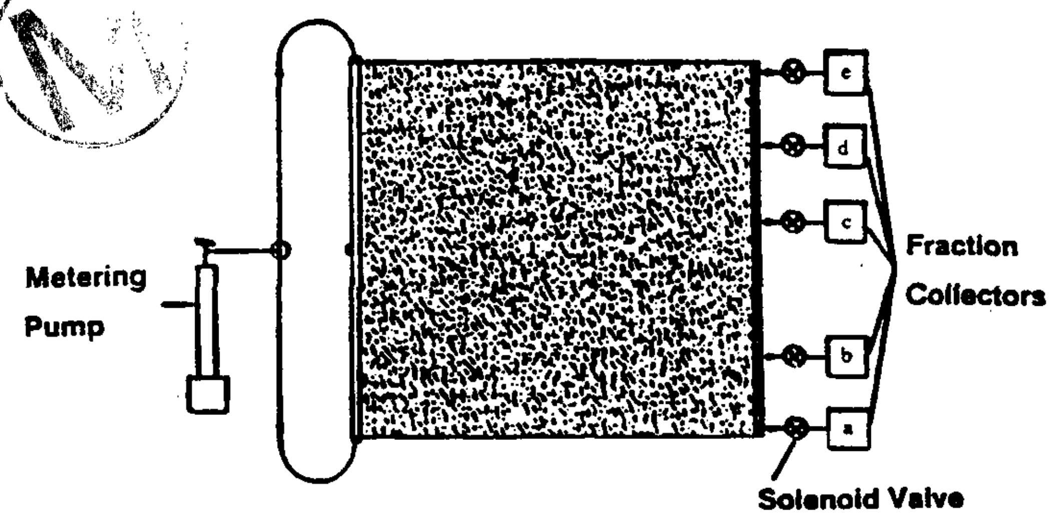


Figure 13. Schematic plan view of the arrangement of the inlet and outlet reservoirs on the large block (Test Case 9).

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.

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 (Figure 14). In the first test water containing a conservative tracer, tritium, has been applied at a controlled rate of 1.76 cm·day-1 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 $cm \cdot day^{-1}$ on the surface at the other side of

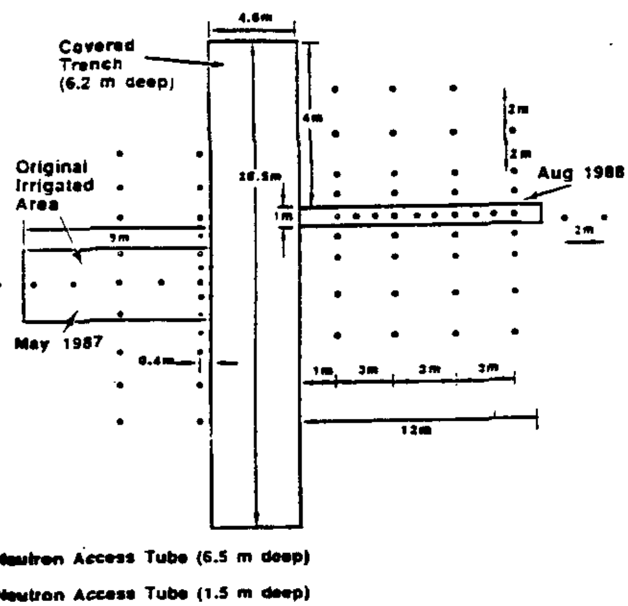


Figure 14. Top view of the trench with irrigated areas (Test Case 10).

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. It includes both field and laboratory experiments. The field experiment is located at the Apache Leap Tuff Experimental Area in non-welded to welded tuff near Superior, Arizona, USA. The laboratory experiments are carried out on larger blocks and on cores from the site. The purpose with the test case is to validate parameters and models relevant for radionuclide transport in fractured unsaturated media against data sets.

Field Experiment

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 (Figure 15). 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.

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.

Block Experiment

Several laboratory experiments have been conducted on blocks containing a single fracture. The blocks were removed from outcrops located near the Apache Leap Tuff Site and subsequently shaped so that the fracture is located through the center of the block (Figure 16).

Preliminary saturated steady-state flow and transport experiments were performed on a block with the dimensions 20 cm x 20 cm x 49.5 cm (block 1). The main purpose was to test and refine the experimental setup as well as test and calibrate the instrumentation.

A transient imbibition experiment was performed on a block with the dimensions 21 cm x 20 cm x 66 cm (block 2). A constant suction was applied at the top of the block and the bottom of the block was left open to the atmosphere. Visual wetting front locations were measured through time.

A series of steady-state flow and transport experiments are currently being performed on block 2. The matrix is held under constant suction at the top and bottom of the block. The fracture has a constant suction applied at the top, and it is open in the bottom, allowing flow to leave the block. Once steady-state flow occurs in the fracture, a pulse of non-sorbed tracer will be applied to the fracture only and the concentration monitored along the fracture and in the fracture outflow.

Core Experiment

A non-welded tuff core measuring 12.72 cm in length and 6.4 cm in diameter was oven dried and then partially wetted to a saturation of 48% with a solution of potassium iodide. The core was then coated with a sealment to prevent moisture or air from leaving the core. The core was also thermally sealed with foam insulation along its length, while a constant temperature (5 and 70°C) was maintained at both ends for a period of 32 days (Figure 17).

During the course of the experiment, temperature and saturation were measured at 1 cm intervals away from the cold end of the core. The final solute concentration along the core was obtained by sawing the core into eight sections and analysing water collected from each section.

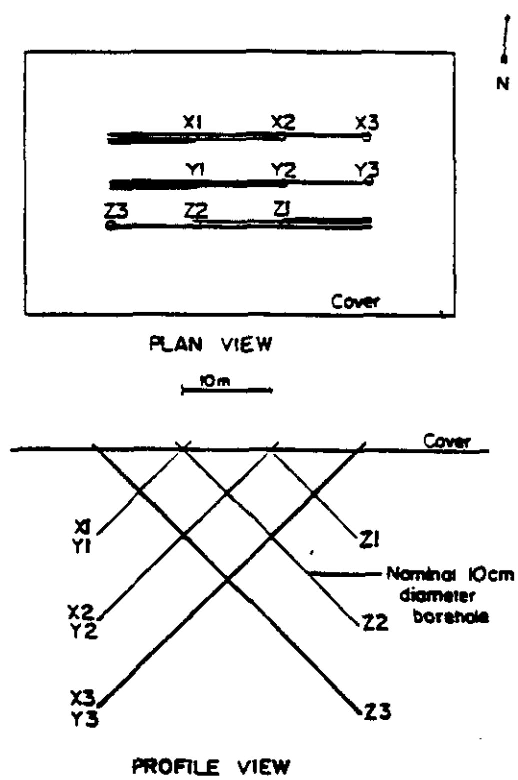


Figure 15. Borehole configuration at Apache Leap Tuff Site (Test Case 11).

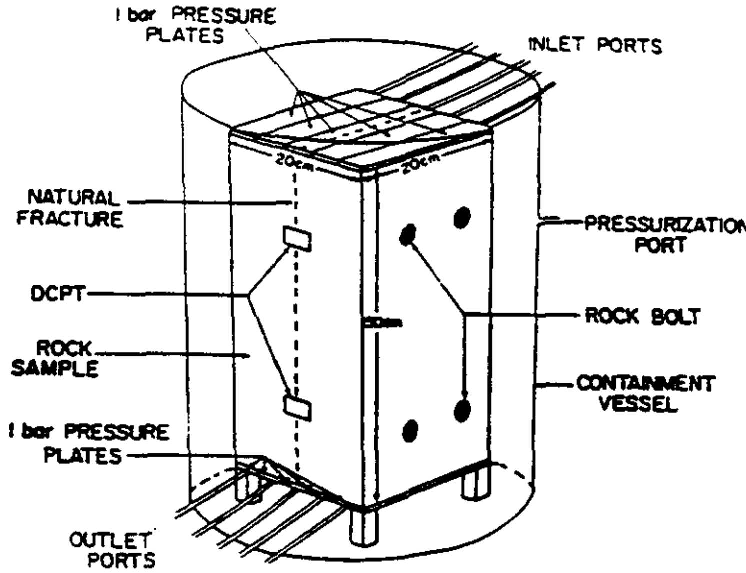


Figure 16. Experimental set-up for unsaturated fracture-matrix flow studies (Test Case 11).

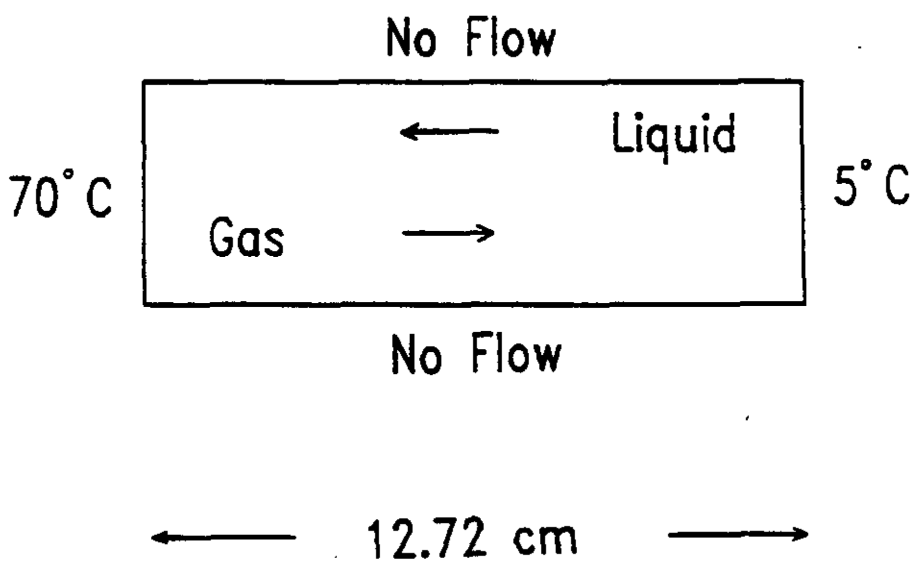


Figure 17. Schematic view of the core experiment (Test Case 11).

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 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.

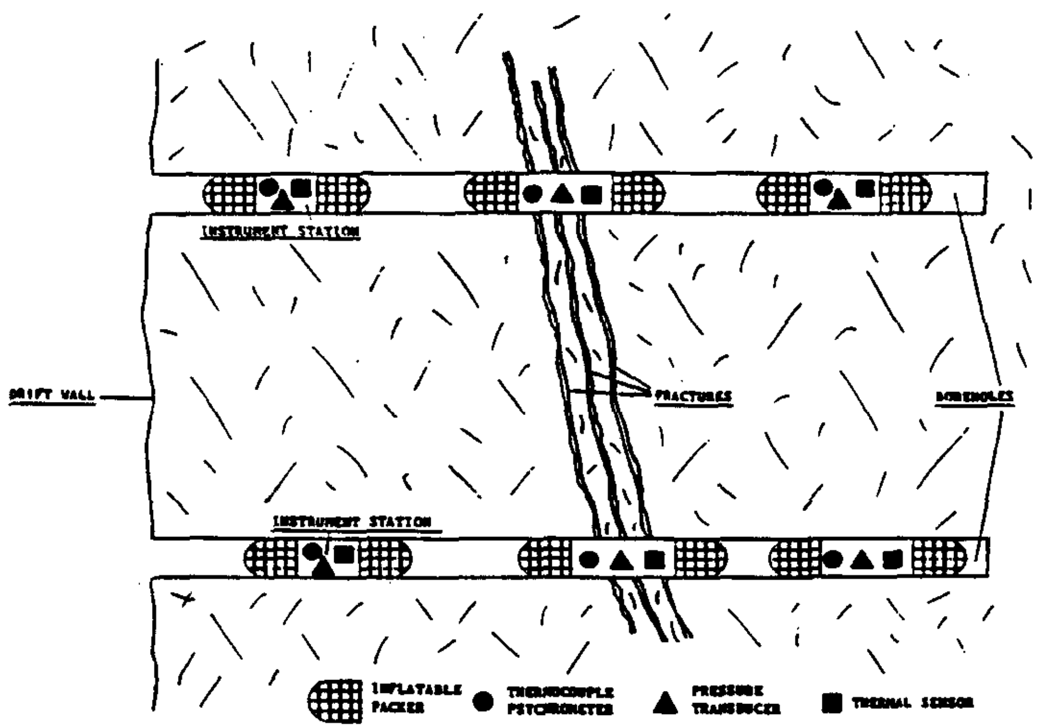


Figure 18. Schematic plan of borehole pair instrumented for long-term monitoring (Test Case 12).

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 (Figure 18). 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 is instrumented. The dry-cored boreholes are instrumented first in order to monitor any crosshole effects caused by the drilling of the wet-cored boreholes. Instrument stations are placed in all four boreholes and will remain in place until the isolated areas of the boreholes have reached equilibration. Each instrument station consists of pressure transducer, thermal sensor and thermocouple psychrometer. Gas-phase tracers are 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 are used to determine the effects of drilling fluids on the hydrologic condition of the core samples. Laboratory experiments are 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 are investigated in a suite of complementary imbibition and moisture-release experiments. These also provide an independent set of transient data set.

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 setup is a column; 0.6 m long, 0.01 m wide and 1.25 m high, filled with glass beads, see Figure 19. Fluid can be circulated through the bed. The pressure head along the bed is 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 have been performed: one set at low salt concentrations to evaluate 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.

Data Available:

- mass fraction profiles (breakthrough curves) for the electrodes
- temperature of the fluid during the experiment
- salt mass fraction in fluid entering the column
- pressure distribution in the column
- total flow rate during the experiment

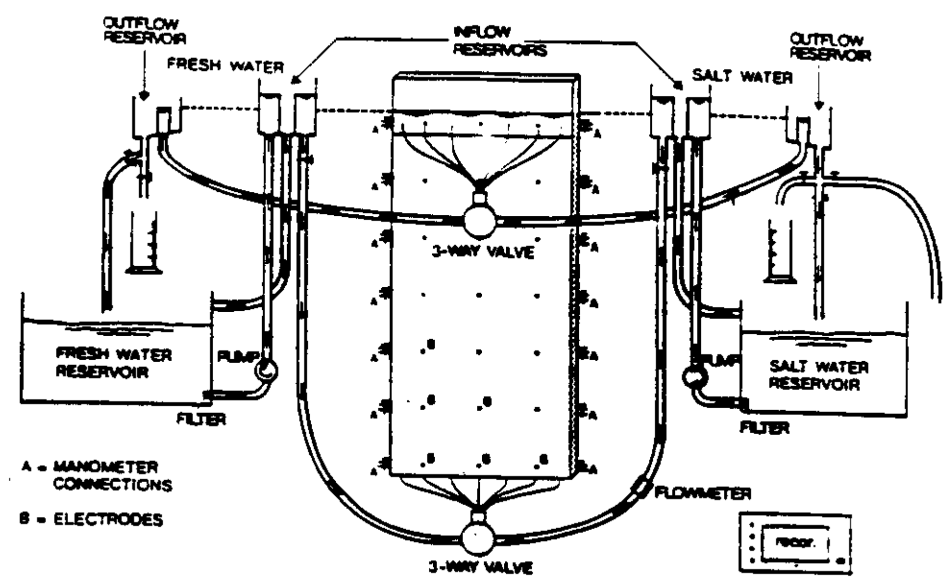


Figure 19. Experimental set-up (Test Case 13).

TEST CASE 14a and 14b

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany.

Introduction

The Gorleben Salt Dome is located in the northeastern part of Lower Saxony in the Federal Republic of Germany. An erosional channel crosses the salt dome from south to north. Test case 14a is based on a pumping test carried out in a section of this channel. Test case 14b is concerned with saline groundwater movement in the same channel.

General Description

The channel crossing the Gorleben salt dome is more than 10 km long and its widths varies between 1-2 km. In this erosional channel a fairly thick sequence of coarse to medium-grained (glaciofluvial) sands has been deposited with intercalations of till. The channel is overlain by silt and clay up to 110 m thick.

The fresh water body is underlain by rather saline groundwater. The salt content usually increases with depth and, especially above the salt dome, reaches saturation at depths greater than 220 m below sea level.

TEST CASE 14a

Pumping test in highly saline groundwater.

This test case provide the opportunity to observe the behaviour of a groundwater system filled with high saline water under simplified conditions (i.e. a system where the conductive flow is predominant).

The deeper aquifer in the erosional channel with saline water was pumped during 3 weeks (Figure 20). The pump test was carried out with a pumping rate of 30 m^3 per hour. About twenty observation wells were monitored more than once a day for five weeks and even more often thereafter. The water level in the closest observation wells were monitored with an ultrasonic apparatus with a precision better than 1mm. Electrical conductivity logs were made in the observation wells before and after the pump test to give information on changes in the salinity distribution in the wells. The electrical conductivity and the amount of water pumped were recorded continuously during the test.

In addition to the pump test selected as an INTRAVAL test case, three other pump tests at higher pumping rates have been performed in the area. The geological and hydrogelogic situation in the aquifer system in the sediments above the dome have been investigated extensively providing large amounts of background information such as, porosity, permeability, chemical compositions etc.

TEST CASE 14b

Saline groundwater movement in an erosional channel crossing a salt dome.

This test case is based on the extensive experimental programme briefly mentioned in test case 14a. The test case concerns the description of the regional complex groundwater flow system in the Gorleben area, including variable density of the groundwater due to salinity.

The first step of this test case could be to describe the present flow situation in the erosional channel crossing the salt dome. This could then be followed up by simulations of behaviour of the salt/fresh water system as a whole during the next thousand years to check whether the modelling of the present situation was sufficient as no significant short term changes in the flow system of salt transport is expected.

Another approach could be to begin the simulations with fresh water and an appropriate source term for the rate of salt dissolution. The calculations could be made for non-steady state conditions until the model correspond to the present situation. If ^{14}C values from water samples is included in the database, transport calculations based on a density-dependent flow system can also be performed.

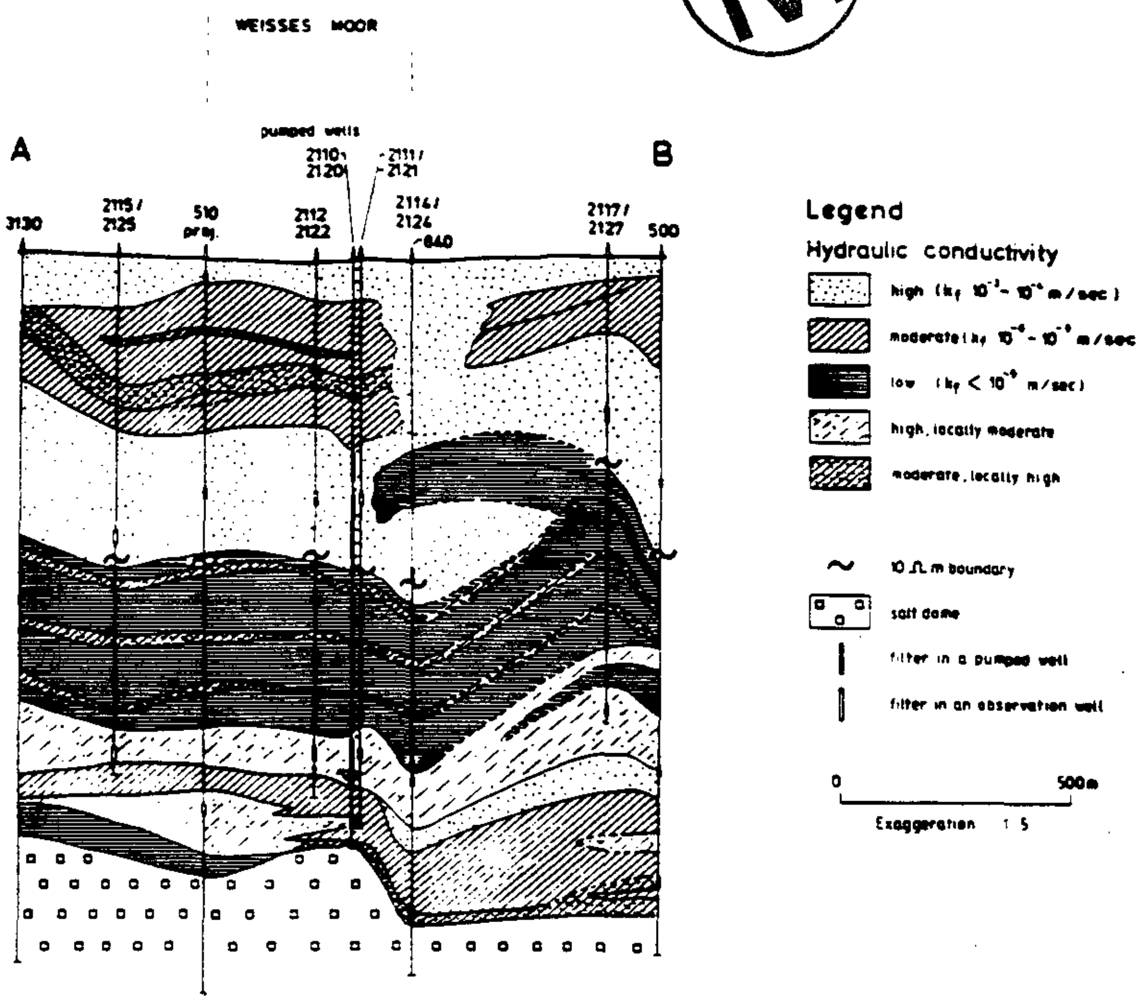


Figure 20. Hydrogeological cross section (Test Case 14).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

TEST CASE 1a

Bogorinski P., Larue J. and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overwiew of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R. and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A. and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

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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/Bundesamt für Strahlenschutz (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. Environmental Protection Agency (United States), U.S. Nuclear Regulatory Commission (United States).

Project Secretariat: Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/Harwell Laboratories, Kemakta Consultants Co., Organisation for Economic Co-operation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

6

May 1990 – October 1990

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

ERRATA

INTRAVAL PROGRESS
REPORT 6
May 1990-October 1990
pp. 16-18

General INTRAVAL Discussion

A time of three years was decided upon for the INTRAVAL project, with the option of an additional three year period.

Phase 1 started in October 1987 and has now come to an end with the launch of Phase 2.

Most of the work with the analysis of the test cases is now finalised. However, validation is a difficult process and plenty of work remains to increase the understanding of geosphere transport. Phase 2 will provide the opportunity and time to further analyse the test cases of Phase 1 as well as new test cases.

The meeting agreed that great strides toward validation have been achieved but also that validation is a difficult task. The "full problem" needs to be addressed, i.e. models, codes, data, performance assessment, and experimental techniques. Areas of uncertainty have been highlighted, for example matrix diffusion.

A systematic analysis of the validation process has been initiated. Data has been assessed, and models as well as codes have been developed, some of which have gained the confidence of the Project Teams of INTRAVAL. It was found that validation is a very different issue to different people.

The project has also provided a forum for peer review, education, and discussions regarding radionuclide transport in general.

The achievements from the first phase of INTRAVAL will be documented in a summary report and in a series of technical reports. In addition reports describing the experiments on which the test cases are based will be prepared.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 2a). An editor for each test case has been appointed. The responsibility of the editors is to compile the test case analyses provided by the Project Teams that have worked with the test case. A report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. A summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report and the technical reports are planned to be published in spring 1992.

Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

Although INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems, the emphasis of the work in Phase 1 has been on the Process Identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the Process Identification issue, it appears to be a natural development to shift the focus in Phase 2 towards Structure Identification. This issue is more complicated than the Process Identification because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for the analysis of a laboratory experiment.

The organisation of INTRAVAL Phase 2 will be similar to Phase 1. Four Working Groups will address the four main types of test cases (Table 2b). Each Working Group will have one leader, possibly aided by another person, and the intention is to meet at least once between each INTRAVAL meeting. To give the Working Groups ample time to do this, INTRAVAL meetings will be held about once a year. The Working Groups (leaders) are responsible for writing a working group report which will form a part of the final reporting.

Table 2a Working Groups for INTRAVAL Phase 1

			Editors:
Working Group 1 *Laboratory experiments*	Test Cases	1a 1b 2 9	P. Jackson J. Hadermann K. Skagius P. Jackson
Working Group 2 *Field experiments*	Test Cases	4 5	D. Hodgkinson C-F. Tsang
Working Group 3 *Natural analogues*	Test Cases	7 8	N. Chapman P. Duerden
Working Group 4 *Unsaturated media*	Test Cases	10, 11, 12	T. Nicholson
Working Group 5 *Salt*	Test Case	13	P. Glasbergen
Working Group 6 *Synthetic Experiment*	Test Case	6	R. Codell

Table 2b Tentative Working Groups for INTRAVAL Phase 2

Working Group 1:	Las Cruces Trench Apache Leap Tuff Site Twin Lake	leader: T. Nicholson
Working Group 2:	Finnsjön Stripa WIPP II	leaders: C-F. Tsang S. Neuman
	"Plans and Schedules" for this group has been compiled by Chin-Fu Tsang. This document can be received from the secretariat.	
Working Group 3:	Gorleben Salt Dome WIPP I Mol	leader: P. Glasbergen
Working Group 4:	Alligator Rivers Analogue Poços de Caldas	leader: N. Chapman

INTRAVAL Progress Report Number 6, 1991

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.

Twentytwo 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 and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 6

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. Phase 1 of the study is in the process of being finalised and a second three year period, Phase 2, has just been initiated.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process.

Seventeen test cases have so far been included in Phase 1 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project, the Alligator Rivers Analogue Project, and the Poços de Caldas Project.

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 in such a way that it is possible to simulate the experiments with model calculations.

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. In order 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 established within the study.

Contact between the participants is maintained by the arrangement of workshops followed by Coordinating Group meetings. Between these conferences, also Working Group meetings take place.

Since the issue of the previous Progress Report, the fifth INTRAVAL workshop and the sixth Coordinating Group meeting was held in Cologne, Germany. During this week the final presentations of Phase 1 modelling results were given, and Working Groups held meetings for preparation of their final reports. The second phase of INTRAVAL was launched and four Phase 2 Working Groups were appointed. Also VOIC assembled for the last meeting of Phase 1.

The Fifth INTRAVAL Workshop and the Sixth Coordinating Group Meeting

The Fifth INTRAVAL Workshop and the Sixth Coordinating Group Meeting were held in Cologne, the Federal Republic of Germany, on the 15th through 19th of October, 1990 with the Gesellschaft für Reaktorsicherheit acting as host. During the week preceding the week of meetings in Cologne, excursions to the ASSE salt mine and the Konrad iron-ore mine, close to Braunschweig in Niedersachsen (Lower Saxony) were organised. Another excursion, to the Hambach open-pit lignite mine, was arranged during the week of the meeting.

The last presentations of new modelling results of Phase 1 were held, but the greater part of the meeting was dedicated to concluding the work performed in Phase 1, and the launching of Phase 2.

As of these meetings, Phase 1 of INTRAVAL has been completed, apart from the report, and Phase 2 is in progress.

The Coordinating Group meeting was held on the 19th of October, 1990. The meeting decided that the Phase 2 of INTRAVAL would be initiated. All proposed test cases (except the Poços de Caldas test case) were agreed upon and four working groups were established to approach the different types of test cases. A final decision regarding the inclusion of the Poços de Caldas test case will be made at the next Coordination Group meeting. At the meeting, Kjell Andersson (SKI) assumed the chairmanship of INTRAVAL in the place of Alf Larsson.

The next INTRAVAL workshop and Coordinating Group meeting will be held in Seattle, Washington, U.S.A., April 22 to 26, 1991.

Validation Overview and Integration Committee (VOIC)

The Validation Overview and Integration Committee (VOIC) in the INTRAVAL organisation, acts for the development of the strategy for systematic application of experiences and knowledge gained from the various INTRAVAL test cases.

In the process of defining INTRAVAL Phase 2, VOIC has given assistance and advice to the INTRAVAL Secretariat and Coordinating Group concerning the outline of the continuation. VOIC has held the view that Phase 2 should be based on ongoing and well documented field experiments. The study should be more directed to validation strategy and performance assessment considering the accomplishments of Phase 1. It was also suggested that various key issues such as scale dependence, heterogeneity, coupled processes, etc. should be highlighted.

VOIC was specially created for Phase 1 of INTRAVAL, its function has been greatly appreciated. As this phase is now being concluded, the work of VOIC is also coming to an end. If VOIC, or a similar committee will be appointed for Phase 2 has not yet been decided.

Presentation of Additional Results from the Project Teams

The Fifth INTRAVAL workshop in Cologne was the final opportunity to present results of Phase 1 work. The test cases will be fully reported in upcoming technical reports.

TEST CASE 1B:

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

Experimental Set-up and Scales:

In this experiment, performed at the Paul Scherrer Institute (PSI) in Switzerland, tracer migration in crystalline bore cores were studied. Water at high pressure was forced to flow through rock cores of granite or gneiss with a diameter of 4.6 cm and a length between 0.8 cm and 5.0 cm. The high pressure was intended to simulate the rock overburden. Tracer (^{233}U) was added to the infiltration water and the tracer concentration was measured in the water sampled at the core outlet. After the experiments the samples were sliced and the surfaces of the slices were auto-radiographed to yield information of flow paths and sorption sites. Complementary results on hydraulic conductivity versus confining pressure, and dynamic porosities of the samples are also available, as well as results from uranium adsorption/desorption experiments.

Analysis by the Project Teams

The Project Team from PSI has analysed all four infiltration experiments with eight different transport models. The curve fitting was achieved "by eye" as well as by least squares fit.

The models take into consideration advection, dispersion, matrix diffusion, sorption (linear and non-linear, both at the flow surface and in the matrix), fracture flow, vein flow, and several flow paths. The number of free parameters varied from five to three for the different models.

The main questions addressed were to identify the dominant transport mechanisms, identify the geometrical factors that affect transport, whether a distinction can be made between various mechanisms and geometries. The Project Team also intended to suggest additional experiments that should be performed in order to support distinction between mechanisms.

It was concluded that a model considering several flowpaths has a sufficient number of parameters to fit all breakthrough curves. The models that did not include matrix diffusion could not give a satisfactory explanation to the breakthrough curves. Linear and non-linear sorption models gave similar fits, but non-linear sorption gave a slightly better result.

It was found difficult to discriminate between fracture and vein flow from the fits. Dispersivities could be extracted reliably for vein flow only, although this is irrelevant from a safety assessment point of view.

The overall conclusions were that insufficient information exist to extract all important parameters from the data. Models with non-linear sorption produce slightly better results than models with only linear sorption. The geometry of the water flow path could not be determined.

In order to obtain better understanding of the mechanisms and geometries, experiments with clearly defined flow geometry should be added. Other experiments that were suggested were multitracer experiments with one non-sorbing tracer, experiments where conditions (flow velocity, input duration, sample size) are varied, and experiments performed on several cores from the same location. To obtain a satisfactory curve-fitting, additional data points around the peak of the breakthrough curve should be collected.

The Project Team from PNC have applied two types of fracture models, a discrete fracture (single continuum) model, and a dual porosity (double continuum) model. The main objective was to identify the dominant parameters that control the transport of tracers and to estimate their values.

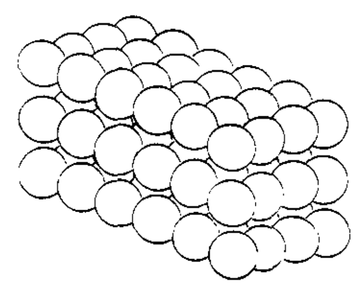

Figure. 1: Spherical block dual porosity model.

The results of the calculations with the two models were also compared. The code used was FTRANS, a finite element code developed by INTERA Inc. The fitting was done by eye as well as automatically (Powell's method).

Figure 2: Discrete fracture model.

Best fit values were determined for the longitudinal dispersivity in the fracture, ε_L^F as well as the adsorption coefficient K_a for both models. The distribution coefficient K_d was estimated for the dual porosity model.

	Model Discrete fract.	Dual porosity	
ε_L^F	$7.00 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	(m)
K_a	$3.65 \cdot 10^{-4}$*	$4.0 \cdot 10^{-3}$	(m)
K_d		$2.0 \cdot 10^{-2}$	(m^3/kg)

* insufficient

Table 1: Results from modelling of Test Case 1.

It was concluded that the best fit was reached with the dual porosity model. Even better results may be reached with a dual porosity model where the matrix is represented by spherical blocks. Calculations applying the single fracture model did not result in a satisfactory fit to the experimental data. Effects of matrix diffusion were not considered in this work, however it was recognized that matrix diffusion may be a key term in this context.

TEST CASE 5:

Tracer experiments in a fracture zone at the Finnsjön research area. Sweden. (Pilot Group Leader: P. Andersson. Swedish Geological Co.)

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated at 10^{-4} m^2/s, the middle 10^{-7} - 10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water/ salt water interface exists in the fracture zone relatively close to the upper previous layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated at 1/300 in the horizontal direction in the zone.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core- and a few percussion drilled boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test was conducted by pumping water from the full length of one borehole and observing the draw-down in 11 wells totalling 40 packed off intervals.

Tracer Tests

Two sets of tracer tests were completed: a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbing tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was performed by pumping in one well and injecting in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from VTT presented their results of modelling the dipole experiment.

The conceptual model consisted of three flow routes having different flow rates. The flow routes were calculated to pass through or very near the observation boreholes. Only a small fraction of the modelled flows are actually sampled in the observation boreholes.

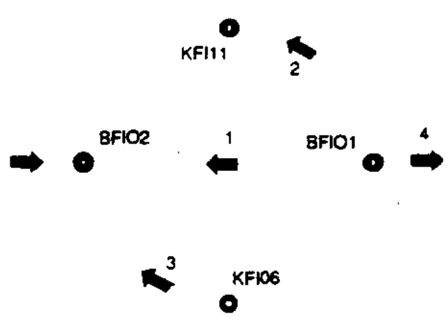

Figure 3: Main field lines and boreholes of dipole experiment.

The Project Team performed a curve-fit of the calculated data to the available experimental data.

It was observed that the flow from the injection hole to the pumping hole was not horizontally uniform. Selective pathways had been established between the two boreholes. A difference of flow was observed between boreholes KFI11 and KFI06 but the tracer concentration profile was very similar between the two boreholes. It was also seen that the actual boreholes will disturb the transmissivity of the system. When the vertical groundwater loss to a nearby fracture plane was considered in the calculations, an improvement of the fit was achieved.

TEST CASE 6:

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland. (Pilot Group Leader: R. Codell US NRC)

This test case is patterned after a tracer migration experiment in a single fracture plane at the Grimsel Rock Laboratory in Switzerland. A highly detailed two-dimensional synthetic data set of hydraulic conductivities and other properties conditioned on the actual data from the Grimsel site has been generated. In addition, results from a number of simulated hydraulic and tracer migration experiments with the synthetic model are available. Based on these data sets the task for the Project Teams was firstly to predict the breakthrough of a non-sorbing tracer at several simulated boreholes and tunnels (Phase 1 of this test case), and secondly, to include also diffusion and chemical retardation in the geosphere (Phase 2 of the test case).

Analysis by the Project Teams

A group of ETH/NAGRA applied a finite element code to the data. The code being tested is still in a development stage, one feature not yet implemented is error analysis. The aim of the exercise has been to estimate the physical parameters of the synthetic geosphere using the hydraulic data of the experiments. The transport data will be used as a check for the transmissivity field estimated by the analysis of hydrological tests.

The direct problem is solved by the finite element method under steady state and/or transient conditions involving one-, two-, and three-dimensional quadratic elements.

The methodology has been implemented to deal with the hydrological data. Interpretation of the hydraulic data of the synthetic system has begun. The flow rate into the drift was predicted with an error margin of 1% .

TEST CASE 8:

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

This test case deals with the natural analogue studies at the Koongarra site in the Alligator Rivers region of the Northern Territory, Australia. A comprehensive experimental and modelling programme has been set up and the main objective is to contribute to the production of reliable and realistic models of radionuclide migration within geological environments relevant to the assessment of the safety of radioactive waste repositories.

Uranium mineralisation at Koongarra occurs in two distinct but related ore-bodies separated by about 100 m of barren schists. Both ore-bodies strike and dip broadly parallel to the Koongarra Reverse Fault, which is the footwall to the ore zone. Primary mineralisation is largely confined to quartz-chlorite schist immediately above the fault zone. A graphitic quartz-chlorite schist forms a distinctive hanging wall unit. The more southwesterly of the two ore-bodies (No. 1 ore-body) has a strike length of 450 m and persists to a depth of about 100 m. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m to the east.

Analysis by the Project Teams

The Project Team from ANSTO presented results from the investigation of time characteristics in the formation of the uranium dispersion zone. The general concept has been to use the Koongarra system heterogeneity and seasonal hydrology changes for the investigation.

The model used is a quasi-two dimensional model describing the transport in a two-dimensional vertical cross-section as transport in two one-dimensional pipes separated by an intermediate zone where no horizontal transport is considered. This zone provides transfer of material from the bottom pipe to the upper pipe, reflecting transport due to seasonal fluctuations in water table. Two approaches were applied, one based on advection-diffusion in the pipes and a second based on open-systems modelling.The rock is considered to contain mineral phases that are accessible to the groundwater as well as those that are inaccessible (see adjoining figure). The adsorbed material is transferred during phase change (eg. crystallisation).

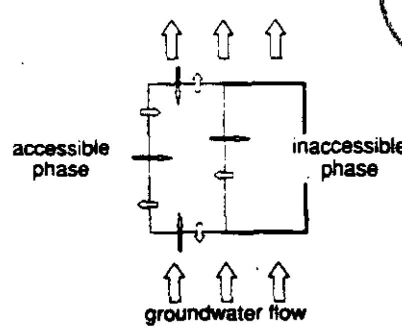

Figure 4: The accessible/inaccessible phase of the rock matrix at the Koongarra site.

The results of modelling to date support the experimentally determined distribution coefficient, K_d, as being between 0.35 and $1.5 \cdot 10^{-4}$ ml/g, the flow rate in the weathered schist being in the order of up to a few metres per year.

The mineral phase exchange rate is such that the rate at which uranium is accumulated in the accessible phase is in the order of the ^{234}U decay-constant. Most of the modelling fittings performed indicate that the mobilisation timescale is in the range of one to two million years. The calculated concentrations of uranium in the accessible/inaccessible phase of the rock are similar to the values observed from core data.

The next step is to improve the applied modelling procedure.

TEST CASE 9:

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

Experimental Set-up and Scales

This test case is based on laboratory experiments on migration of tracers in a single natural fracture in a large block of granite. The size of the block is 91.5 × 86.5 × 49.0 cm (length × width × height). The block was positioned so that the fracture is approximately horizontal and an inlet reservoir was designed to produce an as uniform hydraulic gradient and inlet tracer concentration as possible across the entire fracture width. The outlet reservoir was divided into five compartments, which were sampled in sequence to give breakthrough curves for each compartment. After the experiments were performed the fracture was opened and the flow paths were investigated with alpha-autoradiography.

Analysis by the Project Teams

Two-dimensional radionuclide migration analysis has been performed by CRIEPI. The analysis was performed with the finite element code RMF.

The following models were used :

- Porous Media, two-dimensional anisotropic porous media model (isoparametric element with 4 to 8 nodes);
- Rectangular Block Element, rectangular block model of matrix in dual porosity element;
- Circular Block Element, circular block model of matrix in dual porosity element;
- Fracture, model of discrete fracture.

The sorption was calculated both as linear and non-linear sorption.

Calculations resulted in good agreement with experimental data. It was also noted that the choice of dispersion length, α_L had a strong influence on the breakthrough curve.

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: T. Nicholson, U.S. NRC)

Experimental Set-up and Scales

This test case is in fact three sets of experiments on flow and transport in unsaturated welded tuff. The experiments are supported by the U.S. NRC. The first set of experiments are field experiments at the Apache Leap Tuff Site, the second is a set of laboratory experiments performed on blocks of fractured rock, and the third a set of laboratory experiments performed on bore cores from the site. All experiments have to date been performed by the University of Arizona.

The dimension of the field experiment is in the order of 30 × 30 × 30 m. Nine inclined boreholes have been drilled in three rows, each row with three boreholes. This general set-up will allow for a set of different experiments. In one experiment performed at the site so far, the rock adjacent to one borehole was saturated and the propagation of the wetted front was evaluated by measuring the moisture content in the other boreholes. However, the introduction of the moisture could not be detected in the other boreholes.

Figure 5: Rock block with a single fracture.

The laboratory experiment was performed on Rock blocks of the dimensions 20 × 20 × 50 cm (block 1) and 21 × 20 × 66 cm (block 2). The blocks were chosen so that each block had a single fracture forming a centre plane through the rock (figure 5). The vertical sides of the blocks were hydraulically insulated whereas the top and bottom were attached to porous plates which allowed for controlled unsaturated flow through the block and the fracture. The flow rate between the upper and lower plates was to be used to calculate the unsaturated transmissivity, and the water content of the fracture was monitored using mass balance calculations.

The dimension of the core was 6.4 cm in diameter and 12.99 cm in length. It did not contain any observable fractures. The core was oven dried and then partially wetted with a solution of potassium iodine. The core was then coated to prevent moisture or air from leaving the core. The core ends were held at two different temperatures (70°C and 5°C) whereas the sides of the core were thermally insulated (no heat flow). The temperature and moisture distribution were measured at different intervals of time, as well as the final solute concentration (after 32 days).

Analysis by the Project Teams

The Kemakta/SKI Project Team presented their results of TOUGH and TRUMP modelling (integrated finite difference codes) of multiphase flow in a heated tuff drillcore.

The calculations of moisture distribution, temperature distribution, and relative tracer content were within the expected range of error compared to the experimental data. Differences between the experimental and calculated values may be attributed to heterogeneities, poor material data, and measurement errors.

It was concluded that modelling of transport mechanisms was more successful than the modelling of moisture content.

TEST CASE 13:

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

Experimental Set-up

This test case deals with flow and transport at high salt concentrations. The experimental set-up is a two-dimensional column with the dimensions 0.6 × 1.25 × 0.01 m, filled with glass beads. Fresh water and salt water was alternately circulated through the column. Head and salt concentration are measured at different locations in the column. The duration of a displacement experiment is from two to five hours.

Two sets of experiments have been carried out, one with low salt concentration to estimate the porosity, permeability and dispersivity of the porous medium, and another with high concentration to provide data about the concentration and pressure dis ibution along the column.

A lysis by the Project Teams

The Project Team from GRS, in cooperation with Harwell Laboratories, presented results of calculations where a new approach to the transport problem had been applied.

The new model regards the experimental set-up as a regular hexagonal network of one-dimensional tubes with advective flow. No dispersive/diffusive transport is taken into account by the model. Each tube is allocated a random permeability within a defined variance. The low concentration experiment was used to calculate this variance. The result was local density variations due to concentration changes in each tube. Simultaneous calculations of transient pressure and brine transport were made.

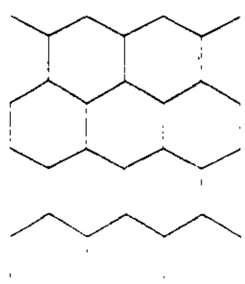

Figure 6: "network of tubes"-model

The recently developed computer code NEWFLOT was used for the calculations. The model used had 50 cells in the flow direction and 15 cells laterally, a total of 4535 connecting "tubes". The density of the salt water was specified as 1200 g/l. The dimensions were not designed to exactly represent the experiment.

It was concluded that dispersion of a low concentration brine could be reproduced by advective flow in a pipe network with random permeabilities. When simulating the high concentration experiment, the results indicate that dispersivity may be a function of the density gradient.

Results of modelling performed at TUB (Technische Universität Berlin) were presented based on one and two-dimensional calculations based on the code FAST C, and made with a Cray-XMP computer.

Modelling was performed based on the data of the low concentration experiment. The results of the propagation of the saltfront with time suggested that the flow of water/brine does not influence the flow directions of the brine. The results were not in accordance with the experimental data, but work still in progress. The question was raised if the porous-medium approach is the correct one for this experiment.

Current Status and Conclusions of Phase 1 Working Groups

WORKING GROUP 1:

(Laboratory Experiments, Test Cases 1a, 1b, 2, 9)

Working Group 1 is in the midst of the reporting stage of Phase 1. Some of the draft reports from Project Teams have been received by the Working Group. Comments were to be received until December 14. The last chance for submission of draft versions of Test Case reports was December 14. The final reports were to be completed by February 14, 1991.

The work has resulted in calibration of standard models, but few have yet considered spatial variability. No work other than to "simulate experiments" has been performed to this date.

A number of general conclusions have been drawn based on the current Project Team work. Consensus was reached as to the processes involved in nuclide transport in fractured rock, matrix diffusion, dispersion, etc. Agreement has been reached on the general methodology of the work, assessing quality of experiments, and implications for repositories, as well as suggestions of additional experiments for better understanding of the actual processes. It was also concluded that the number of parameters in the models need to be constrained to be able to use the models for prediction.

For future work, it was commented that not enough testcases addressed different scales and that experiments did not give enough data for a complete characterisation of the experiment.

WORKING GROUP 2:

(Tracer Experiments in Crystalline Rock, Test Case 4, 5)

Three different Project Teams have used different approaches to the Stripa experiment, test case 4.

The approach to test case 4 of LBL/USDOE has been one of "pseudo-independent" pathways. The Project Team from KTH/SKI has calibrated a fracture network model with Stripa data and the INTERA/NIREX team has performed a fractal analysis of the tracer travel times. The different approaches seem to fit together, not contradicting each other. One of the conclusions of the work of all Project Teams involved with test case 4 has been the recognition of the concept of channelling.

Difficulties have existed in the form of poor injection flow-rates and background flow patterns (all tracers did not arrive to the point of detection).

Seven Project Teams have modelled the Finnsjön experiment, test case 5. However, substantial amounts of data still remain unprocessed.

Most modelling teams did not consider the injection conditions. It was concluded that it is important to perform hydrologic and tracer tests simultaneously.

For the dipole experiment, the teams have chosen different models but all have found that advection and dispersion were important parameters. Differences of opinion exist regarding the existence or not of matrix diffusion. A difficulty that has been identified is the determination the geometry of the site.

At this time, there is a lack of complementary data, i.e. laboratory data, etc. Also, validation strategies have not yet been discussed, this needs to be approached in the continuation of the work based on these test cases.

A general conclusion of the achievements of the Working Group was that very good interaction between the modelling groups had been achieved.

For Phase 2, the intention is to analyze all data available. For example core samples (porosities, diffusivities, and geo chemistry), salinity data and single hole radar measurements remain to be examined from the Finnsjön experiment.

Concerning the Stripa test case, data from additional experiments performed in the Stripa mine will be made available.

In Phase 2, work will also be initiated on data from the WIPP 2 experiments.

WORKING GROUP 3:

(Natural Analogs, Test cases 7 and 8)

A Project Summary Report has been completed for the Alligator Rivers Analogue Project. A summary of this will be presented as the INTRAVAL Phase 1 report for Test Case 8. The report includes the baseline information on the work performed at KTH.

Work on Test Case 8, the Alligator Rivers Analogue Project, is still in the initial stages. Because the lack of processed information, the report which is being prepared will not be an INTRAVAL Phase 1 final report but a report of the initial approaches performed as a part of the INTRAVAL study. An elaborate test case description will be presented, and also a presentation of the data available.

For Phase 2 of INTRAVAL, the focus of test case 7, Poços de Caldas, will be on redox front processes. The aim is to model geochemical transport across a moving front. Phase 2 will also provide a good opportunity to test diffusion transport and chemical equilibrium/kinetic models.

For test case 8, the Alligator Rivers Project, three Phase 2 test cases have been prepared. The first is a hydrogeological approach, a scenario for 2-D and 3-D fluxes across the site. The second concerns geochemistry, formation of the secondary ore-zone and recent movement of the dispersion fan. The third test case will address the transport within the ore-zones. These are developed versions of the Phase 1 test case.

Phase 2 of INTRAVAL provides the study of the natural analogues with the opportunity to give more consideration to geochemical aspects of a natural analogue.

WORKING GROUP 4:

(Experiments in the Unsaturated Zone. Test cases 10, 11, and 12)

The Working Group 4 is well under way preparing the Working Group report on the unsaturated test cases.

Measurements in the unsaturated zone is still very much dependent on the development of new experimental methods. This is one explanation why high-quality data is difficult to procure. Despite the experimental difficulties, three test cases have been modelled.

Important knowledge has been gathered to address the validation issue of the unsaturated test cases, however little or no validation attempts have yet been made. The validation issue is mainly left to be addressed in Phase 2 of INTRAVAL.

It was stressed that the knowledge and experience gained from work performed in the saturated zone is valuable also for performing experiments in the unsaturated zone.

The results of the modelling exercises have been a greater comprehension of the involved processes as well as developed laboratory and field techniques.

A number of recommendations have been identified in preparation for INTRAVAL Phase 2. Conceptual models, experimental methods, and numerical solution techniques will be investigated more closely in Phase 2.

WORKING GROUP 5:

(Salt and Brine Related Experiments, Test Cases 13, and 14)

Working Group 5 is in the midst of preparing the test case report. The report will address the brine transport experiment, Test Case 13. The experiments at the Gorleben Salt Dome, Test Case 14a and 14b, will be approached in Phase 2.

A workshop in Gorleben, Germany, was held in May 1990 where the results of Test Case 13 were discussed in detail. A writing workshop was held in Bilthoven, the Netherlands, in January, 1991, to compile the reports.

A number of objectives were defined for the salt related test cases at the beginning of the first phase of INTRAVAL. These objectives were to use data for calibration of transport models developed for brine environments, to compare model predictions with experimental data, to draw conclusions on the validity of the classical Darcy's/Fick's laws at high brine concentrations, and to identify the numerical structure of the model applied. At the conclusion of the Phase 1 work, the objectives for Phase 1 have been met except the validity of Darcy's/Fick's laws.

A conclusion that has been reached is that the experimental set-up may vary with porosities, location of measurement, and may be dependent on time.Simulation of high-concentration experiment using porosities and dispersivities from the low-concentration experiment did not provide satisfactory results. To improve the simulation of the slope of the break through curves, lower values of dispersion required. No consensus was reached on explaining the observed discrepancies between the laboratory results of brine front migration and model simulations at high concentrations. The influence of the laboratory set-up was discussed.

It was observed that Fick's law was not valid for the conditions at the experiment. A reformulation of the adsorption constant in Fick's' law provided satisfactory agreement with experimental data. This may be reached by substituting the constant, as defined by classical theory, with a nonlinear function. No attempt to formulate this function has yet been made.

WORKING GROUP 6:

(Synthetic Test Case, Test Case 6)

The Grimsel Rock Laboratory Synthetic Experiment has involved a true validation attempt. Even though the experiment is based on synthetic data, no backfitting has been made.

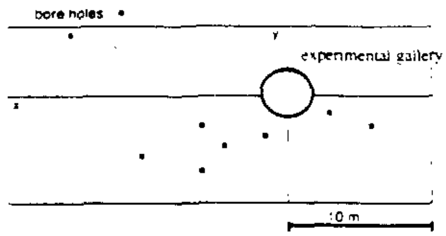

Figure 7: The small scale description of the synthetic migration experiment.

The following methods were applied by the project teams:

- Potential Flow (NRC, Team 1)
- Kriged T and H (NRC, Team 1)
- Conditional Simulation (NRC, Team 1)
- T Zonation with Manual Adjust (NRC, Team 2)
- Inverse Model (CNWRA, ETH/NAGRA)

The project team at ETH have applied an inverse methodology (with pilot points). The steady state base case and one of the transient tests have been analysed with encouraging results related to head and flux comparisons.

Conditional Simulation-runs were performed by NRC with the original data as well as runs using data from three additional boreholes. The results were compared. The additional data resulted in lower correlation to the measured data. This behaviour has not yet been explained. Problems exist in the form of shortage of computer time, lack of data, and the difficulties when alternative phenomena led to the same observations.

Presentation of CEC Program Directory

The Commission of European Communities (CEC) directory of computer programs for assessment of radioactive waste disposal in geologic formations was presented. The objectives of the directory are to gain an overview of current development and use of computer programs and to list such programs along with reviews of selected programs.

More than 300 programs are listed under a wide range of topics. Many program descriptions also include a review of the program.

The participants of INTRAVAL were asked to be generous with contributions of information to make it possible to make an informative directory with well specified information regarding the computer codes in use today. It was pointed out that more information, in addition to the name of the code, result in higher probability for a review in the directory.

General INTRAVAL Discussion

A time of three years was decided upon for the INTRAVAL project, with the option of an additional three year period.

Phase 1 started in October 1987 and has now come to an end with the launch of Phase 2.

Most of the work with the analysis of the test cases is now finalised. However, validation is a difficult process and plenty of work remains to increase the understanding of geosphere transport. Phase 2 will provide the opportunity and time to further analyse the test cases of Phase 1 as well as new test cases.

The meeting agreed that great strides toward validation have been achieved but also that validation is a difficult task. The "full problem" needs to be addressed, i.e. models, codes, data, performance assessment, and experimental techniques. Areas o uncertainty have been highlighted, for e: imple matrix diffusion.

A systematic analysis of the validation process has been initiated. Data has been assessed, and models as well as codes have been developed, some of which have gained the confidence of the project teams of INTRAVAL. It was found that validation is a very different issue to different people.

The project has also provided a forum for peer review, education, and discussions regarding radionuclide transport in general.

The achievements from the first phase of INTRAVAL will be documented in a summary report and in a series of technical reports. In addition reports describing the experiments on which the test cases are based will be prepared.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 2). An editor for each test case has been appointed. The responsibility of the editors is to compile the test case analyses provided by the Project Teams that have worked with the test case. The report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. The technical reports are planned to be published in spring 1991. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report is planned to be published late 1991.

Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

Although INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems, the emphasis of the work in Phase 1 has been on the Process Identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the Process Identification issue, it appears to be a natural development to shift the focus in Phase 2 towards Structure Identification. This issue is more complicated than the Process Identification because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for the analysis of a laboratory experiment.

The organisation of INTRAVAL Phase 2 will be similar to Phase 1. Four Working Groups will address the four main types of test cases (see table 2). Each Working Group will have two leaders (all have not yet been appointed), and the intention is to meet at least once between each

Table 2: Working Groups for Phase 2

Working Group 1:	Las Cruces Trench Apache Leap Tuff Site Twin Lake	leaders: Tom Nicholson –
Working Group 2:	Finnsjön Stripa WIPP II	leaders: Chin-Fu Tsang Shlomo Neuman
	"Plans and Schedules" for this group has been compiled by Chin-Fu Tsang. This document can be received from the secretariat.	
Working Group 3:	Gorleben Salt Dome WIPP I Mol	leaders: Peter Glasbergen –
Working Group 4:	Alligator Rivers Analogue Poços de Caldas	leaders: Neil Chapman –

INTRAVAL meeting. To give the Working Groups ample time to do this, INTRAVAL meetings will be held about once a year. Working Groups should write a technical report to summarise experiences of the different test cases.

Phase 2 Test cases

Based on the interest of the participants of the Cologne meeting, the following test cases were decided to be included in INTRAVAL Phase 2. Inclusion of the Poços de Caldas test case will be decided at the next Coordinating Group meeting.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden

The Stripa 3D experiment is included in Phase 1 as Test Case 4. The intention is now to further analyse the Stripa 3D experiment. An extended set of complementary data will become available since much information has been gathered on fracture statistics, hydraulic testing data as well as on water chemistry in the 'site characterization and validation' program. A new drift has been excavated near the old 3D drift and instrumented with plastic sheets and other water collection devices. In addition, channeling experiments in individual fractures have been performed and will provide data on the variability of hydraulic transmissivities and fracture apertures over 2 m lengths along five fractures. Results from tracer tests performed between two holes in the same fracture plane are also available.

FINNSJÖN

Finnsjön tracer experiments, Sweden

This experiment is included in Phase 1 as Test Case 5. Three types of experiments have been performed, hydraulic interference tests, a radially converging tracer experiment and a dipole tracer experiment. The emphasis of the work in Phase 1 has been on the radially converging tracer test. For Phase 2, all three experiments will be used as well as the coupling between them. This would mean an increase in geometrical scales to distances between 150 and 1500 metres. Another objective for INTRAVAL Phase 2 is to incorporate existing laboratory data from core samples of the fracture zone.

GORLEBEN SALT DOME

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany

This experiment is included in INTRAVAL Phase 1 as Test Case 14. As experimental data was not available in time for inclusion, the test case has been transfered to Phase 2.

The Test Case is based on a hydrogeological investigation programme in the area of the Gorleben salt dome, situated in the northeastern part of Lower Saxony. The principal aim has been to understand and determine the groundwater movement in the strata surrounding a salt dome. Freshwater in the uppermost parts of the aquifer system is in such situations commonly underlain by highly saline groundwater. The groundwater movement in such a system depends to a large degree on its salinity. Special experiments have been performed to obtain information on hydrogeological structure, hydraulic parameters and groundwater movement.

ALLIGATOR RIVERS

Radionuclide migration in the weathered zone of the Koongarra uranium deposit, Northern Territories, Australia

This natural analogue study is included in Phase 1 as Test Case 8. The analysis of the data base from the Alligator Rivers Analogue is still in progress. The number of Project Teams that have tackled this test case during Phase 1 is limited since a broad and innovative approach is needed for the analysis. This fits well with the focus of Phase 2.

The Koongarra uranium ore deposit is found in the Alligator Rivers region of the Northern Territories. Uranium mineralisation occurs at Koongarra in two distinct but related orebodies, which strike and dip broadly parallel to the Koongarra Reverse

Fault. Primary mineralisation is largely confined to quartz-chlorite schists: secondary mineralisation is present from the surface down to the base of weathering at about 25 meters depth and forms a tongue-like body of ore dispersing downslope for about 80 meters. The objective of the study is to deduce the timescale and the rate of the uranium mobilisation which resulted in the redistribution of the ore-body along the general groundwater flow direction.

POÇOS DE CALDAS

Poços de Caldas, Minais Gerais, Brazil

The Poços de Caldas Natural Analogue study is included in Phase 1 as Test Cases 7a (redox-front movement) and 7b (colloid transport). Since the data have not yet been available to the Project Teams it has been proposed to transfer the part concerning the redox-front movement and uranium movement to Phase 2. The part concerning colloid transport will not be continued since no evidence of colloid movement has been found in Poços de Caldas.

At the Cologne meeting the interest among the participants was too low to motivate Poços de Caldas as a Phase 2 test case. It was however decided to keep it within the project at least until the next meeting which will be in Seattle, April 1991.

LAS CRUCES TRENCH

Las Cruces trench, Nevada, USA

This experiment is included in INTRAVAL Phase 1 as Test Case 10. The experimental site is located at the New Mexico State University College Ranch, northeast of Las Cruces. Water and tracers are applied in a carefully controlled fashion to the surface of an experimental plot. The motion of water and the transport of various tracers through the vadose zone are monitored. The purpose of the experiments is to test deterministic and stochastic flow theories by comparing model predictions with observed measured flow and transport parameters. Additional experiments will be performed at the site and it was proposed to include the experiments at Las Cruces Trench as a Test Case in INTRAVAL Phase 2. Models calibrated against data from the already performed experiments can be used to predict water flux and solute transport in the experiments.

APACHE LEAP TUFF

Apache Leap Tuff site, Arizona, USA

This experiment is included in Phase 1 as Test Case 11. The Phase 2 exercise will be an extension of the efforts already performed. At the experimental site, the tuff formation is approximately 600 meters thick. The unsaturated zone extends to great depth due to topography and to pumping associated with nearby mining activities. The objective is to learn how to predict water flow and solute transport through unsaturated fractured rock under field conditions. Data from experiments made at different scales, i.e core, block and field, are already available, and additional experiments of similar types will be performed.

MOL

Migration of tritium in clay at Mol, Belgium.

A piezometer nest is placed in a single bore hole drilled horizontally from the gallery of the Hades underground research facility at Mol, Belgium. The nest is equipped with several filters at 1 m intervals through which tritiated water is injected. An additional five piezometer nests have been installed for radionuclide injection, but these have not yet been loaded. Two of these nests are intended for determination of anisotropy in the clay (perpendicular and parallel to the bedding of the clay). The data from these additional tests will be made available to INTRAVAL as they arrive.

The experiment was originally designed to make in situ determinations of migration for comparison with values determined in the laboratory. The spatial scale of the experiments is in the order of 2 m migration distance involving about 30 m^3 of clay. The time required for an experiment is in the range of 1-4 years. The first tritium injection was carried out two years ago. The spatial scale of the complementary laboratory experiments is in the order of a few centimetres, and the time scale is in the order of weeks. The validation aspects of the experiments are coupled to radionuclide migration in clay and the scale dependence of the migration parameters.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada

The test case comprises 20, 40, and 260 m natural gradient radio-tracer experiments performed in a sandy to gravel aquifer at the Twin Lake site. The experiments were performed in 1982, 1983 and 1987–1988. The longest experiment ran for about a year. The spatial separation of the measuring points are about 5 m in the flow direction and 0.5–1 m in the direction perpendicular to the flow. For the 1982–1983 experiments approximately five hundred thousand data points exists on the spread of iodine. A very large amount of hydrogeological and geophysical data has also been collected. New experiments are planned for the autumn 1990.

Sand and gravel aquifers could hardly be considered for radioactive waste disposal. In that sense, this test case has a limited relevance for the validation with regard to radioactive waste disposal. However, the test case could potentially provide a set of detailed data that could be used for validating the necessary conditions generally assumed in transport models, i.e. to answer the question whether a general transport model can predict the results of any field experiment where there is little uncertainty in the data.

WIPP 1

Brine Flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

Field experiments are conducted in the underground facility at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The underground facility is located 655 m below ground surface within bedded evaporites, primary halite, of the Permian Salado Formation. The WIPP, currently scheduled to be commissioned in late 1990, is intended to be a permanent repository for low-level and transuranic wastes generated by the United States' defense programmes.

WIPP1 is a Test Case based on experiments performed to determine the nature of brine flow through bedded evaporites of the Salado Formation. The experiments are designed to provide different types of data with the purpose to evaluate whether Darcy's law correctly describes the flow of brine through evaporites, or whether a different type of model, perhaps one involving creep-driven flow, is more appropriate. Three principal types of measurements are being made: brine-inflow rates, pore-pressures and permeabilities, at a number of scales ranging from 4.5 cm diameter boreholes to 3 m diameter rooms. The test case is concerned with the validation of conceptualization's and models used in interpretation of experiments and in modelling of brine inflow to the repository. The objectives are to integrate the results of all the experiments within a comprehensive and consistent model of brine flow through evaporites.

WIPP 2

Groundwater flow at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

WIPP 2 is based on extensive geologic and hydrologic investigations at the WIPP. The experiments were originally performed to provide data to be used in developing a regional groundwater - flow model and subsequent performance assessment calculations. The database available for this test case is very large, and thus suitable for further study by the INTRAVAL project. Geologic studies have taken place at the WIPP, beginning 1975. These include detailed investigation of numerous surface features for the purpose of delineating subsurface features or irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991 - 2 in order to better delineate a hypothesized fractured region. Sixty wells have been completed to the Culebra dolomite at 41 locations to provide information on the hydraulic properties of the Culebra. Variation in Transmissivity is related to fracturing. Where present, fracturing causes the culebra to behave as a double porosity medium with respect to both hydraulic responses and solute transport. Pumping tests, tracer tests, geochemical and isotope studies have also been performed at the site.

The experimental programme is currently scheduled to continue through May 1992. In late 1990 or early 1991, the programme may be expanded to include gas threshold-pressure testing, and tracer testing through a fractured anhydrite bed.

Appendix 1

Progress Report Number 6

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 Managing Participant appoints 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 costs, travelling expenses, 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 intervals of time, 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.

List of INTRAVAL Participants

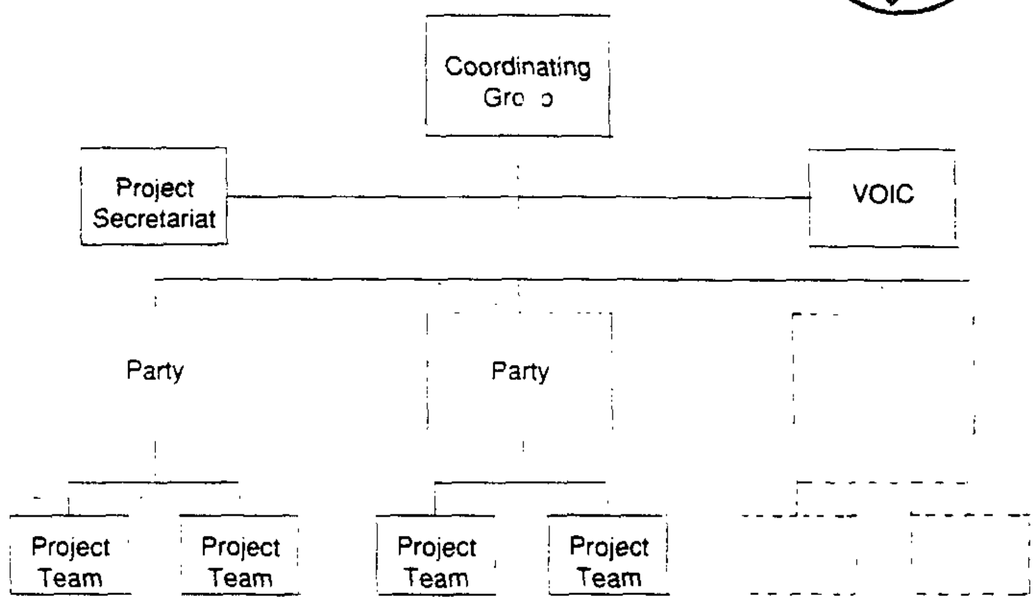

Figure 1: INTRAVAL Organisational Chart

Managing Participant:	SKI
Coordinating Group:	
Chairman:	A. Larsson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	K. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
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	Massachusetts Institute of (MIT) Technology L. Gelhar
	Pacific Northwest Laboratories (PNL) G. Gee
	Sandia National Laboratories (SNL) P. Davis
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Organisation for Economic Cooperation and Development/ Nuclear Energy Agency (OECD/NEA) Member of Secretariat: C. Thegerström	
International Atomic Energy Agency (IAEA) S. Hossain (observer)	
State of Nevada L. Lehman (observer)	

Appendix 2

List of Test Case Related Presentations at INTRAVAL Workshops

TEST CASE 1a

Bogorinski P., Larue J. and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overwiew of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R. and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A. and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Application of Experiment Design Methods to Test Case 1a, INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A. and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P. and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J. and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K. and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K. (CSD) and Ikeda Y. (MAPI), PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R. and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R. and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 1b

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J. and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E. and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P. and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries.INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E. and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J. and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J. and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L. and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 2

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R. and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B.. Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 3

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculations, INTRAVAL Workshop, Barcelona, April 1988.

Cole C. and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K. and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H. and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 4

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B. and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W. and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W. and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W. and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 5

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P. and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P. and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A. and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A. and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V. and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H. and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Kasturagi T. and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L. and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön, Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Br ndan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R. and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 6

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R. and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U. and Vomvoris S. ,Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 7a

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L. and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 7b

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Po(os de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 8

Davis S., Hydrology Sub-Project, INTRAVAL Workshop, Tucson, November 1988.

Duerden P. and Golian C.. Presentation of Koongarra and Draft Test Case. INTRAVAL Workshop, Barcelona, April 1988.

Duerden P.. Presentation of Test Case 8. INTRAVAL Workshop, Tucson, November 1988.

Duerden P.. Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C.. Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C.. Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C.. A Quasi Two Dimension Open Sytem/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C.. Test Results of the Simplified 2D Modelling of the Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D.. Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I.. Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M.. Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D.. Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 9

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M.. Preliminary Results on Test Case 9 by Using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A. and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

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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/Bundesamt für Strahlenschutz (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreteé 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 (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. Environmental Protection Agency (United States), U.S. Nuclear Regulatory Commission (United States).

Project Secretariat: Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/Harwell Laboratories, Kemakta Consultants Co., Organisation for Economic Co-operation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

7

November 1990–April 1991

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

INTRAVAL
Progress Report No. 7, 1991

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.

Twentyfour organisations 'Parties' from thirteen countries participate in INTRAVAL. The Project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 7

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three years of the study, Phase 1, is in the process of being documented and finalised and a second three year period. Phase 2, was initiated and started in October 1990.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems.

Ten test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

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 in such a way that it is possible to simulate the experiments with model calculations.

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.

Contact between the participants is maintained by the arrangement of Workshops followed by Coordinating Group meetings. Between these conferences, also Working Group meetings take place.

Since the issue of the previous Progress Report, the sixth INTRAVAL workshop and the second Phase 2 Coordinating Group meeting has been held in Seattle, Washington, U.S.A. During the workshop participants described initial work performed on the Phase 2 as well as modelling results achieved so far. This was followed up by group discussions on further steps of the analyses and planning of intermediate working group meetings. The progress of the INTRAVAL Phase 1 Final Reports and the Executive Summary report was discussed both in plenary meetings and within working groups set up for finalisation of the documentation of Phase 1.

INTRAVAL Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

The organisation of INTRAVAL Phase 2 is similar to Phase 1. The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Parties organise Project Teams for the actual project work. A Pilot Group has been appointed for each test case in order to secure information transfer from the experimentalists to the Project Secretariat and Project Teams. At suitable intervals, about once a year, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. Four Working Groups have been set up addressing different types of test cases (Table 1). Each Working Group will have one leader, possibly aided by another person, and the intention is to meet at least once between each INTRAVAL meeting. The Working Groups (leaders) are responsible for writing a working group report which will form part of the final reporting of INTRAVAL Phase 2.

Table 1. Tentative Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Leader(s)
1	Las Cruces Apache Leap	T. Nicholson
2	Finnsjön Stripa WIPP 2	C.F. Tsang
3	Gorleben WIPP 1 Mol	P. Glasbergen
4	Alligator Rivers Twin Lake	P. Duerden

The Sixth INTRAVAL Workshop and the Second Phase 2 Coordinating Group Meeting

The sixth INTRAVAL Workshop and the second Phase 2 Coordinating Group Meeting were held in Seattle, Washington, USA, on the 18th through 22th of April, 1991 with the U.S. Department of Energy acting as host. In connection to the meeting a tour was arranged to the Hanford site near Richland, Washington .

At the workshop a number of technical presentations of Phase 2 modelling work were given. The modelling work of the Phase 2 test cases are in an initial stage. Much time was spent on the finalisation of the Phase 1 reports. All final reports are now available in draft form and in most cases they were sent out to the participants prior to the workshop. An outline for the Executive Summary report was presented and the content of the report was discussed.

The Coordinating Group meeting was held on the 24th of April, 1991. The Coordinating Group decided not to include Poços de Caldas as an test case in INTRAVAL Phase 2 since no Project Teams have indicated their interest in modelling the experiment. Due to the deletion of the Poços de Caldas experiment a rearrangement of the structure of the Phase 2 Working Groups were proposed, moving the Twin Lake case from Working Group 1 to Working Group 4 (see Table 1). The Coordinating Group also decided to dissolve the VOIC (Validation Overview and Integration Committee) as Phase 1 of INTRAVAL is ended. It was decided to form a new group for Phase 2 with the major objective to support the secretariat in writing the final reports.

The next INTRAVAL meeting will be held in Sydney, Australia on the 10th through 14th of February, 1992. The tentative plans for remaining INTRAVAL Workshops are: November 1992, October 1993 (last workshop) and May 1994 (Final meeting). Prior to the next INTRAVAL workshop separate Working Group meetings are planned, see Table 2.

Table 2. Planned Working Group meetings.

Working Group	Date	Location
1	June 27, 1991	Washington
2	Oct. 9–12, 1991	New Mexico
3	Oct. 14–16, 1991	New Mexico
4	June 12–15, 1991 Sept. 9–11, 1991	Sydney Chalk River

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in an Executive Summary Report and a series of Technical Reports. The Technical Reports will cover the descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports will describe in detail the experiments on which the test cases are based. The technical reports are being prepared by six Working Groups. An editor for each test case has been appointed and the responsibility of the editors are to compile the test case analysis provided by the Project Teams that have worked with the test case.

A draft version of most of the technical reports were available to the participants prior to the workshop in Seattle. The draft versions were discussed during the workshop and the responsible editors will as a next step include given comments and prepare a new version.

The technical report describing the experiments on which the test cases are based has been circulated for approval among the Pilot Groups, and given comments have been included. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC (Validation Overview and Integration Committee).

The Summary Report and the Technical Reports are planned to be published in the spring 1992.

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University College Ranch, 40 km northeast of Las Cruces in New Mexico, USA. Water and tracers are applied in a controlled fashion to the surface of an experimental plot. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4×9 m and 1×12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas.

In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4×9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1×12 m) on the opposite side of the trench and in the third experiment tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area. The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition, laboratory experiments on cores have been performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from PNL/USNRC has performed two dimensional simulations of the Plot 2b experiment with the integrated finite difference code PORFLO-3. The model domain is 12×6 m. Semivariograms were used to estimate the covariance of the saturated hydraulic conductivity. The saturated hydraulic conductivity measured in the laboratory does not show a lognormal distribution, whereas the field measurements of the saturated hydraulic conductivities show more of a lognormal distribution. The water content distribution from neutron probes and the tritium concentration from core samples were used as initial conditions. A flux of 1.8 cm/day and a normalised tritium concentration of 1.0 was applied over an area corresponding to a strip source. Zero-flux boundaries were applied at the remainder of the top boundary and at the sides. The lower boundary was set to be unit gradient. The results showed some correlation between the simulations and the experiments. Further research will include Monte Carlo simulations.

The Project Team from SNL/USNRC presented their work performed for INTRAVAL Phase 1 together with their plans for Phase 2. They will identify a performance measure closely related to the regulations for low level waste. The simulations planned to be performed are Monte Carlo simulations using a two-dimensional heterogeneous field and Richards equation model.

The Project Team from CNWRA/USNRC presented a preliminary study of the Plot 2a experiment. They used a modified version of the integrated finite difference code PORFLO-3. The hydraulic properties of 180 soil sample locations were used, which means that each sample represents a subzone with individual properties in the two-dimensional grid used to represent the trench wall. It is planned to perform a series of calculations with different solute concentration boundary conditions, i.e. prescribed concentration or prescribed mass flux during the infiltration of tracers and zero concentration or zero mass flux when the supply of tracer is cut-off. The future plans is to assess the worth of soil hydraulic data, initial water content and solute sampler density. The Plot 2a experiment will be used for calibration and the Plot 2b experiment will be predicted based on this calibration.

The Project Team from CNWRA/USNRC discussed validation and refutation of models by testing procedures for unsaturated flow models. Spatially distributed models differ by their degrees of freedom, which are determined by the product of the number of heterogeneities, number of effective flow domains and effective dimensionality. A black box model has no degree of freedom, whereas, a homogeneous column has one degree of freedom. A deterministic three-dimensional strip source infiltration model with 300 000 material heterogeneities has 10^6 degrees of freedom. The numerics of a code can be tested by truncation error analysis, stability analysis, and mass balance analysis. Other internal and comparative tests are comparisons with analytical solutions, comparisons between coarse and fine mesh predictions, and inter-code comparisons.

Other topics to look at are uncertainties due to sparse sampling and incomplete knowledge of spatially distributed and non-linear properties of unsaturated medium in situ. The degree of validation has to be quantified via a performance measure. Probabilistic decision making could be performed by comparison of models differing only in the value of some adjustment parameters. Another test is to correlate a single model to observations and evaluate the probability of error and compare with actual prediction errors. Tests of consistency and numerical occurrence are an integral part of validation. However, only refutation and not validation is possible by logical inference.

APACHE LEAP TUFF

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, U.S.A

Experimental Set-up and Scales

The test case is based on field experiments performed at the Apache Leap Tuff Site in tuffaceous rock near Superior, Arizona, USA, with the aim to predict water flow and solute transport through unsaturated fractured rock under field conditions. A multistage experimental plan is used to estimate parameters related to hydraulic, pneumatic, thermal and solute transport in unsaturated tuff. Laboratory experiment have been performed on drill cores and on rock blocks to determine important parameters for solute transport, fracture flow, thermal induced flow, etc. These experiments were included also in INTRAVAL Phase 1. Fifteen boreholes have been installed and used for the in situ site characterisation. The INTRAVAL Phase 2 study is focused on two related field experiments, one with and one without imposed temperature gradients. Data for the first experiment are available or underway and the field heating experiment will begin at the end of 1991. The INTRAVAL participants are invited to perform predictive modelling. Water and gas injection recovery tests are currently underway to determine temporal and spatial responses as well as other flow characteristics.

Analyses by Project Teams

The US NRC Project Team presented some modelling results for the large block experiment included also in INTRAVAL Phase 1. They had examined two different blocks (0.2×0.2×0.5 m and 0.2×0.2×0.7 m) containing a natural fracture oriented vertically near the centre. The blocks were mounted on a support frame and enclosed within a chamber to prevent evaporation. Water was then supplied at a constant head on the top and the water potential was measured with microtensiometers. The two-dimensional finite element code VAM2D was used in the performed simulations. The aim was to test the fracture matrix flow concepts. Both the matrix and the fracture (0.1 cm wide) were treated as equivalent porous media. The effective porosity of the fracture was set to 97% and the van

Gneuchten characteristic curve data were taken from the literature. The major conclusions were that the fracture acts as a barrier and that the code overpredicts the wetting front movement.

The Project Team from UAZ/US NRC presented their research work concerning the use of pneumatic testing to determine hydraulic properties of rocks. The major advantage with pneumatic tests are that they can be performed faster than hydraulic tests. The techniques to be used are adapted from gas and oil industry.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of a fractured zone including a large-scale interference test and two large-scale tracer tests, one radially converging test and one dipole experiment. This test case was included also in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling since it became available too late. The modelling of the dipole experiment will therefore be the focus of Phase 2.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to 10^{-4} m^2/s, the middle layer to 10^{-7} - 10^{-6} m^2/s and the lower layer to 10^{-4} m^2/s. The middle layer is not continuous. A fresh water - salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below than above the zone. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock is penetrated by several core-drilled and some percussion-drilled boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes at 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells, totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbed tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from CEA/IPSN presented their plans for this test case. They contributed to this test case also during INTRAVAL Phase 1 but will now use an improved synthetic model for their simulations. The flow parameters will be interpreted from the interference test using an inverse model. Thereafter a global model will be set-up for all boreholes and the tracer tests will be simulated.

The Project Team from VTT/TVO discussed their modelling results and also phenomena, geometries and source terms in field experiments in fractured rock. The first phenomena to be studied is the hydrodynamic dispersion because it is unavoidably encountered in any experiment. Dispersion cannot be controlled just by one experiment as it is both time and length dependent. Actually the dispersion as such is not of primary interest for nuclear waste repository performance assessment as the waterflow rates in the repository conditions means that matrix diffusion will disperse pulses much more than the hydrodynamic dispersion.

To study the matrix diffusion the water flow rates in the experiments should be as small as practically possible. Retardation due to sorption should be studied not only in batch type experiments but also in transport experiments by injection of both non-sorbing and sorbing tracers at identical conditions. It should be confirmed that the potential field used during the experiment is stable against small variations. The transport paths should be studied one by one, as superposition of the different curves is easier than to identify the contributions from different flow paths from a composite curve. The duration of injection of tracers shall be as short as possible and the concentration should not be so high that the properties of the injected solution deviates too much from the properties of the carrier flow.

The Project Team has modelled both the radial and the dipole experiments during Phase 1 using a concept of channelled flow in two dimensions and also tracer transport in two dimensions in channels with varying aperture with a linear velocity profile. The transport times were calculated from measured transmissivities in boreholes. A fixed value of 5 cm were used for the characteristic width over which the velocity varies from zero to its maximum value. The measured breakthrough curves were very sensitive to the length of the injections, which were not measured very accurately. However, an overall agreement between the calculated and measured breakthrough curves was obtained in both experiments.

Conterra/SKB presented some modelling work performed for Finnsjön related to their internal project SKB-91. They have performed stochastic continuum modelling of mass arrival at Finnsjön with both unconditional parametric and conditional non-parametric approaches. A vertical section of Finnsjön, 1 km long, has been looked at. Data were collected from five boreholes in Zone 2. 50 realisations were run to get the hydraulic conductivity field for each method. It was difficult to compare the two methods and the effects of conditioning could be seen. The non-parametric conductivities were generally lower than the parametric. Both groundwater simulations, mass arrival and particle tracking analyses were performed. It was concluded that Zone 2 acts as a barrier for transport.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiments, Sweden.

Experimental Set-up

This test case is based on three dimensional tracer tests performed in the Stripa mine in Sweden. The experiment forms part of the International Stripa Project.

An experimental drift was excavated in the old iron-ore mine in Stripa. The 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 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, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments. The experiment was a test case also during INTRAVAL Phase 1.

In addition to the 3D tracer experiments data from two other experiments performed in the Stripa mine, the 'Channelling experiment' and the 'Site Characterisation and Validation Program', will be made available to the INTRAVAL Participants during Phase 2. The channelling experiment consists of two kinds of experiments. In the single hole experiments, holes with a diameter of 29 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture in 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simple packer systems. A double hole experiment was also performed, for which two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were made between the holes in both directions. Tracers were injected at five locations in one hole and monitored at many locations in the other hole. The 'Site Characterisation and Validation Program' includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes, and finally a new drift was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analysis by the Project Teams

The Project Team from BRGM/ANDRA is working with the 3D tracer experiment. They use a classical approach and have finalised the geometrical model and are working with the flow model. Thereafter the transport model will be tackled. The geometric model is based, i.a., on statistics of fractures and fissures. The model contains three main sets of fractures, one sub-horizontal and two sub-vertical. The fractures are simulated as circular discs in a three dimensional network. Very small fractures have been eliminated as their importance for flow and transport has been found to be of minor importance. The elimination of small fractures has, however, an impact on the connectivity. The flow simulations are made with the code TRINET. The flow model is smaller than the network model in size. Simulations have been performed both with constant conductivities and log-normal distribution of the conductivities.

The Project Team from VTT/TVO presented some results for this test case. They have used the same model as presented earlier for the Finnsjön experiment, i.e. a generalised Taylor dispersion model. In this case they used two to four channels and the properties of the channels were adopted from Chin-Fu Tsang, LBL, who has used a deconvolution technique, in which long and varying injection rates are taken into account when studying the transport properties of channels. The characteristic width of the velocity profile in the channels varied between 2 and 15 cm, which would indicate that hydraulic dispersion dominates over matrix diffusion for this experiment. Actually, the breakthrough curves could be explained entirely by hydrodynamic dispersion alone. Some preliminary sensitivity studies have been initiated.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development facility. The WIPP is located in the Delaware Basin, of which the northern part is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporites. Water bearing zones within the rocks that underlie, host, and overlie the WIPP repository have low permeabilities and storativities, are generally confined, and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been obtained to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells to the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests each of two months duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Pilot Group has evaluated the experimental data. The transmissivity in the Culebra varies in the range from $< 10^{-9}$ to $> 10^{-3}$ m^2/s, due to fracturing. The evaluation of fracture properties and distribution is necessarily qualitative, relying on interferences drawn from pumping tests, as the cores are too broken to allow statistical studies where the fractures are located. The hydraulic tests, performed at a variety of scales, ranging from single-well drillstem tests to long-term pumping tests, have been interpreted using an analytical solution for homogeneous single- and double porosity systems. The interpreted transmissivities change as the scale of test changes reflecting a heterogeneous distribution of fractures. Double-porosity simulations gave good fit to the pumping test drawdown response. Simulations of the transient responses with a transient-calibrated transmissivity field gave also rather good fit to observed head values within the uncertainty of the measurements. The models used assumed homogeneity and one question is on what spatial scale, or over what range of hydraulic properties a homogeneous model can provide representative properties.

The convergent tracer tests have been analysed using a one-dimensional radial-flow, double-porosity model, SWIFT II. Three orthogonal fracture sets were simulated and anisotrophy were incorporated by making flow rate a function of direction. Dispersivity was approximated as 10% of the flow-path length, matrix porosity (0.16) and tortuosity were derived from core tests. The fracture spacings were set within the range 0.15–0.48 m and anisotropies (K_x/K_y) between 3 and 7 were needed to match the breakthrough curves (example in Figure 1).

The Pilot Group has also performed two-dimensional calculations of the flow field and the fastest travel paths in the Culebra dolomite. The system consists of a borehole penetrating both the repository and an underlying pressurised brine pocket, with contaminant release and offsite transport in the overlying Culebra. The transmissivity distribution in the Culebra has a variance of 6–7 orders of magnitude. To get a good fit of the transmissivity distribution, both real points and added data point were needed. The model used for contaminant transport is a double porosity model with variable density flow. The maximum breakthrough for a conservative nonretarded solute is reached after about 10 000 years at a boundary 5 km away.

The Project Team from INTERA/NIREX has looked at how the transition from field data to a realistic full flow and tracer model simulation can be facilitated. What does the field data tell about spatial variability on scales from the inter-well distances downwards? They have used the measured transmissivities in order to address the inverse problems for flow and transport. The analysis uses a conceptual rock-property model based on the statistical self-affinity of fractals, which yields realisations of measured fields, conditioned by the data points. The Project Team uses one by themselves developed code AFFINITY. The transmissivities from 39 wells within the WIPP model region were used to obtain a variogram. The AFFINITY code generated the realisation of the transmissivity field matching the structure of the variogram, interpolating all 39 measurements. As a check 151 random samples from the realised field were used in order to generate a synthetic variogram which compared well with the original, see Figure 2. The pressure field and associated Darcy velocity field calculated from the realised transmissivity field indicates a highly channelled flow. A similar calculation including a single borehole pump test shows that the flow is concentrated into a few discrete channels. A borehole injection test was also simulated by tracking particles through the flow field after being initially placed at a single location.

The Project Team from AEA/NIREX presented their proposed approach to the test case as well as some preliminary results. The Culebra database is very large. This offers the opportunity to build models based on a subset of data and then to use these models to make predictions which can be tested against already known data. The methods intended to be applied are primarily of geostatistical nature and the feeling is that this is the best scientific approach to problems of spatial variation and uncertainty. There are two basic types of geostatistical methods. In the first type, statistical methods, such as kriging, are used to estimate hydrogeological parameters which are then fed into purely deterministic flow and transport calculations.

The second method, which is intended to be used by the team, is a stochastic approach. The groundwater flow and transport problems are treated as stochastic differential equations solved by simulations or Monte Carlo methods. In the first phase of the work a very simple stochastic model will be used and a set of Monte Carlo simulations will be performed. The Turning Bands method will be used to generate a set of realisations of the transmissivity, which will have a multivariate log-normal distribution and an exponential variogram with the parameters obtained from the available experimental transmissivity data. These unconditional simulations will be conditioned on the known transmissivities. Particle paths and transit times will be calculated from the computed pressure or head fields. So far an experimental variogram for the logarithm of the transmissivity based on some of the measurements has been calculated. Attempts have also been made to fit four different model variograms to the data, namely spherical, exponential, gaussian and cubic. The best fits were achieved with spherical and exponential variograms, and in these cases no nugget effects were required. The parameters calculated for the exponential variogram were used in a conditional simulation of the transmissivity field. Finally, particle paths were calculated. The calculations will be developed and refined and detailed comparisons with the experimental data as well as with the results of other groups will be made in the future.

The Project Team from VTT/TVO have performed preliminary analyses of three tracer breakthrough curves from one of the tracer test (H-11). They used the same model as was used for both the Finnsjön and Stripa test cases. The breakthrough curves are very asymmetric and the first part of the tracers arrives very fast. The explanation to this could be that many channels could be involved and there might be a very large matrix diffusion, similar to diffusion into stagnant water in areas with porosity of the order of 1. There might also be a time dependent source term, releasing tracer over several hundreds of hours, which might give the observed long tail. Only one channel was included in the model but the injection procedure resulted in a spreading of the tracer out in the surrounding followed by a slow recovery and further transport in the channel. The model seems to reproduce the observed breakthrough curves rather well, see Figure 3.

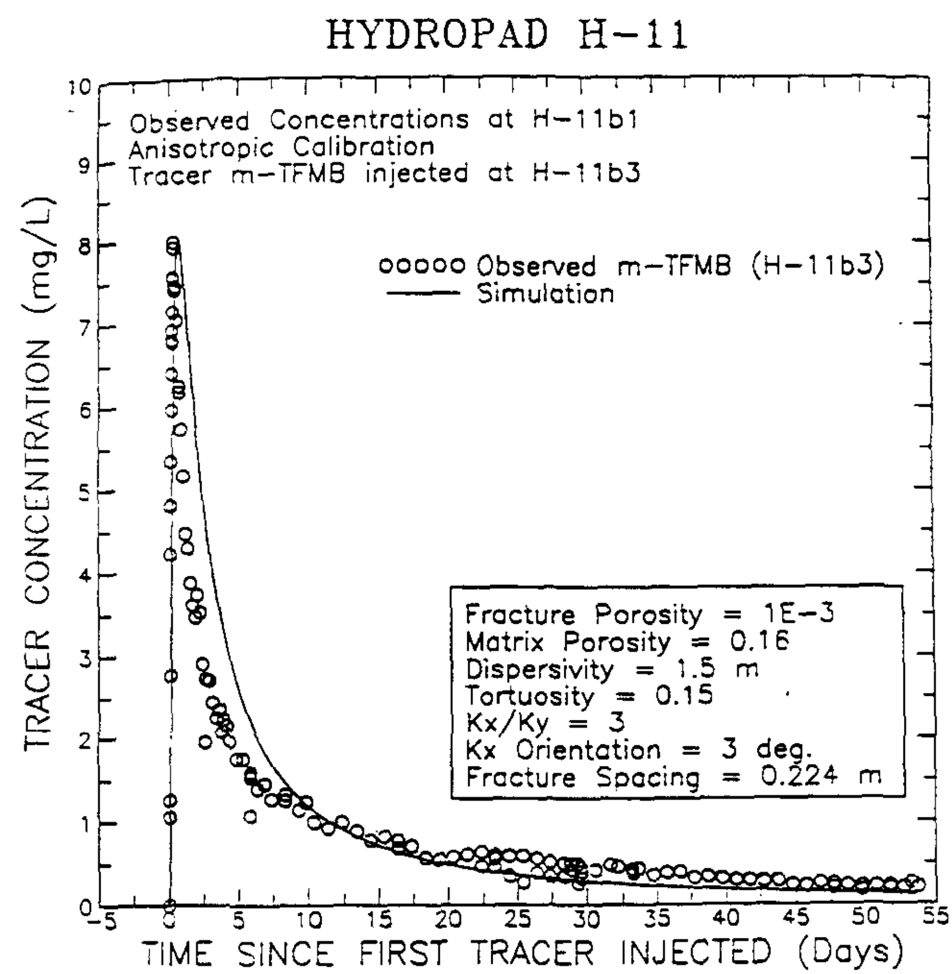

Figure 1. Tracer concentration versus time. The figure shows both observed values and the results of a simulation. (WIPP 2)

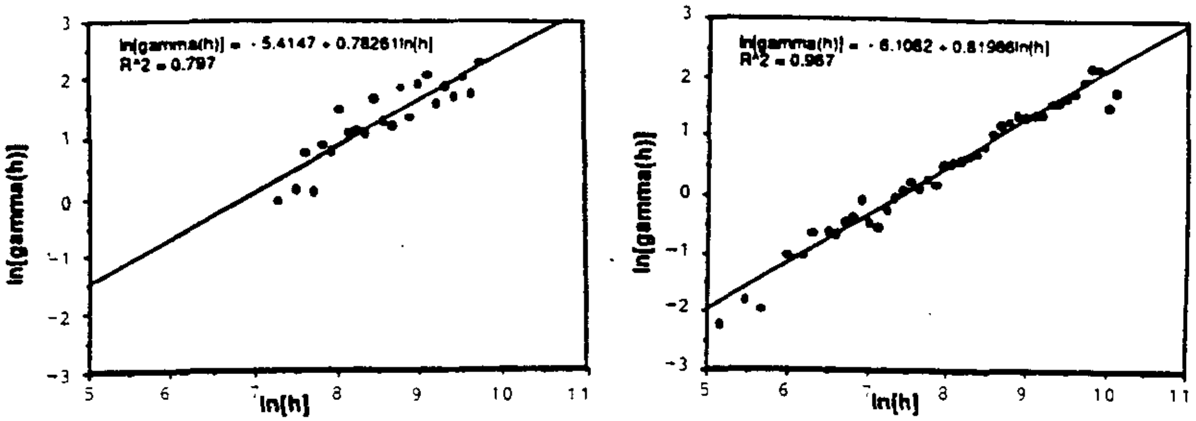

Figure 2. (a) Variogram fitted from transmissivity data of 39 wells. (b) Synthetic variogram fitted from 151 random samples from final realisation. (WIPP 2)

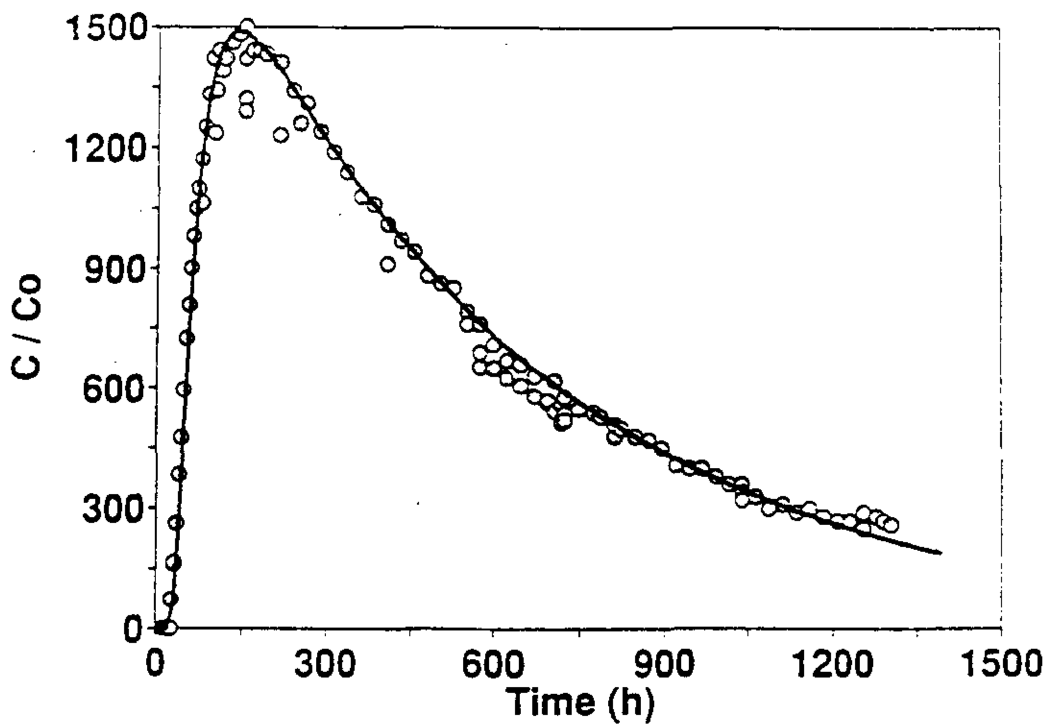

Figure 3. Breakthrough curve. Figure shows observed values (dots) and results of a simulation (line). (WIPP 2)

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental set-up

The Gorleben salt dome is located in the north-eastern part of Lower Saxony in the Federal Republic of Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel the 'Gorleben Channel' more than 10 km long and 1 - 2 km wide crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in the fresh water and three in the saline water. One of the pumping tests, where the pumped well penetrates the entire deeper aquifer in the erosional channel, will form the bases for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of 3 weeks. The second part of the test case is an extension in both time and length scales and comprises regional groundwater flow modelling and salt dissolution as well as the interaction between the two.

Analysis by the Project Teams

No presentations were given by the Project Teams during the INTRAVAL workshop, but contributions are expected from a number of teams in the future.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental set-up

The WIPP, located in Carlsbad, New Mexico is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments will form the bases for this test case:

— small scale brine-inflow experiments
— pore pressure and permeability testing
— integrated, large scale experiment.

Brine inflow rates are measured at three scales: in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal cylindrical room, 107 m long with a diameter of 2.9 m.

Analysis by the Project Teams

The Pilot Group has made interpretations of data. The model used to analyse the small-scale experiments is one-dimensional, radial. Darcy flow assuming a homogenous isotropic medium and a uniform initial pore pressure. The apparent diffusivities are on the order of 10^{-10}–10^{-7} m^2/s determined from the rate of decay of the brine inflow rate. The permeability is determined from the magnitude of the brine inflow rate, and are on the order of 10^{-10}–10^{-7} m^2/s, if the brine viscosity is assumed to be $1.6 \cdot 10^{-3}$ Pa·s and the pore pressure is

10 MPa. A lot of activities are underway both concerning the experiments and the interpretation of data, i.e. determination of parameter uncertainties for the data set, statistical evaluation of the data, modification of the used model to include more complex processes, redesign of the measurement equipment and procedures as well as planning for additional measurements and experiments.

The Pilot Group has also interpreted some of the permeability tests (S0P01 and L4P51). They have used the code GTFM, a one-dimensional radial-flow model. Fully confined porous medium with uniform permeability and pressure throughout the tested layer was assumed. The fitted parameters were the hydraulic conductivity, the formation pore pressure and the distance to a boundary. The specific storage and the test-zone compressibility were assumed parameters. The classical groundwater definition for the specific storage, assuming negligible grain compressibility, gives a specific storage about a factor four lower than the complete definition as the porosity in the deformable halite is very low, 0.1–3%. Compressional-wave velocity of halite is observed to decrease by up to 50% in the disturbed rock zone around the repository which can be translated to a 400 % increase in specific storage. The conclusion is that the specific storage is important. The interpretations of the two tests show that the hydraulic behaviour appears to be that of a porous medium with a hydraulic conductivity of about $4 \cdot 10^{-14}$–$6 \cdot 10^{-14}$ m/s and a formation pore pressure of about 2–4 MPa and no indications of boundaries out to at least 8 m in the first test (S0P01) and a no-flow boundary 2 m from the borehole in the second test (L4P51).

MOL

Migration experiment in Boom Clay Formation at the MOL Site, Belgium.

Experimental set-up

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, called piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady state pressure distribution as a function of the depth into the clay was measured by manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the centre) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6, located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are at the time being limited.

Analyses by the Project Teams

The Pilot Group presented results from performed modelling. The Boom clay has been modelled as a homogeneous anisotropic medium as clay is a stratified medium and the governing transport mechanisms considered were advection–dispersion. A number of measured concentrations at filter 4 and 6 are available and the modelled results for these points gave rather good fits, see Figure 4, for the following parameter values: hydraulic conductivity $3.2 \cdot 10^{-12}$ m/s, hydraulic gradient –18.9 m/m, Darcy velocity $6.0 \cdot 10^{-11}$ m/s, dispersion length 0.002 m. The tracer HTO has a retardation factor of 1. The diffusion accessible porosity was set to 0.35, horizontal dispersion to $4.1 \cdot 10^{-10}$ m^2/s and vertical dispersion to $2.0 \cdot 10^{-10}$ m^2/s. The sensitivity to the diffusion accessible porosity (0.30–0.40) and the hydraulic conductivity ($3 \cdot 10^{-12}$–$1 \cdot 10^{-10}$ m/s) was studied before the values of the parameters were selected.

The Project Team from SNL/USNRC has applied a special validation strategy developed during INTRAVAL Phase 1 to Mol site data. A quantitative evaluation of fit between theory and experiments for suggested parameter values was made. An analytical solution of the convective dispersion equation was used to calculate the breakthrough of HTO in filters 4 and 6. Three cases were studied. A base case using bench-scale variables with convective dispersion, a diffusion only analysis with fitted parameters, and a convective-dispersive case with fitted parameters. Three different methods of comparisons between measured data and calculated data were used; eyeball, linear regression of measured vs calculated data and residual analysis (both eyeball and runs analysis). A fourth method for comparisons, variogram of residuals, is planned for but the database does not include enough data yet. The outcome of the analyses are presented in Table 3 below. The base case could be rejected according to the outcome of all tests except for the residual runs analysis. The pure diffusive case and the convective-dispersive case with fitted parameters could only be rejected in the residual runs analysis. The conclusions are that the performed analysis could not differentiate between the tested conceptual models and that the data base is too limited.

Table 3. Summary of comparisons (MOL).

Test	Base case	Diffusion	Convection–dispersion
Eyeball	reject	not reject	not reject
Linear regression	reject	not reject	not reject
Residual analysis, eyeball	reject		
Residual analysis, runs	not reject	reject	reject

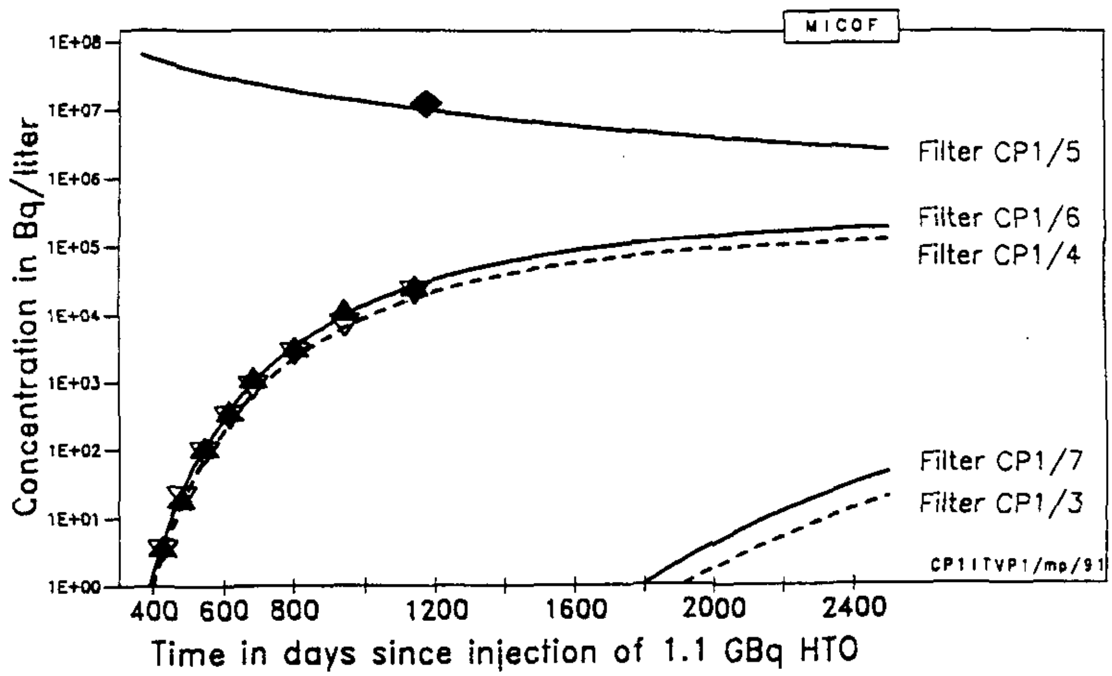

Figure 4. Breakthrough curves. The figure shows both observed values and results of simulations. (MOL)

ALLIGATOR RIVERS

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

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies, which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental program including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Analyses by the Project Teams

The Project Team from CISRO/ANSTO has performed both two- and three-dimensional modelling of the groundwater flow through the Koongarra uranium orebody. Earlier modelling studies of the area has shown a considerable uncertainty not only in hydraulic conductivities but also in the locations and types of model boundaries. Therefore this group decided to investigate flow in vertical sections at a much larger regional scale than has been done before with the aim to identify the real boundaries of the local flow system near the orebody. They simulated the flow in a cross-section oriented from northwest to southeast which passes through the Koongarra orebody.

The finite element grid used was rectangular with a length of 26 km and depth in the range of 1 to 3 km. The results of the two dimensional large scale modelling gave some confidence that three-dimensional modelling of the smaller region near the orebody may be relatively insensitive to the thickness of the Kombolgie sandstone and the depth of the impermeable bedrock. The two-dimensional modelling in vertical section showed the likelihood of a creek to act as a discharge boundary for the groundwater system, and the break in slope and the change in hydraulic conductivity between the Kombolgie sandstone and Cahill schist being the other major discharge region. In addition to the two-dimensional modelling, aerial photographs showed several distinct vegetation boundaries. Based on this information the appropriate domain for modelling the local groundwater system would be almost triangular. A finite difference model, BIGFLO, was used for the local simulations. The studied region was 3×3 km and 1 km deep. Groundwater surface elevations were defined at all nodes along the creek and along several other lines. In the top layer high flow rates were seen in the weathered zone and in the Koongarra Fault. It was observed that the flow is from northwest to southeast at the right side of the domain and much more towards the south at the left side.

The Pilot Group has also been studying the uranium activity ratios in different iron mineral phases to look for time indication keys in the system. The activity ratio of ^{234}U to ^{238}U and ^{230}Th to ^{234}U in both amorphous (accessible) and crystalline (inaccessible) iron phases has been modelled and compared with experimental data. The model assumes one dimensional advection dispersion in porous medium and the rock stratum is presented as a series of one dimensional boxes. The interaction between rock and water is modelled as two general processes, leaching and deposition, i.e. the K_d concept. The radionuclide transfer between the two rock mineral phases are nucleus recoil. The processes of crystallisation considered is structural rearrangement of ferrihydrite to hematite or crystallisation of ferrihydrite to goethite (through ferric(III) ions). The K_d-values and porosities used were experimentally determined and the water flow velocity was from hydrology findings. Phase transition rates and estimates of recoil transfer were fitted parameters. The model was fitted to the activity ratios vs distance in both accessible and inaccessible rock, as well as to the concentration ratio between accessible and to inaccessible rock vs distance, and the total uranium concentration in the selected region. The very initial curves presented were found to be quite sensitive to all parameters.

The Project Team from US NRC presented results from geochemical modelling of the formation of secondary uranium minerals at the Koongarra site. Two phases of secondary uranium mineralisation can be distinguished: in situ alteration of pitchblende to uranyl silicates (sklodowskite, uranophane) and formation of uranyl phosphates (saleeite, torbernite) from mobilised uranium in the dispersion fan. These latter processes have been simulated by making reaction path calculations with the code EQ3/6 using data from the site on water chemistry and minerals.

Regarding the formation of uranyl silicates, it was concluded that the model results are consistent with modern formation of the uranyl silicate zone from reaction of silica-rich water with uraninite, but present uranium levels in the water are generally too low to form uranyl silicates. Furthermore, the uranyl silicate minerals formed in the calculations are not the same as those formed at the site. This was concluded to be mainly a result of lack of data in the uranyl silicate data base.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental set-up

Aquifer testing ranging from large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of AECL research facilities, the Chalk River Nuclear Laboratories. The laboratories are located 200 km northwest of Ottawa, Canada, in the Valley of Ottawa river. The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes natural gradient tracer (^{131}I and HTO) experiments over distances 20, 40 and 260 m. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contribute hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations etc.

Analysis by the Project Teams

The Project Team from SNL/USNRC has made some initial analyses of the Twin Lake data. After evaluation of the experiment they applied a validation strategy developed during INTRAVAL Phase 1. It was pointed out that when model and experiment do not agree the reason can either be problems with the used model or problems with the experiments. It is therefore important to determine whether an experiment is adequate for model validation before starting the modelling. The adequacy of the Twin Lake data are based on the consistency of flow and transport and the mass balance. Part of the validation strategy developed consists of testing model structures and comparison of model results and experimental results. Three different techniques for comparisons were used, experimentally determined concentrations versus modelled concentrations, concentration residual versus time, and variogram analysis of residuals. Statistical tests, such as linear regression and residual analysis are needed to translate graphs into quantitative measures. The tests discussed so far only give probabilities of rejecting a good model and no information about acceptance of a bad model. Previous modelling by the Pilot Group with a one dimensional advective–dispersive model, and the experimental breakthrough curves at a preselected position as performance measure, indicates a model structure error with all the different comparison techniques.

The Project Team from CEA/IPSN presented their view on this test case. The main points of interest are that the dataset contains a great number of measured points at different time and spacial scales. In their modelling work they will use the finite element code METSIS.

The Project Team from CEA/DEMT/ANDRA plans to perform stochastic modelling using the finite element integration code TRIO. The problem at the time being is high Peclet numbers in the used mesh and lack of permeability data.

Distribution of Background Information and Databases

Background information and databases will be distributed to the INTRAVAL Participants either by the Secretariat or by the Pilot Groups according to Table 4. The information is distributed only on request from the Project Teams.

Table 4. Distribution of Background information and databases.

Test case	Distributor	
Las Cruces Trench	Pilot Group	T. Nicholson, NRC[1)]
Apache Leap Tuff	Pilot Group	T. Nicholson NRC[1)] T. Rasmussen, UAZ[1)]
WIPP 2	Pilot Group	E. Gorham, SNL[1)]
Gorleben	Pilot Group	K. Schelkes, BGR[1)]
Alligator Rivers	Pilot Group	P. Duerden, ANSTO[1)]
Twin Lake	Secretariat[2)]	
Finnsjön	Secretariat[2)]	
Stripa	Secretariat[2)]	
WIPP 1	Secretariat[2)]	
Mol	Secretariat[2)]	

1) Full organisation name, see List of INTRAVAL Participants in Appendix 1
2) Kemakta Consultants Co., Pipersgatan 27, S-112 28 Stockholm, Sweden

Other Information

S. Hossain, IAEA, presented an ongoing International Project (NSARS) where the application of geospheric models in an integrated safety assessment of near-surface radioactive waste disposal facilities are studied. 17 organisations from 17 different countries participate in the project. The objectives of the project are to:

- improve confidence in the results of safety assessments through model intercomparison and validation
- help in establishing international consensus on the approaches to safety assessment
- facilitate exchange of information, its documentation and wider dissemination.

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 Inspectorate (SKI) acts as Managing Participant. 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 expenses, 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.

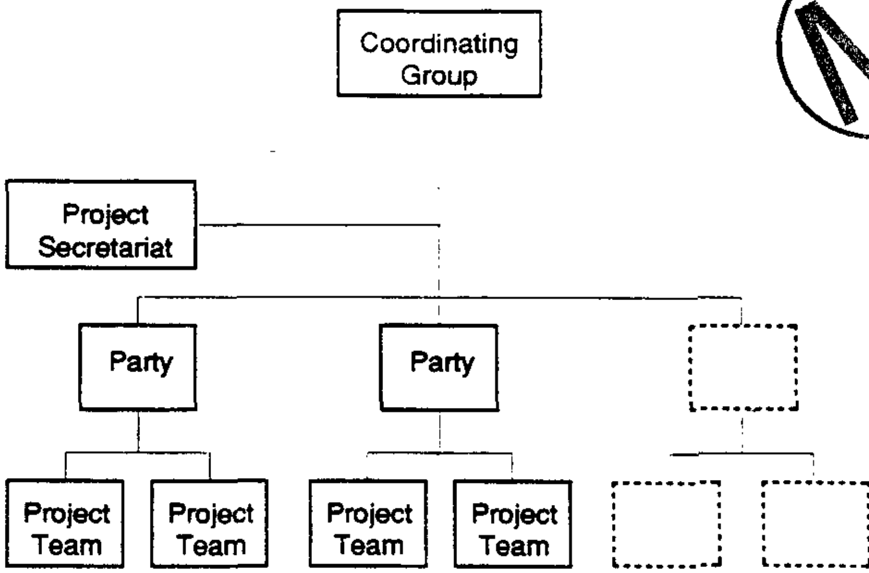

Figure 5. INTRAVAL Organisational Chart.

Managing Participant:	SKI
Coordinating Group	
Chairman:	K. Andersson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	J. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	K. Andersson, SKI
	J. Andersson, SKI
	M. Ericsson, KEMAKTA
	B. Grundfelt, KEMAKTA
	P. Jackson, AEA Technology
	A. Larsson, KEMAKTA
	K. Pers, KEMAKTA
	K. Skagius, KEMAKTA
	C. Thegerström, OECD/NEA

List of INTRAVAL Participants

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
Agence Nationale pour le Gestion des Déchets Radioactifs, France L. Dewiere	(ANDRA)	Commissariat à l'Energie Atomique M. Durin	(CEA/DMT)
		Bureau de Recherches Geologiques et Minières J.P. Sauty	(BRGM/STO)
Atomic Energy of Canada Ltd., Canada T. Chan	(AECL)	Atomic Energy of Canada Ltd. T. Chan (AECL-WR) G. Moltyaner (AECL-CRL)	(AECL)
Atomic Energy Control Board, Canada D. Metcalfe	(AECB)	Atomic Energy Control Board, D. Metcalfe	(AECB)
Australian Nuclear Science and Technology Organisation, Australia P. Duerden	(ANSTO)	Australian Nuclear Science and Technology Organisation C. Golian	(ANSTO)
Bundesanstalt für Geowissenschaften und Rohstoffe/ Bundesamt für Strahlenschutz, Federal Republic of Germany K. Schelkes (H. Illi)	(BGR/BfS)	Bundesanstalt für Geowissenschaften und Rohstoffe K. Schelkes	(BGR)
		Bundesamt für Strahlenschutz	(BfS)
Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire, France J. Gomit	(CEA/IPSN)	Ecole Nationale Supérieure des Mines de Paris P. Goblet	(EDM)
Empresa Nacional de Residuos Radioactivos, S.A., Spain J.C. Mayor	(ENRESA)	Universidad Politécnica de Valencia J. Gomez-Hernández A. Sahuquillo	(UPV)
Gesellschaft für Reaktorsicherheit mbH, Federal Republic of Germany P. Bogorinski	(GRS)	Gesellschaft für Reaktorsicherheit mbH P. Bogorinski	(GRS)
Forschungszentrum für Umwelt und Gesundheit, Federal Republic of Germany R. Storck	(GSF)	Forschungszentrum für Umwelt und Gesundheit E. Fein	(GSF)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
Her Majesty's Inspectorate of Pollution, United Kingdom K. Butter	(HMIP/DoE)	Atkins Engineering Sciences T. Broyd	(AES)
Industrial Power Company Ltd., Finland J. Vira	(TVO)	Technical Research Centre of Finland S. Vuori	(VTT)
Japan Atomic Energy Research Institute, Japan H. Matuzuru	(JAERI)	Japan Atomic Energy Research Institute H. Kimura	(JAERI)
		Central Research Institute for the Electric Power Industry M. Kawanishi	(CRIEPI)
		Hazama-gumi A. Kobayashi	(HAZAMA)
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Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, U.S.A. Water and tracers are applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone is monitored. This test case was included also in INTRAVAL Phase 1. During Phase 1, data for site characterisation and model calibration were collected. In a new experiment (Plot 2b)during phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport .

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4× 9 m and 1×12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium has been applied at a controlled rate of 1.8 cm/day on the area sized 4× 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracer below the surface of the soil. The movement of the water front was also observed visually on the trench. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1×12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) will be added with the water on the area sized 1×12 m.

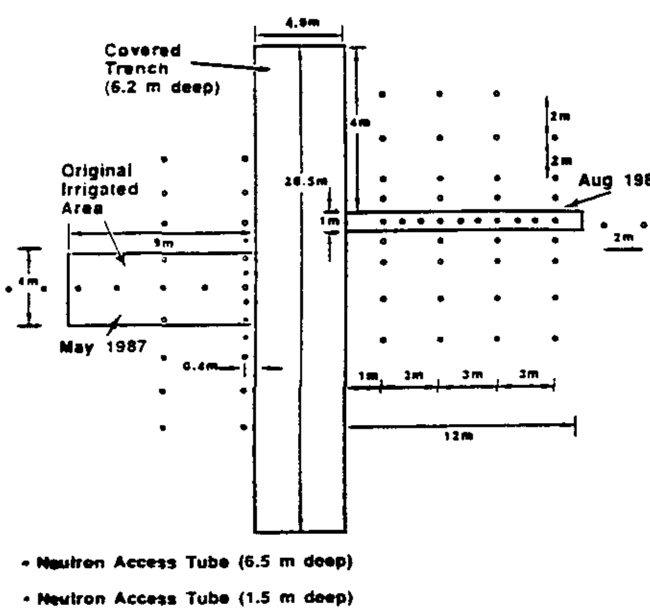

Figure 6.Top view of the trench with irrigated areas.

Available data

- — water retention data
- — density profiles
- — particle-size analysis data
- — saturated hydraulic conductivities (laboratory and in situ)
- — water content
- — tensiometer data
- — solute concentration

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

Field experiments are conducted at the Apache Leap Tuff Site in tuffaceous rock near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depth due to topography and to pumping associated with a near-by underground mine. Laboratory experiments are conducted using cores obtained during borehole drilling at the field site and using shaped blocks removed from the field site. Relevant processes include hydraulic, pneumatic, thermal, and solute transport components which will be [illegible]ugated using experiments over several length and time scales, on cores (6–10 cm, minutes), rock blocks (50 cm, month), in situ (1–30 m, years). This test case was included also in INTRAVAL Phase 1, where the main efforts were spent modelling the laboratory core and block experiments. The ultimate objectives of this case in Phase 2 will be to water flow and solute transport both with and without imposed temperature gradient under field conditions. In addition, laboratory core heater measurements are performed estimate important parameters.

Field experiments

The experimental site with an undisturbed thermal regime has been under study for three years. Fifteen boreholes were installed (twelve inclined and three horizontal) and used for the in situ site characterisation, while the obtained cores are used for logging the fractures and characterizing the rock matrix. A plastic cover was placed over the rock surface (30× 50 m) to prevent evaporation as well as precipitation from infiltrating into the rock. These experiments included testing for temperature, water conctnet and saturated hydraulic conductivities.

Water and gas injection-recovery tests are currently underway to determine temporal and spatial responses as well as other flow characteristics. The experiments should be completed by the end of 1991.

The purpose of the field heating experiment is to evaluate the magnitude and distribution of induced fluid flow around a heat source in unsaturated fractured tuff. The experimental plane for this experiment will consider preliminary experiment conducted in a road tunnel for which some data sets are available. The experiments will begin end of 1991.

Available data

Laboratory core measurements:

- — rock matrix physical and hydraulic properties (porosity, bulk density, moisture characteristic curves)
- — [illegible]neumatic and thermal conductivities as a func-[illegible]ion of water content.

Laboratory block experiments:

- — rock matrix physical and hydraulic properties (porosity, bulk density, moisture characteristic curves)
- — unsaturated hydraulic conductivity of rock matrix
- — solute concentrations
- — fracture properties
- — etc.

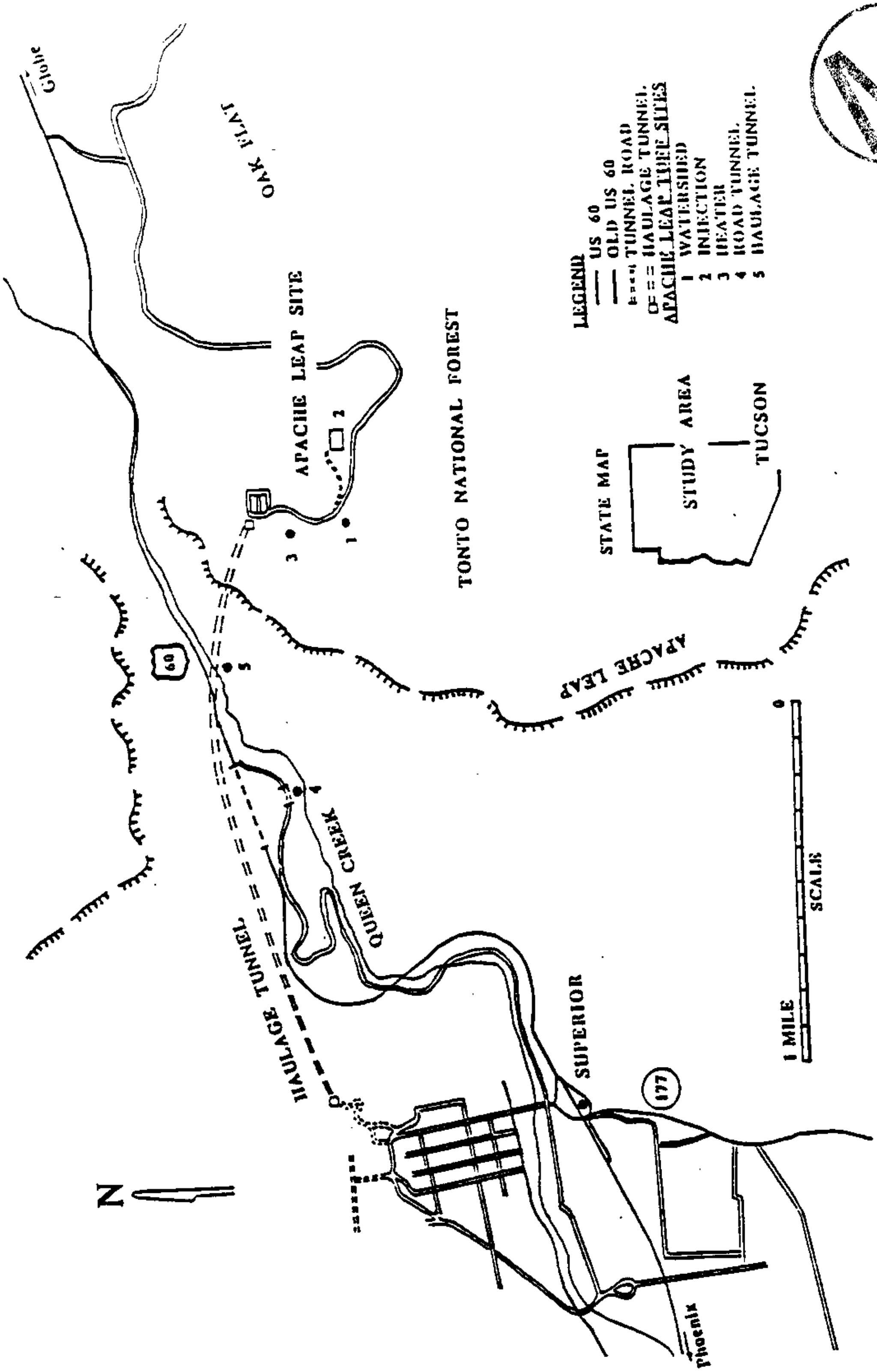

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Field imbibition/redistribution experiment:

— water injection volumes in four boreholes
— rock matrix and fracture hydraulic properties (at 3 m intervals)

Laboratory core heating experiment:

— physical, hydraulic, pneumatic and thermal properties of the rock matrix
— solute concentration
— temperatures
— water contents

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 –2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involve detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used for modelling during INTRAVAL Phase I. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated at depth ranging between 100–350 m by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8).

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. In each injection hole three sections were packed off, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part inbetween. Nonsorbing tracers were injected in 9 different intervals of the zone. Totally 11 different tracers were injected, 8 of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

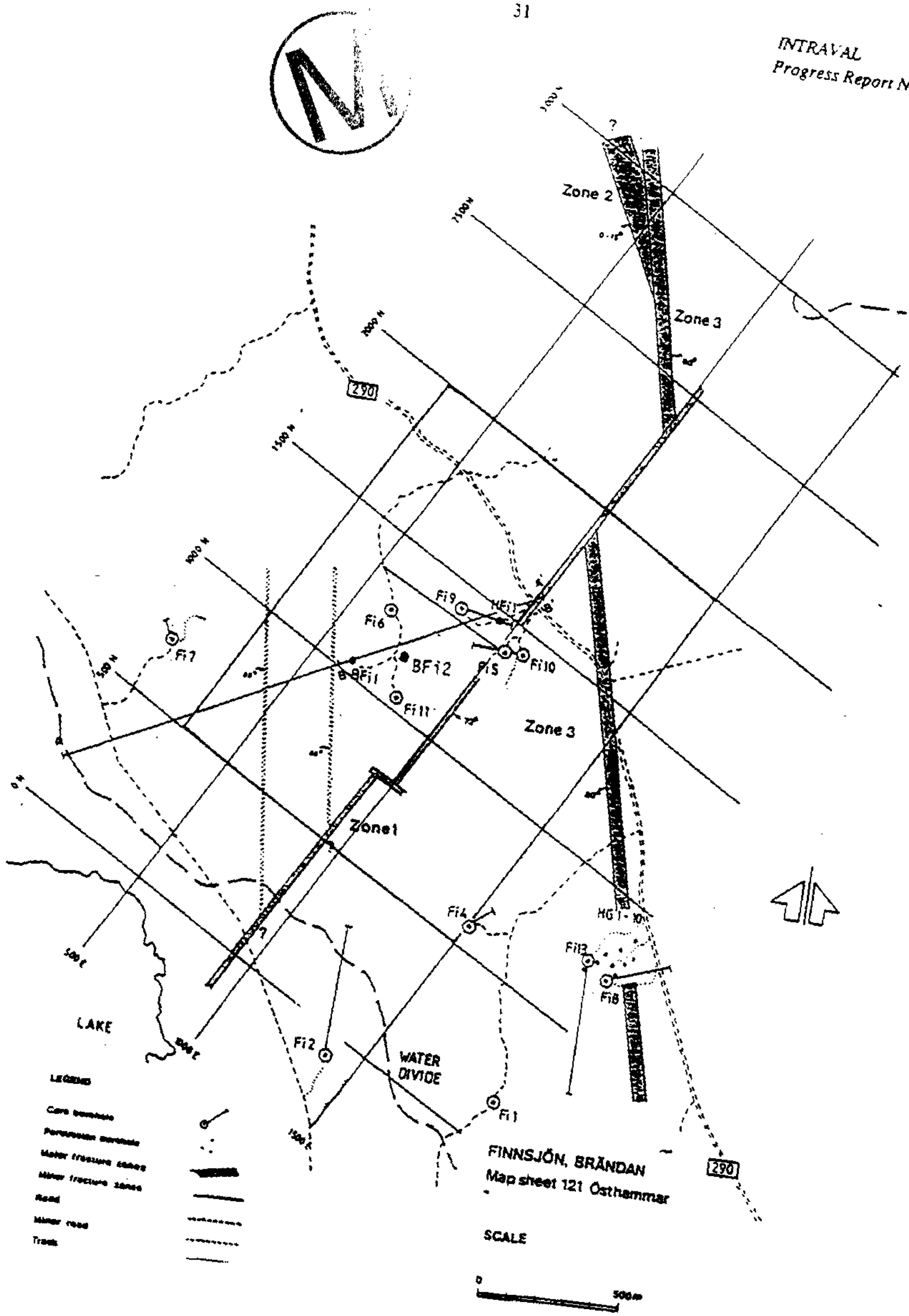

Figure 8. Borehole location in the Brändan area.

Available data

Interference tests:

— primary drawdown responses
— graphs of the recovery of groundwater head after pumping stops
— tracer injection information
— tracer breakthrough curves

Radially converging experiment:

— tracer breakthrough curves
— tracer injection information
— groundwater levels
— relative hydraulic head differences
— temperature and electrical conductivity of pumped water

Dipole experiment:

— tracer breakthrough curves,
— tracer injection information,
— hydraulic heads and groundwater levels
— temperature, electrical conductivity and redox potential of the pumped water.

In addition, geological data are available from surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3D experiment, data from two other experimental programmes performed in the Stripa mine, the 'Site characterisation and Validation Programme' and the 'Channelling Experiments' are or will be made available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The 'Site Characterisation and Validation Programme' includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes, and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The 'Channelling Experiments' comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3D experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. 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 (Figure 9).

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 nine separate sections with increased permeability 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.

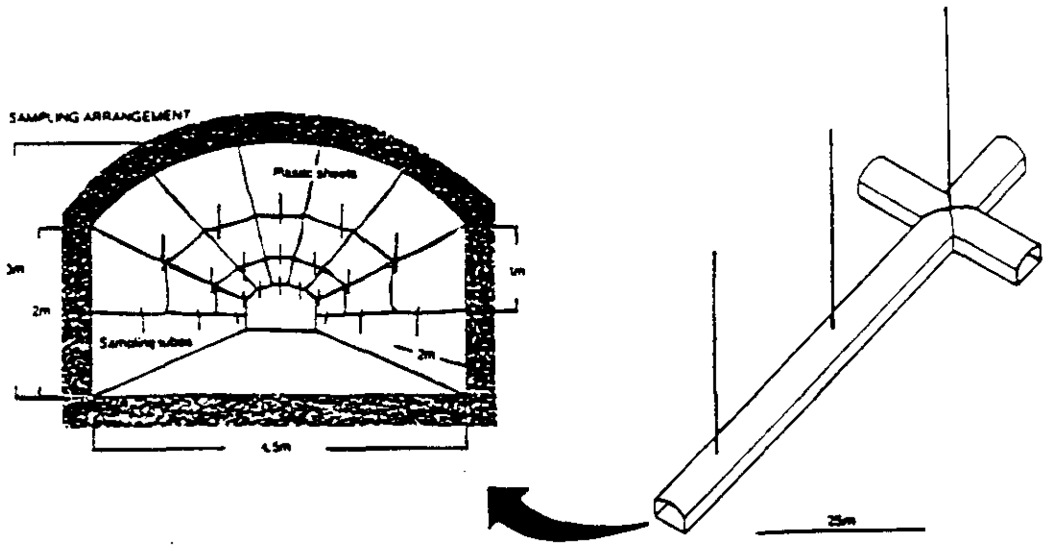

Figure 9. Layout of experimental 3D drift at Stripa and sampling arrangement.

The concentrations of the injected tracers were between 1000 and 2000 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.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show 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 six months of injection, tracers from at least five 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 several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

Site Characterisation and Validation programme (SCV)

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125×125× 50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics. Thereafter three new holes were drilled, 100–150 m long. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next, six boreholes, 100 m long, were drilled in the same direction as the new drift should be excavated. The water flow and its distribution were measured in these holes. These holes were also used for a tracer (salt) experiment. Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut through one major fracture zone, 5-10 m wide, which gave more than 99% of the total water inflow. Tracer experiments were per rmed in this fracture zone from 7 spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two nonsorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

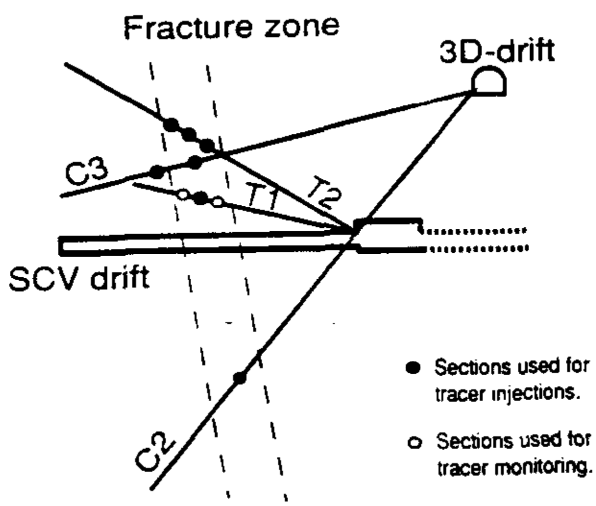

Figure 10. Layout of tracer experiment (SCV).

Channelling experiment

The channelling experiments consists of three different types of test: the 'single hole experiment', 'the double hole experiment'. and the 'tracer test'.

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (see Figure 11) was used to inject water all along the fracture plane. The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multi-pede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas, in total 12 holes were drilled.

The double hole experiment was performed in a fracture where the single hole test has shown that channels exist. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests more coarse tests were performed. In the detailed pressure pulse tests water was injected in one of the holes at a section of 50x 50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was than reversed,

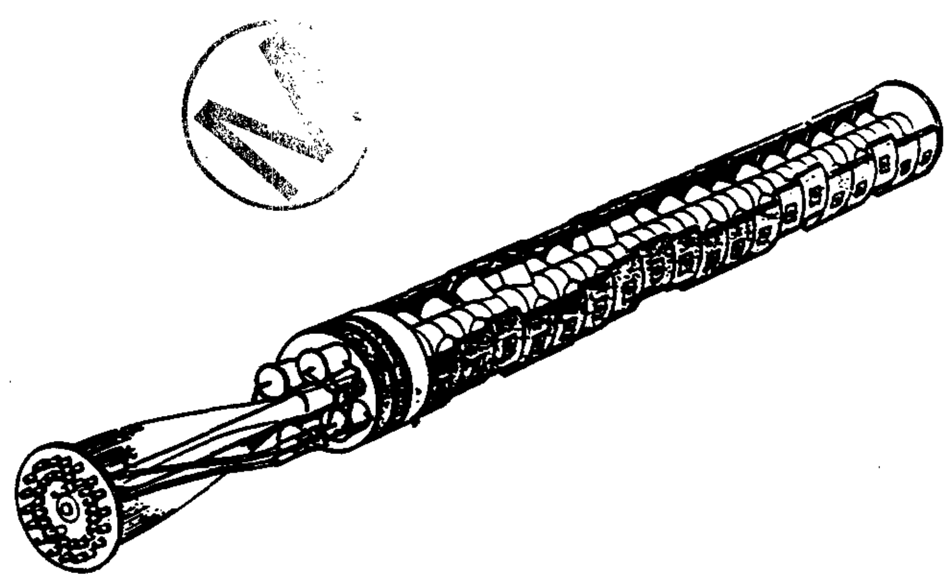

Figure 11. Design of the Multiped packer (Channelling Experiment).

i.e. injection from the second hole and monitoring in the first hole.

In the tracer test five nonsorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranin, Eosin yellowish, Ebenyl brilliant flavin, Duasyn acid green V and Phloxine B were injected continuously during 4 weeks.

Summary of Available Data:

3D Experiment

— water flow rates
— tracer concentration in water to test site
— rock characteristics and fracture data
— water chemistry
— injection pressures and injection flow rates
— hydrostatic pressures
— diffusivity and sorption data
— daily logs

Site Characterisation and Validation (SCV)

— core logging and fracture mapping in drifts
— geophysical single hole logging
— rock stress measurements
— borehole radar
— borehole seismics
— hydraulic investigations
— hydrochemisty
— water flow rates
— tracer breakthrough curves

Channelling Experiment

— number of fractures
— number of intersections
— information about infilling
— fracture lengths
— opening area of fractures
— pressure response
— tracer breakthrough

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite, at the WIPP site. The WIPP, located in Carlsbad, New Mexico, U.S.A., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation, Figure 12. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The hydrology of this zone is to be focussed on in this test case. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have taken place. These include detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991–92, in order to better delineate a hypothesised fractured region, a high transmissivity zone in the southeast corner of the site.

Sixty wells have been completed to the Culebra dolomite at 41 locations to provide information on the hydraulic properties (Figure 13). Large variation in transmissivity related to fracturing has been identified.

Well test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behavior of the Culebra. In general these data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

System	Series	Group	Formation	Member
Recent	Recent		Surfic. Deposits	
Quarternary	Pleistocene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ocholan		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

Objectives of the Test Case

A number of different objectives can be identified. One possible objective could be to determine if the hydrologic data support the derived transmissivity distribution and/or the model boundary conditions. Related to this objective could be an evaluation of the uniqueness of the derived transmissivity distribution. A third related objective could be to determine the uncertainty in the transmissivity distribution.

An additional important objective could be to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time. Related to this objective could be an evaluation of the uncertainty in predictions of radionuclide travel time. Other objectives could be to detemine if the paleoflow directions inferred from the geochemical/isotopic data could be reproduced using the current transmissivity distribution and boundary conditions altered to simulate increased rainfall; to determine if halite gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration in the transmissivity distribution; to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features.

Available data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic-test data from all well locations
- raw and interpreted tracer-test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well locations
- calibrated steady-state regional groundwater-flow model
- calibrated transient regional groundwater-flow model

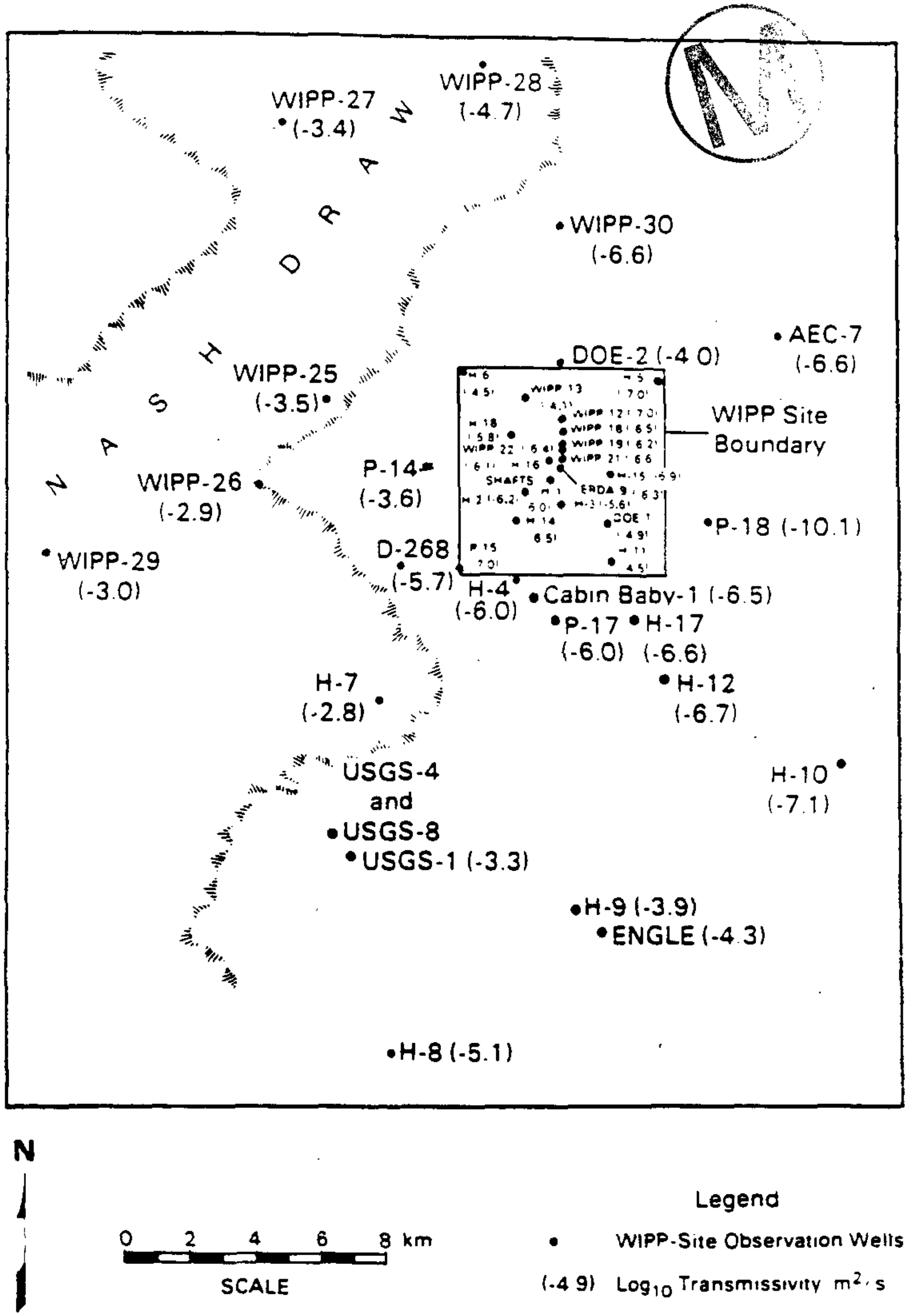

Figure 13. Culebra Wells and measured transmissivity near the WIPP Site.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the north-eastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1–2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock (a residue of the dissolution process of salt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

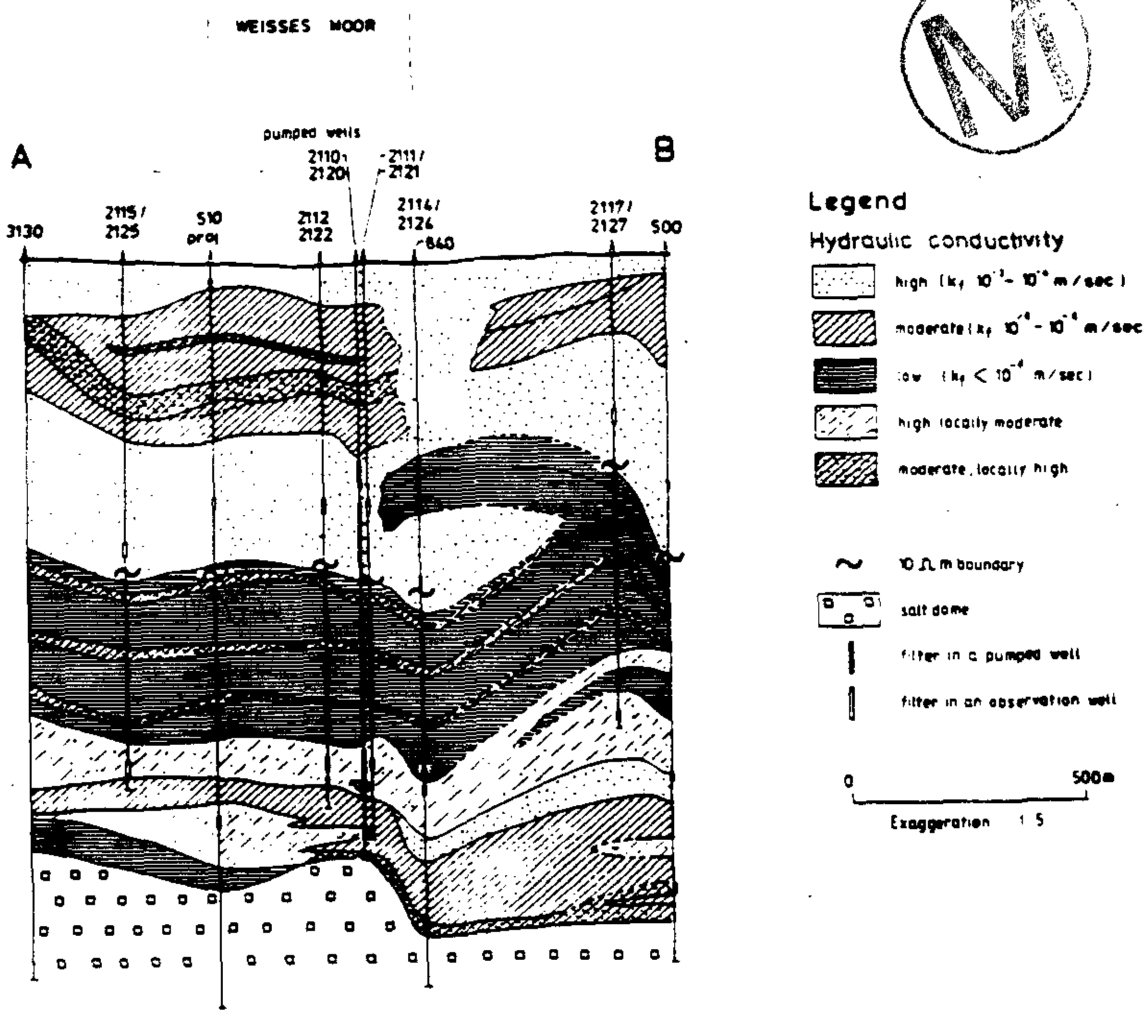

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

Experimental design

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. Information obtained during these tests were information on boundaries, the hydrogeological structure, connections between different aquifers, hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the *pumping tests the pumped well penetrates the entire* deeper aquifer in the erosional channel, Figure 14. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of 3 weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the bases for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available data

The data available from the selected pumping test:

— borehole locations (maps)
— hydrogeological data (groundwater levels etc.)
— pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP located in Carlsbad, New Mexico is an underground research and development repository (see Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of *data with which to determine whether Darcy's* Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Experimental Design

Data from three types of experiments will form the bases for this test case:

— small scale brine-inflow experiments
— pore pressure and permeability testing
— integrated, large scale experiment

Small scale brine-inflow experiments

Brine-inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (see example in Figure 16), and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole. Chemical analyses of brine collected are also available. The brine-inflow measurements in the 10 cm in diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore-pressure and permeability testing

Pore-pressure measurements are made in boreholes with a diameter of 10 cm and of 2 to 27 m length, drilled at a variety of orientations. Pore-pressure are measured in brine filled, packer isolated intervals in the boreholes. Factors other than the formation pore-pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are monitored. The boreholes are also used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, large-scale experiments

A horizontal cy drical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the room is now being measured, as will the brine inflow in the room when it appears. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore-pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore-pressure measurements, and measurements of borehole deformation and brine inflow. Brine inflow, humidity and room closure will continue to be measured past January 1992.

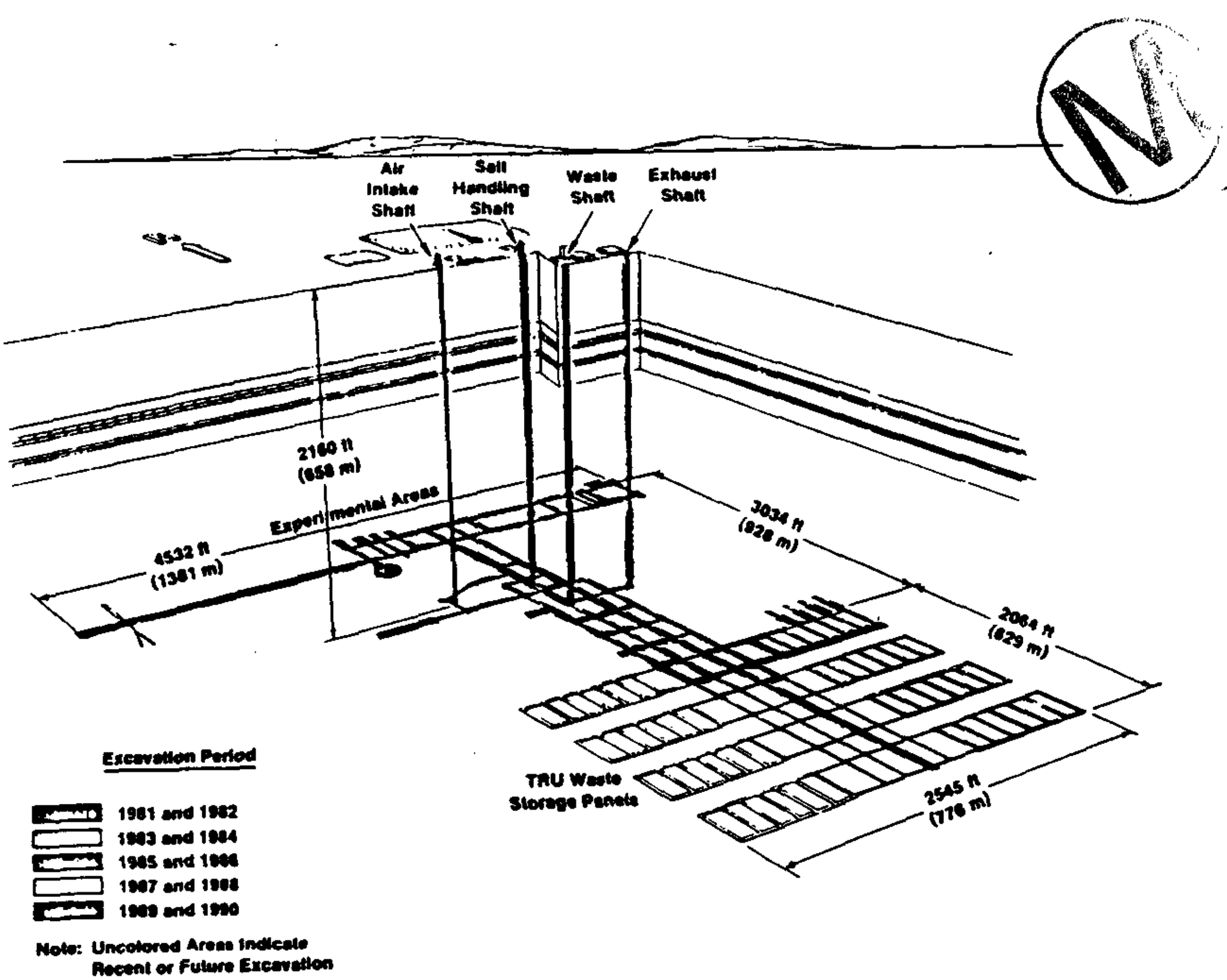

Figure 15. Schematic view of the WIPP site.

Available data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

— brine inflow rates
— humidity
— room closure, borehole deformation
— pore-pressure
— data from permeability-tests
— rock property data
— general stratigraphic information
— core logs

Supporting information

A number of technical issues that are important to the WIPP's performance are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

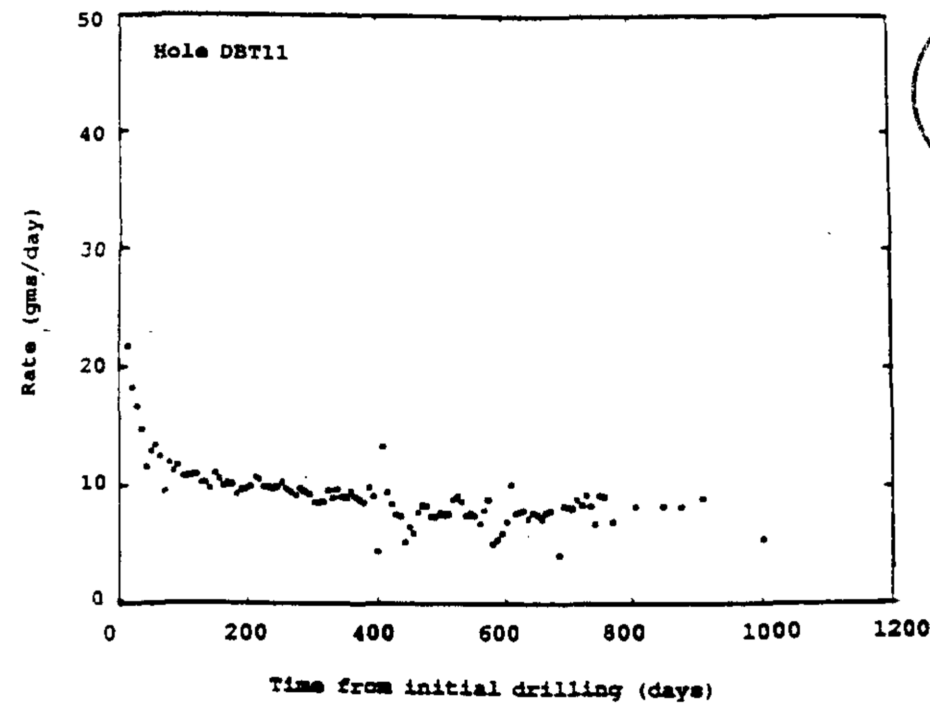

Figure 16. Brine inflow rate vs time in a borehole (Hole DBT11).

MOL

Migration Experiment in Boom Clay Formation at the Mol Site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the in situ test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

In an underground research laboratory (Figure 17) in the Boom Clay formation at a depth of 220 m a number of piezometers, a so called piezometer-nest, has been installed (Figure 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand pipe makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system is left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day with a duration of about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. So far tracers have been monitored only in the filter closest to the injection filter, i.e. filters 4 and 6. The sampling was started 3 months after the start of the injection and continues at a two months interval. To avoid disturbance of the HTO concentration distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

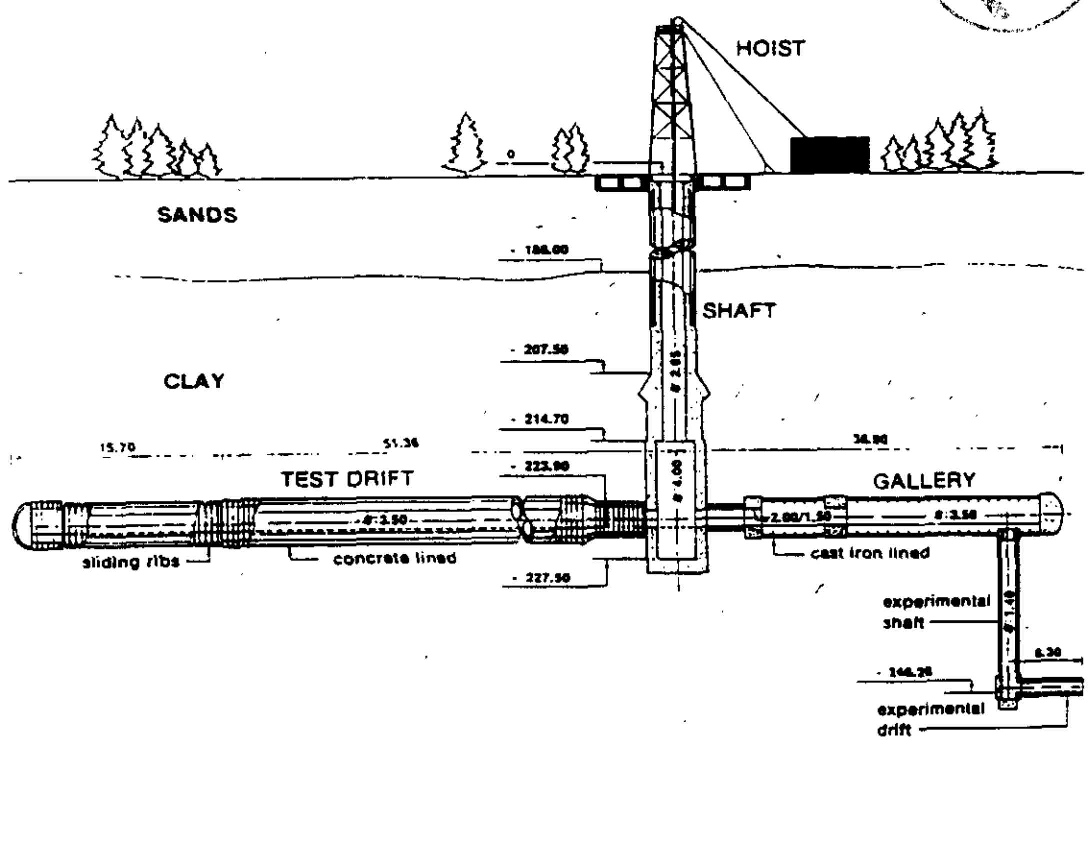

Figure 17. Scheme of the underground facility at Mol.

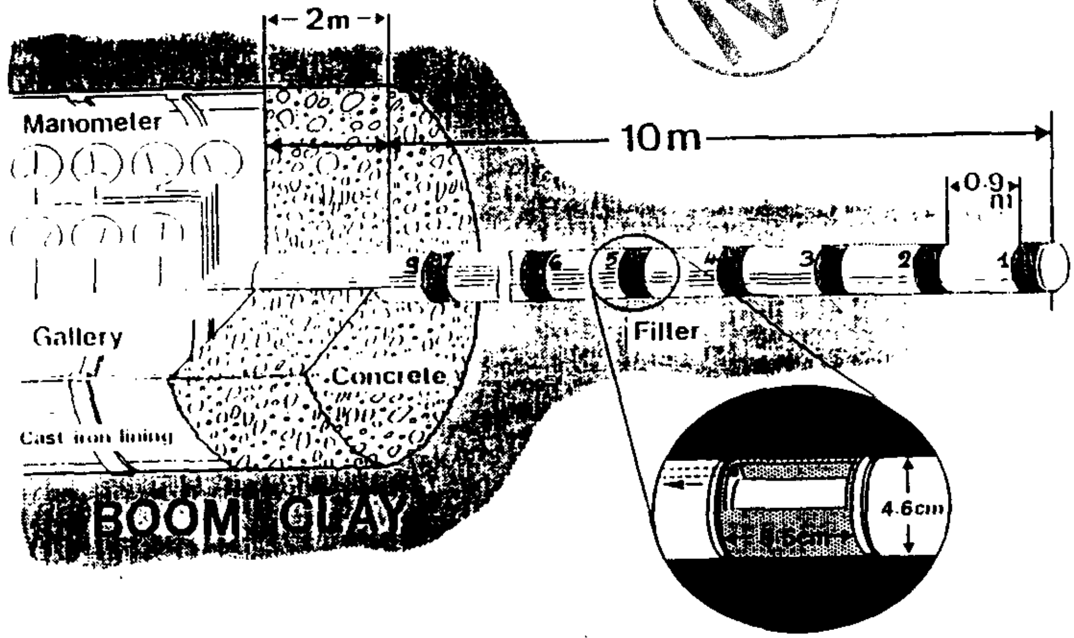

Figure 18. Conceptual view of the piezometernest.

Available Data

— steady state pressure distribution in the clay
— HTO concentration as a function time
— tracer injection data

Supporting information

Supporting data is available from laboratory experiments and other in situ experiments. Transport parameters such as the product of effective porosity and retardation factor, apparent dispersion constant, diffusivity, etc., have been estimated. A number of laboratory experiments have been performed, such as through diffusion, percolation experiments with clay cores. The Boom clay is rich in organic matter, with a large part linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

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

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participation organisations are: The Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists, secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

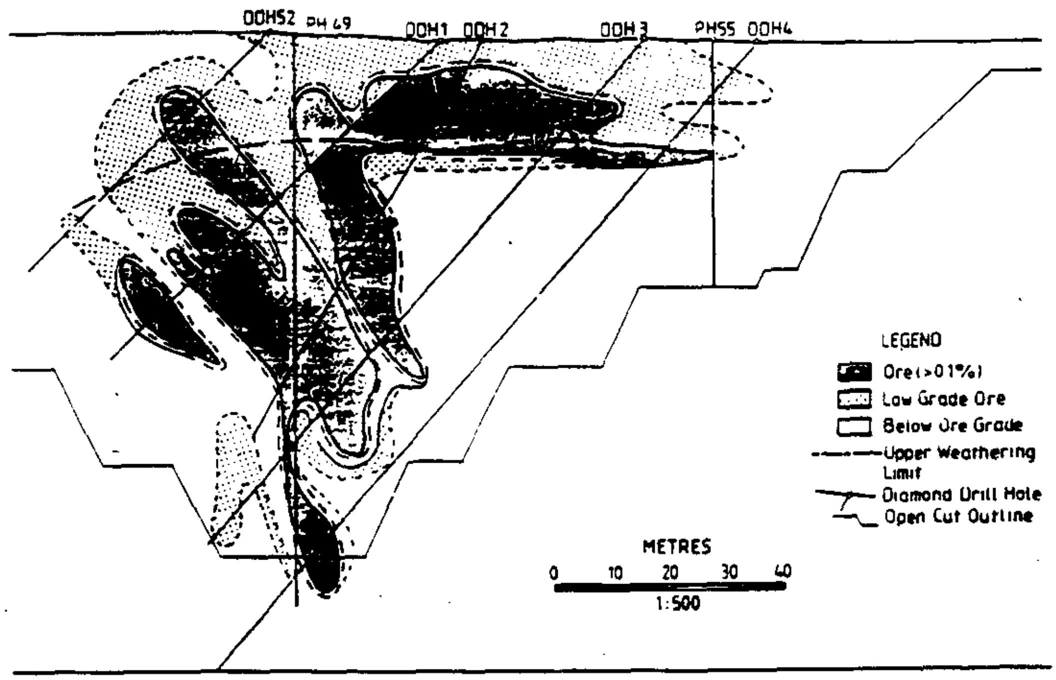

Figure 19. Cross section showing the dispersed zone at the Koongarra deposit.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses

— results from porosity and permeability measurements on drill core samples

Hydrochemistry

— pH, Eh, D.O., conductivity and temperature in groundwaters
— groundwater concentrations of cations and trace metals
— groundwater concentrations of uranium series nuclides and isotopes

Geology, mineralogy, radiochemical

— uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
— uranium series radioisotope activity ratios data for selected samples in the ore zone
— results from chemical analyses of core samples
— mineralogical composition of samples
— concentrations and activity ratios of uranium and thorium in different mineral phases
— concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20- 40- and 260-metres natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Data Available

A large database containing data both from field and laboratory experiments is available, containing:

— permeameter test data
— small-scale dispersion
— porosities
— grain size composition
— hydrogeological data
— geophysical data
— mapping of tracer migration (Figure 21)

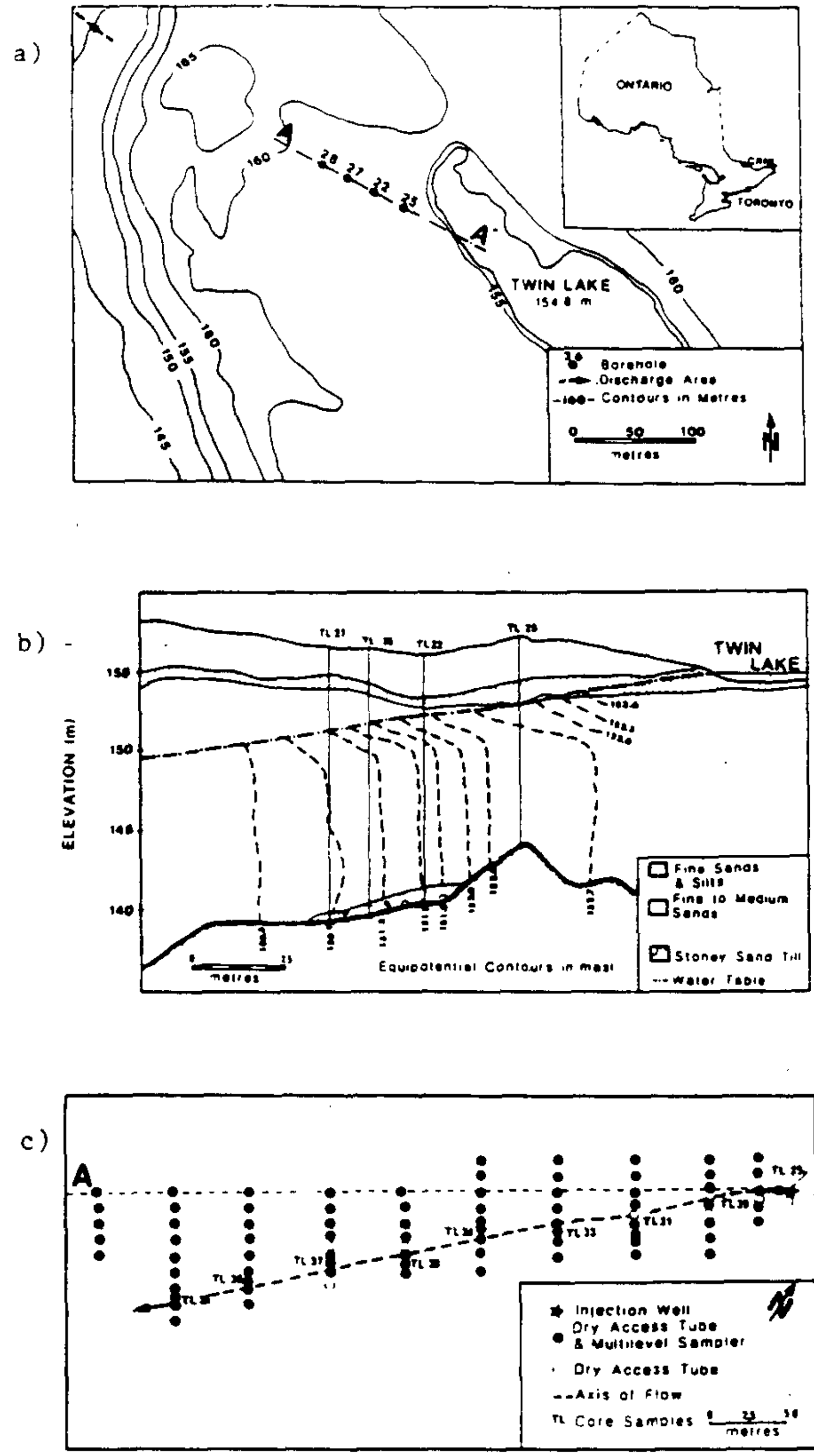

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

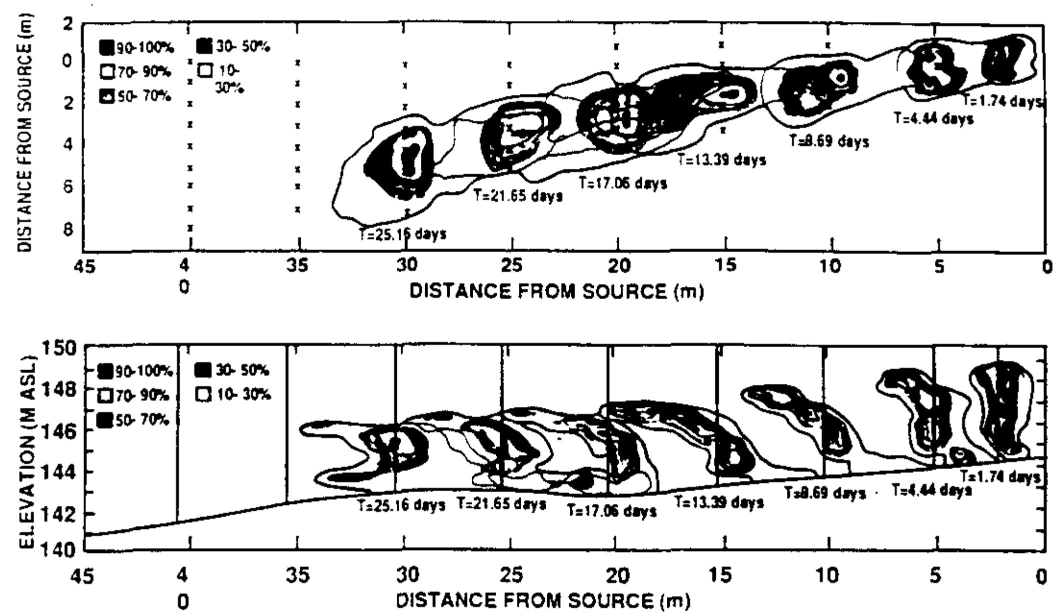

Figure 21. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a. INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P., and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., and Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries, INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E., and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J., and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J., and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L., and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

Radionuclide Migration in Single Natural Fissures in Granite (TEST CASE 2)

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R., and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2. INTRAVAL Workshop, Barcelona, April 1988.

Tracer Tests in a Deep Basalt Flow Top (TEST CASE 3)

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H., and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Flow and Tracer Experiments in Crystalline Rock Based on Stripa 3D Experiments (TEST CASE 4)

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B., and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W., and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W., and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W., and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

Tracer Experiments in a Fracture Zone at the Finnsjön Research Area (TEST CASE 5)

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P., and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A., and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Katsuragi T., and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L., and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön. Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Brändan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R., and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

Synthetic Data Base, Based on Single Fracture Migration Experiments in Grimsel (TEST CASE 6)

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R., and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U., and Vomvoris S., Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Redox-front and radionuclide movements in an open Pit Uranium Mine, Pocos de Caldas (TEST CASE 7a)

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Pocos de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L., and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

Morro do Ferro Colloid Migration Studies (TEST CASE 7b)

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Natural Analogue Studies at the Koongarra Site in the Alligator Rivers Area (TEST CASE 8)

Davis S., Hydrology Sub-Project. INTRAVAL Workshop, Tucson, November 1988.

Duerden P., and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open System/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C., Test Results of the Simplified 2D Modelling of th Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

Radionuclide Migration in a Block of Crystalline Rock (TEST CASE 9)

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M., Preliminary Results on Test Case 9 by using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A., and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J., and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J., and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A., and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M., and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 Metre, INTRAVAL Workshop, Tucson, November 1988.

Evaluation of Unsaturated Flow and Transport in Porous media Using an Experimental with Migration of a Wetting front in a Superficial Desert Soil, Las Cruces Trench (TEST CASE 10)

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D., and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T., and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I., and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R., and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems. INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M., and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R., and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Evaluation of Flow and Transport in Unsaturated fractured Rock Using Studies at Apache Leap Tuff Site (TEST CASE 11)

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson. November 1988.

Evans D., Rasmussen T., and Sully M.. Rock Matrix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Non-isothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

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INTRAVAL Parties:

Agence Nationale pour le Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Atomic Energy Control Board (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz (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 mbH (Federal Republic of Germany), Forschungszentrum für Umwelt und Gesundheit (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 Protection (The Netherlands), National Radiological Protection Board (United Kingdom), Power Reactor and Nuclear Fuel Development Corporation (Japan), Studiecentrum voor Kernenergie (Belgium), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy–OCRWM (United States of America), U.S. Department of Energy–WIPP (United States of America), U.S. Environmental Protection Agency (United States of America), U.S. Nuclear Regulatory Commission (United States of America).

Project Secretariat:

Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/AEA Technology, KEMAKTA Consultants Co., Organisation for Economic Cooperation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

8

May 1991 – February 1992

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

INTRAVAL
Progress Report Number 8, 1992

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.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 8

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990. The last workshop will be held in the autumn 1993 followed by a final meeting mid- 1994.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both in regard to the processes and site-specific systems.

Ten test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have 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 in such a way that it is possible to simulate the experiments with model calculations. 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.

Contact between the participants is maintained by arranging workshops which are followed by Coordinating Group meetings. Working Group meetings take place between the workshops.

Since the issue of the previous Progress Report, the seventh INTRAVAL workshop and the third Phase 2 Coordinating Group meeting were held in Sydney, Australia. During the workshop the participants described the modelling work performed and discussed the results achieved so far. Additional background information has been made available for some of the test cases, and an additional experiment in unsaturated media was included.

A tentative schedule for the final reporting of the project was discussed and it was concluded that extended outlines of the reports have to be available in November 1992. The finalisation of the Phase 1 final reports proceeds according to plan. All test case reports are scheduled for printing in May 1992 and the Executive Summary report is scheduled for printing in the autumn 1992.

The Seventh INTRAVAL Workshop and the Third Phase 2 Coordinating Group Meeting

The seventh INTRAVAL workshop and the third Phase 2 Coordinating Group Meeting were held in Sydney, Australia, on the 10th through 14th of February, 1992, with the Australian Nuclear

Science and Technology Organisation (ANSTO) acting as host. At the workshop technical presentations of the modelling results achieved by the Project Teams were given. Many of the teams discussed validation issues. The final reporting of INTRAVAL phase 2 was initiated and it was decided that extended outlines of the Working Group reports should be available in November 1992.

The Coordinating Group meeting was held on the 14th of February, 1992. At this meeting Mr. Johan Andersson, SKI, the former secretary, was elected as new Chairman of the INTRAVAL Coordinating Group replacing Mr. Kjell Andersson who has resigned from the SKI. Mr. Björn Dverstorp was elected the new secretary. The time schedule for the finalisation of the INTRAVAL project was agreed upon (see section about Working Groups). An INTRAVAL Subcommittee for Integration (ISI) was formed and the proposed charter was adopted. It was decided to arrange a topical session (full day) on validation issues at the next workshop. The validation session will be divided into a morning session reserved for invited speakers and an afternoon session with discussions.

The next INTRAVAL workshop will be held in San Antonio, Texas, USA, on the 9th through the 13th of November, 1992. A field trip to the WIPP site will be arranged the week before the workshop. The tentative time schedule for the remaining INTRAVAL activities are: the fourth and last workshop in September 1993, and a final meeting in autumn 1994. Separate Working Group meetings are scheduled prior to the next INTRAVAL workshop.

INTRAVAL Sub-Committee for Integration (ISI)

At the first Phase 2 INTRAVAL Coordinating Group Meeting, the Coordinating Group approved the establishing of a subcommittee to the INTRAVAL Coordinating Group. The purpose of the INTRAVAL Subcommittee for Integration (ISI) is to assist the INTRAVAL Secretariat by integrating the activities of the Working Groups, the validation approaches and the lessons learned for the INTRAVAL Project. The activities include preparation of an integration report to become part of the INTRAVAL Phase 2 final reports. The Committee members shouldtake part in workshops and related activities and give suggestions for future activities.

The Committee consists of the Chai[illegible] of the four INTRAVAL Working Groups and additional members elected by the Coordinating Group and members of the Secretariat.

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in an Executive Summary Report and a series of technical reports. The technical reports cover descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports is a compilation of descriptions of the experiments on which the test cases are based. The technical reports have been prepared by six Working Groups. An editor for each test case has been appointed with the responsibility to compile the test case analysis provided by the Project Teams that have worked with the test case.

The reporting proceeds according to plan. All test case reports are scheduled for printing in May 1992 and the Executive Summary Report is scheduled for printing autumn 1992.

Information from the Phase 2 Working Groups

Four Working Groups have been set up addressing different types of test cases (Table 1).

Table 1. Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski
4	Alligator Rivers Twin Lake	P. Duerden

A chairman has been elected for each Working Group, sometimes aided by another person. The chairs of the Working Groups are responsible for the preparation of Working Group reports, which will form part of the final reporting of INTRAVAL Phase 2.

Since the last workshop in Seattle, USA, in April 1991, all Working Groups have arranged meetings. Minutes from most of these meetings are available on request from the Project Secretariat. The meetings held are presented in Table 2. During the workshop in Sydney one and a half day was dedicated to Working Group meetings.

Table 2. Working Group meetings held between May 1991 and April 1992.

Working Group	Date	Location	Test Case
1	June 1991	Rockville, USA	Apache Leap Tuff
1	November 1991	Rockville, USA	Las Cruces Trench
1	December 1991	Berkeley, USA	Apache Leap Tuff
2	October 1991	Santa Fe, USA	
3	October 1991	Santa Fe, USA	
4	July 1991	Sydney, Australia	Alligator Rivers
4	September 1991	Twin Lake, Canada	Twin Lake

Prior to the next INTRAVAL workshop a number of Working Group meetings are scheduled (Table 3).

Table 3. Scheduled Working Group meetings.

Working Group	Date	Location	Test Case
1	March 1992	Yucca Mountain	Yucca Mountain matrix infiltration*
1	May 1992	Las Cruces, USA	Las Cruces Trench
1	July 1992	Berkeley, USA	Apache Leap Tuff
2	June 1992	Forsmark, Sweden	
3	June 1992	Traben-Trarbach, Germany	
4	Summer 1992	Canada	Twin Lake

*USA experiment (new experiment in INTRAVAL study).

INTRAVAL Phase 2 Reporting

The final documentation of INTRAVAL Phase 2 study will comprise Working Group reports from the four Working Groups and a Phase 2 Executive Summary report. In addition, a special report on integrated conclusions from the INTRAVAL Project will be prepared by the INTRAVAL Subcommittee for Integration. The tentative schedule for the printing and publishing of these reports are by the end of 1994.

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 × 9 m and 1 × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from CNWRA/USNRC has modelled the Plot 2a experiment with the finite difference code PORFLOW-3, which handles variably saturated fluid flow, heat and mass transfer. The presented results are based on comparisons of model predictions and measurements of first and second moments and point concentrations. The calculations were carried out with five different models with different spatial resolution of soil-hydraulic properties and initial conditions. The simplest model assumes one uniform material zone while the most complex model includes 180 zones. The initial conditions are based either on measurements with thermocouple psychrometers and tensiometers or on measured water contents. The complex models all overpredicted the vertical spreading of the tracer bromide, whereas the more simple models gave better predictions of the bromide concentrations. None of the models correctly predicted the depth of movement of the tracer plume at later times. It was pointed out that the limited spatial resolution of the concentration sampling could be one explanation to the fact that the simpler models appeared to perform better.

The Pilot Group from University of New Mexico/USNRC presented their initial look at a validation methodology with application to the Las Cruces experiments. The results of performed blind model predictions have been provided to the Pilot Group for comparison with observed data using simple statistical tests. The quantities to be compared are point values of water contents, solute concentrations, first detection times at specific horizons as well as some integrated values (0th, 1st, and 2nd moments versus time and flux through specific horizons versus time). The performance measure used is scatter plots of observed quantity versus the predicted quantity. This performance measure estimates the ability of the used model to predict observed mean behaviour for this special experiment over the temporal and spatial scales of this experiment. So far, the Pilot Group has looked at performed predictions of the water content. The predictions made are based on five different conceptual models for the soil properties; two for a uniform and isotropic soil, one for a heterogeneous but isotropic soil, and two where the soil properties have stochastic distributions. Linear regression, with a confidence interval of 99%, used on the experimental water content versus predictions with the different models would reject all predictions of the situation on day 70 (Figure 1), all model predictions except one (with uniform isotropic soil) would be rejected for day 310.

Regression used on normalised change in water volume will reject all models tested. There are a number of limitations in the test used as the error bounds are based on uncertainty in estimating the parameters due to scatter in observed data. The error bounds decrease with an increased number of measurements and less scatter in data. The test used may lead to rejection even though the difference between integrated observation and predicted mean behaviour is as small as less than 10%. It was concluded that the statistical method applied may not be appropriate to model validation because models can be rejected even though the maximum predictive error is small. Furthermore, if the model is rejected, it is not possible to know whether the reason is due to error in the conceptual or mathematical model, a parameter estimation error, an experimental error, or invalid statistical assumptions.

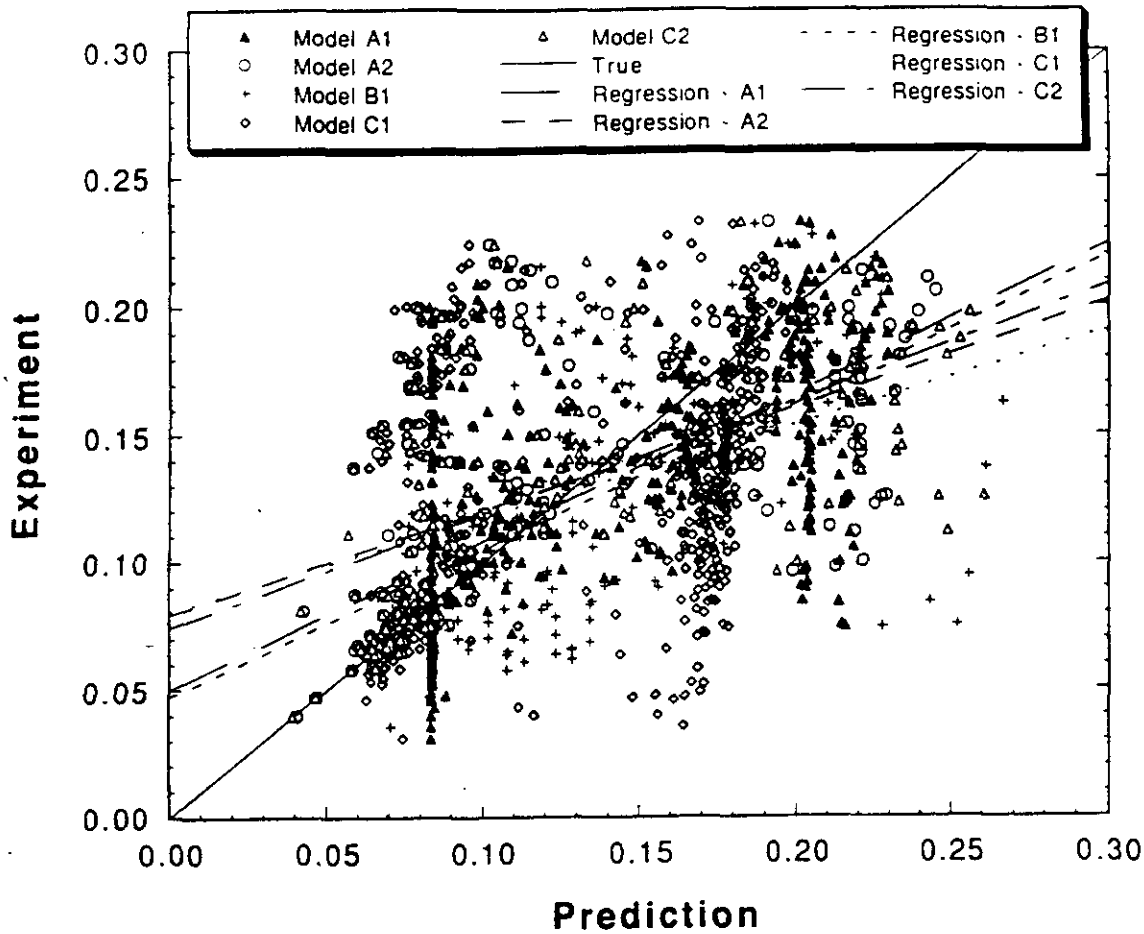

Figure 1. Scatter plots of observed versus predicted voulmetric water content day 70. Also presented are linear regression lines for five conceptual models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics: how a thermal source will affect air, vapour, water and solute movement in geologic media, especiallyunsaturated fractured rock, and the water and air transport properites of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory nonisothermal core measurements. A cylindrically shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimize heat loss along the sides of the core. During the experiment, a horizontal temperature gradient is established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to characterise water and air transport properites from fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which is 92.5 cm long, 21.0 cm high and 20.2 cm wide and contains a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The position of the wetting front in the fracture over time and the position of the wetting front in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are plans to perform field investigations. However, most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Analyses by Project Teams

The observer from the State of Nevada presented some initial benchmark calculations with the code VTOUGH (a vectorised version of TOUGH) of an one-dimensional infiltration experiment. The code will later on be used for simulations of the Apache Leap Site experiments.

The Project Team from USNRC has looked at vapor phase flow and transport in unsaturated fractured rock. The mechanisms of importance for gas transport in unsaturated rock are moisture and temperature difference between air in rock and atmosphere, binary diffusion, barometric pressure variation, wind, repository heat, and possibly volcanic heat. In dry climates there may be a substantial loss of water to the atmosphere due to flow in the gas phase in the rock which is important for the hydrology. Not only water may be transported in the gas phase, but also carbon-14, iodine-129, and volatile compounds of other elements, i.e., technetium and selenium. Modelling of the transport of C-14 has been performed both with a transport model and with a geochemical model. No calculations has been performed for Apache Leap, but the approach is of interest for the Test Case. The first step in the calculations with the transport model is to calculate a steady state gas flow in two dimensions for a number of times. Thereafter particles, in this case C-14, are traced in a gas flow field interpolated from the steady state calculations. This model has been used for simulations of the release of carbon-14 from an underground repository to the atmosphere. The retardation coefficient used for carbon-14 was 100, based on the carbonate geochemistry. A geochemical model for simulations of the transport of carbon-14 in one dimension has also been used. The carbon transport model in this case is based on the chemical equilibria for the carbonate system in gas, liquid and the solid phase and the transport is controlled by transport and transfer between gas, liquid and solid phases. It was concluded that a significant amount of calcite rapidly will precipitate around the repository and then redissolve slowly. Carbon-14 released early will be partially incorporated in this calcite and trapped for thousands of years. Carbon-14 released late will be unretarded by calcite precipitation until the migration wave reaches a point, where the temperature still is increasing and calcite is precipitating. An overall conclusion from this study, based on data inadequate for the Apache Leap site, is that vapor phase considerations are potentially important to a repository in unsaturated fractured rock. Apache Leap research could then support the validation of vapor phase transport models for repository performance assessment.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of a fractured zone including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment were never used for modelling, since it became available too late. The modelling of the dipole experiment therefore is the focus of Phase 2.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s, the middle 10^{-7}–10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water-salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core drilled (and some percussion drilled) boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbed tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Project Team from PNC presented preliminary analyses of the Finnsjön experiments using a stream tube approach. The rock was modelled as two layers of an equivalent porous medium, a high conductive layer (2 m thick) and a low conductive layer (10 m thick). The mass transport parameters, dispersivity and porosity, were estimated from the radially converging tracer tests. Location of stream lines, equipotential curves and velocity along the streamlines were generated from the results of the dipole tests. This information together with the estimated transport parameters were used to simulate the tracer breakthrough curves at the pumping borehole in the dipole tests.

The mass transport in both the high conductive zone and the low conductive zone was expressed by one dimensional advection–dispersion equations for each stream line. The hydraulic conductivity in the high conductive layer was assumed to be 10^3 times higher than in the low conductive layer, but the dispersivity in both layers was assumed to be equal. Calculated and measured breakthrough curves of the tracers In-EDTA, Gd-DTPA and I^- in the pumping hole in the radially converging test showed satisfactorily agreement (Figure 2). The dipole test was fairly well simulated with best-fit values of dispersivity and porosity from the tracer breakthrough between the same boreholes in the radially converging test. With best-fit parameter values from tracer breakthrough between the other boreholes in the radially converging test, the calculated peak concentrations in the dipole test were 0.4–3 times the observed. A sensitivity analysis of the influence of the porosity of the low conductive layer shows that the mass transport in this layer cannot be neglected.

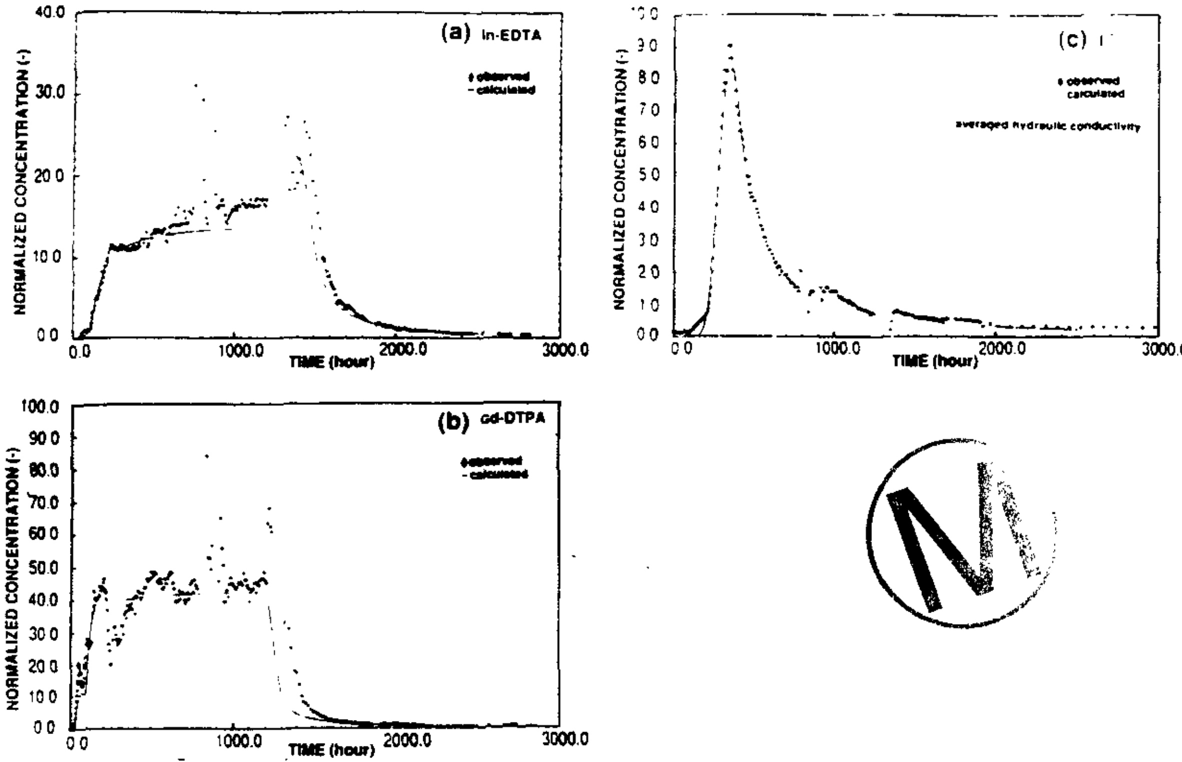

Figure 2. Breakthrough curves of (a) In-EDTA, (b) Gd-DTPA, and (c) I for radially converging tests at the pumping borehole.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiments, Sweden.

Experimental Set-up

This test case is based on three dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

An experimental drift was excavated in the old iron ore mine in Stripa. 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 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 pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments. The experiment was a test case also during Phase 1 of INTRAVAL.

In addition to the results from the 3D experiment, data from two other experiments performed in the Stripa mine, the 'Channeling Experiment' and the 'Site Characterisation and Validation program', are available to the INTRAVAL Participants during Phase 2. The 'Channeling Experiment' consists of two kinds of experiments. In a single hole experiment, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simpler packer systems. In a double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole. The 'Site Characterisation and Validation program', with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, includes a number of investigation steps with modelling predictions in between. The first investigation includes a few long boreholes used to characterise the rock volume. Additional boreholes were drilled and used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the 'Validation Drift', was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

Geosigma/SKB has performed radar and saline tracer test to provide data on the geometry of flow-paths in the fractured rock and possible changes in flow-paths caused by excavation of the new 'Validation Drift'. The experiment includes two tests, one before and one after the excavation of the drift. The results of the tests indicate that the drift cut through one major fracture zone. The excavation of the drift caused 3–4 times longer tracer travel times and the tracer occupied a larger volume of the rock in the second experiment, i.e. after the excavation of the drift. The possible cause of delayed tracer inflow could be due to stress redistribution, two-phase flow conditions, blast damage or chemical precipitations. Geosigma/SKB has also performed some modelling. A two-path advection-dispersion model with different mean velocity and dispersivity in the two paths gave a good fit with measured breakthrough curves, whereas assuming only one-path did not give as good a fit (Figure 3).

The Project Team from VTT/TVO has applied a deconvolution procedure to the long and varying injection flow rates and the corresponding tracer breakthrough curves to obtain equivalent breakthrough curves for a delta function puls injection. It can be suspected that peaks in the deconvoluted data are artifacts and they should therefore be considered having large error bars or small probabilities to present a real system behaviour. The analysis of experimental data in order to find the system behaviour should be carried out by taking error estimations into account. The idea is that there does not exist 'the solution' for the problem but a 'region' of acceptable solutions. The Stripa 3D data seems to be 'explained' by matrix-diffusion-like phenomena with very narrow channels and diffusion from the channels into stagnant areas, but other conceptual models may also apply.

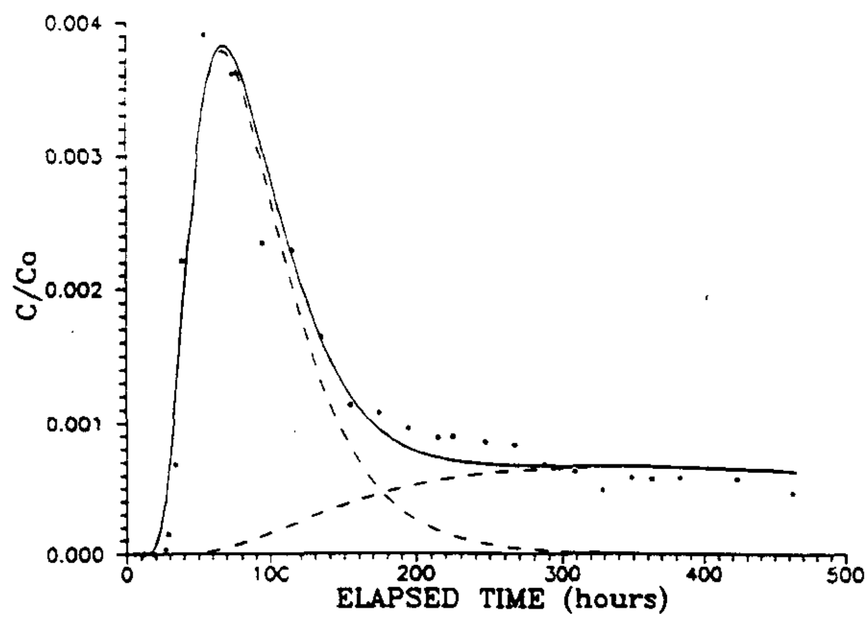

Figure 3. Breakthrough curve for Amino G in grid element 265. The solid line represents the regression estimate with a two-path model.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below groundsurface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. Sixty wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two month duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Pilot Group gave an overview of their work with the development of a new conceptual model for regional groundwater flow in the strata above the Salado Formation. The model, a basin model, is a three-dimensional closed hydrologic unit bounded on the bottom by an 'impermeable' rock unit, on the top by the ground surface, and on the sides by groundwater divides. All recharge to the basin is by infiltration of precipitation and all discharge is by flow across the groundwater table to the land surface. Differences in elevation of the groundwater table across the basin are assumed to be the driving force for groundwater flow. The stratigraphic interval modelled extends from the top of the Salado Formation to the land surface. The conductivity in the six different homogeneous and isotropic layers identified are either 10^{-11} or 10^{-8} m/s.

Several important simplifications have been introduced in the model, each stratigraphic layer is homogeneous and the hydraulic conductivities used to represent strata containing evaporities is probably much higher than the actual hydraulic conductivity of these units. The higher conductivity was used to emphasize the possible role of vertical flow.

The initial conditions for the simulation was intended to represent flow in a wet climate assumed to exist 20 000 years ago (time = 0). The initial condition was generated by providing a surface infiltration rate sufficient to raise the groundwater table to land surface and allowing a steady-state flow field to develop. To simulate a change in climate the infiltration was then set to zero for 20 000 years (time = 20 000 years). Thereafter the maximum infiltration rate was increased to 1 mm/yr for 15 000 years (time = 35 000 years).

Initially (at time = 0) the groundwater table looks very similar to the specified surface topography. The rate of vertical flow in the Culebra is extremely slow, because two model layers with low permeability ($K = 10^{-11}$ m/s) are located between the groundwater table and the Culebra, and the difference in head between the groundwater table and the Culebra is small. There is a slow downward flow into the Culebra over a large area in which the groundwater table is high and a slow upward flow out of the Culebra over a large area in which the groundwater table is low during the wet periods. The groundwater table drops 40 m at the most during this period. The infiltration of 1.0 mm/yr for 15 000 years raised the groundwater table to the land surface again.

An important aspect of the basin model that is demonstrated by these simulations is the similarity of potentiometric surface of confined aquifers and the water table. The identification of such a correlation in measured heads is on the way to confirm that the relief of the water table drives flow in deep aquifers. The calculations also demonstrate that changes in the position of the water table tend to occur in regions where it is elevated. That is the case in the region in which the vertical component of the flow is downward and the Culebra receives leakage from above. With the basin model it cannot be shown that vertical flow does occur. However, the calculations demonstrate that a hydrologic system, for which vertical leakage is an important component, the basin model is a possible conceptual model. The vertical flow rate received in the calculations is very small but its quantity could be large over time.

The Project Team from UPV/ENRESA presented a probabilistic modelling approach of particle movement simulations in the Culebra dolomite. They used a krieged transmissivity field into which 21 fictitious points were added to create enough heterogeneity to reproduce the field measurements. The transmissivities varied between 10^{-10} and 10^{-3} m/s. The team performed Monte Carlo simulations to calculate particle arrival times and locations. The transmissivity field was calculated with the code *GCOSIM3D*, the groundwater flow was modelled with the MODFLOW code and particle tracking was calculated by the MODPATH code. All three models were used in 200 realizations and a probabilistic assessment of arrival times and arrival locations was performed. The piezometric maps from the different realisations varied greatly. They concluded that stochastic models contain a confidence interval which a deterministic model does not include. However, the reality is still unique and permeabilities are not random. The Project Team also introduced some thoughts about the theory of further conditioning of the transmissivity fields. They proposed that the hydraulic heads should be calculated from each realisation of the transmissivity field and compared with observed heads. The transmissivity field and boundary conditions would then have to be modified so that the agreement between calculated and observed heads would become acceptable.

The Project Team from AEA/NIREX had performed their modelling work on the WIPP data with stochastic models. They started up with a preliminary study with 300 conditioned realisations of the transmissivity fields and continued with a second study with 1000 conditioned realisations. Most of the calculations were performed with exponential variograms but power-law (fractal) variograms were also used. The flow was calculated using the finite element code NAMMU with 40×60 nine-node quadrilateral elements and biquadratic interpolation. The results from the transport calculations were particle pathlines, transport times and exit points. From the preliminary calculations it was concluded that conditioning of the transmissivity field was important, possibly more important than parameter uncertainty. Calculations with 300 and 1000 realisations gave very similar results for the release from well H-1. Applying power-law variograms gave nearly the same results as the first preliminary calculations with exponential variograms, although the results from the calculations with power-law variograms gave less confident results. The models used were checked in various ways. The trend and variogram parameters were estimated by least-squares fitting, maximum-likelihood, and chi-squared minimisation/Kolmogorov-Smirnoff minimisation. The first two tests both gave low confidence in variogram fits, whereas the chi-squared minimisation failed. A model with a trend and an exponential variogram gave no large difference compared to the preliminary calculation (exponential variogram), except that the standard deviation for the particle exit position increased. The WIPP 2 test case provides a large data set which gives the opportunity to build models on a subset of data and make tests with the remainder of the data.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in the Federal Republic of Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire deeper aquifer in the erosional channel, will form the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The Pilot Group (BGR) has performed numerical studies using the SUTRA code to investigate the density dependent groundwater movement in the Gorleben Channel. The objective was to investigate whether steady-state conditions exist in the system today, and also to check the influence of hydrogeological and hydraulic parameters in the model calculations. A two dimensional, 15 km wide and 250 m deep cross-section was selected. The boundary conditions used were, no flow at the bottom, no-flow and no-flux at the sides, linear prescribed pressure at the top with free outflow, and fresh water infiltration. The permeability distribution was developed from a very simplified case in the first calculations to a more realistic description of the hydraulic system by introducing more and more heterogeneities in the system.

A number of long-term (up to several hundred thousand years) simulations to predict the present day density distribution were conducted, starting with different initial conditions for the density distribution. So far the calculations indicate that steady-state conditions have not yet been reached in the groundwater system in the erosional channel. It was also concluded that a realistic picture of the geological setting is essential to be able to predict the present day density distribution. The results of the calculations are dependent on the time-scale of the simulation as well as on the selected initial density distribution, which indicate that additional paleoclimatic information is necessary. It was also concluded that the calculated density distribution is strongly dependent on the transverse dispersivity.

The Project Team from BFS performed calculations for the first part of the test case, the pumping tests. The specific permeability ($3.5 \cdot 10^{-12}$ m^2), storage coefficient ($5 \cdot 10^{-4}$), and aquifer thickness (44.6 m) were estimated with an analytical model using regression technique to minimise the residuals in draw-down in the observation wells. The fitted drawdown curve corresponded well to that observed. The determined parameters were then used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep rock was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed both for constant density of the water and for density dependent flow, i.e an increased density with depth. The boundary conditions in the pumped well was either constant withdrawal along the whole well or constant withdrawal only at the well screen. No large differences in drawdown could be seen between the different calculations except for a small influence of the well screen location at early times. Consequently, the influence of density dependent flow is less than the influence of the well screen location. It was also concluded that other types of experiments have to be created to allow for validation of density dependent flow.

The Project Team from GRS presented some results from two-dimensional calculations of the groundwater flow in the Gorleben Channel. They used the finite element code NAMMU5C, which includes an extension for transient saline flow. The boundary conditions were, no-flow at the bottom and fixed head on the sides and at the top. The first calculations were carried out for freshwater and the groundwater velocity in the lower aquifer was calculated to be around 1 m/yr, whereas the velocity in the upper part of the aquifer was some orders of magnitude higher. The future plans are to reconsider the selected boundary conditions before brine transport is introduced in the two dimensional model. A three dimensional model of the channel will then be built and used for freshwater simulations before introducing brine transport also in this model.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m.

Analyses by the Project Teams

The Pilot Group (SNL/WIPP) has modelled the hydraulic testing in the test zone including the anhydrite Marker Bed 138, a 17 cm thick zone containing subhorizontal fractures. The test zone is about 11 m above the ceiling of Room 7. The performed test sequence included an initial pressure build-up period, two pulse withdrawal tests, a 10-day constant pressure flow test and a final pressure build-up period. Pulse tests cannot uniquely quantify permeability independently of specific storage, but provide a good estimate of initial pore pressure. Constant pressure flow tests provide estimates of permeability and are required to quantify specific storage. Pressure build-up tests can quantify permeability independently of specific storage, they provide a good estimate of initial pore-pressure, and also a check on measured test zone compressibilities. An analytical and a numerical interpretation of the pulse withdrawal tests gave similar results. The permeability was determined to be $2.9 \cdot 10^{-19}$ m^2. The test zone compressibility determined from the simulations is a factor 2 lower than the measured value. This parameter affects the simulations most at early times when compliance effects are occurring. The analytical and numerical interpretation of the permeability from the constant pressure flow test differs with a factor of 3 ($1 \cdot 10^{-19}$ m^2 with the analytical model and $2.9 \cdot 10^{-19}$ m^2 with the numerical model). The observed high flow rates over the first days could not be matched by any of the two models. These flow rates are probably artificially high because of tool compliance and borehole squeeze.

The interpretation of the pressure-buildup tests gave the same estimate of the permeability ($2.9 \cdot 10^{-19}$ m^2) both with the analytical and the numerical method. Both methods also showed a high test-zone compressibility. The integration of analytical and numerical interpretation techniques of different types of test provides a high degree of confidence in the interpreted results.

MOL

Migration experiment in Boom Clay Formation at the MOL Site, Belgium.

Experimental set-up

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are limited at the time being.

Analyses by the Project Teams

The Pilot Group (SCK/CEN) presented their modelling of the migration of the HTO tracer. The Boom clay was modelled as a homogeneous anisotropic saturated porous medium. The governing transport mechanisms considered were either advection–diffusion or diffusion only, as one question is whether advective transport is apparent from the existing data. One important parameter in the modelling is the porosity accessible for diffusion which was set to 0.34 to get the best fits of the two models. Concerning other parameters, the best fit of the diffusion only model was obtained with a diffusivity of $4.05 \cdot 10^{-10}$ m^2/s, and an almost identical value $4.03 \cdot 10^{-10}$ m^2/s, was obtained for the advection–diffusion model. Other fitted parameters were also identical or almost identical and it was concluded that advective transport is not apparent from this analysis of existing data.

The Project Team from SNL/USNRC presented an initial analysis of the effect of anion exclusion on transport in the Boom clay at Mol. The concern was enhanced transport velocities or flux due to this phenomena and as pure Darcy flow behaviour is usually assumed as the governing transport mechanism, the anion exclusion represents a conceptual model uncertainty. Their anion exclusion model has not yet been applied to the data, since more information concerning ionic strengths, zeta potential and pore size distribution are needed.

ALLIGATOR RIVERS

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

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies, which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles in Koongarra groundwaters.

Analyses by the Project Teams

The Project Team from CSIRO/ANSTO gave a short summary of the ARAP Hydrology workshop held in October 1991. The discussions at this workshop resulted in consensus on a number of important issues. Firstly, there is general agreement that most of the horizontal groundwater flow occurs at or below the bottom of the weathered zone and that the system can be viewed as a confined aquifer with essentially horizontal flow below the base of weathering. Secondly, there is little evidence for significant flow across the Koongarra Fault. Thirdly, there appears to be a highly conductive zone to the southeast (mine grid) of the No. 1 ore body. Fourthly, it appears that directions of flow are influenced by the orientation of planes of schistosity, or by fractures sub-parallel to these planes. Fifthly, there is evidence from standing water level measurements that the gradient in hydraulic head sometimes reverses towards the fault near the ore body.

The Project Team from CSIRO/ANSTO also gave a presentation of their new groundwater flow modelling attempts, in which most of the above described features are taken into account. They used the finite element groundwater flow model AQUIFEM-N to model a two-dimensional aquifer 1 km×3 km located near or below the transition zone. The model domain is bounded by the Koongarra Fault to the west (mine grid), the Koongarra Creek to the east, the Nourlangie gauging station and a small non-perennial creek to the south and a small non-perennial creek to the north of the No.2 ore body. Koongarra Fault is assumed to act as a non-flow boundary. Koongarra Creek and most of the other creeks are assumed to act as mixed boundaries. At a mixed boundary neither the head at the boundary nor the flux across the boundary is prescribed, but a relationship between the two. The model parameters required are (i) either the hydraulic conductivity and aquifer thickness or the aquifer transmissivity, (ii) the aquifer storage coefficient, and (iii) time averaged recharge of the land surface. The aquifer is assumed to be homogeneous but not isotropic. The time averaged recharge of the land-surface varies sinusoidally in time. In the base case calculation the hydraulic conductivity ratio in the modelled aquifer is 10 (K_{11}/K_{22}, $K_{11} = 1\ md^{-1}$) and the anisotropy orientation varies almost continuously throughout the region. Each simulation was performed for a two-year period to allow the effects of initial transient effects to dimininish. During the wet season the calculated flow patterns are intuitively reasonable with flows oriented to the southeast (mine grid), the calculated velocity is 1-2 m/yr. The overall flow orientation of the dry season is not entirely pleasing and the flow rates are very low.

The Project Team from CRIEPI investigated the distribution of fractures and the attitude of schistosity in the Cahill Formation in and around the western part of the No. 1 ore body using a Borehole TV. The obtained schistosity attitudes clearly explains the contour maps of the measured drawdowns in aquifer tests, which showed an asymmetric pattern. Schistosity in fractured rocks could be considered as a main factor for the hydraulic anisotropy, and the permeability in the direction parallel to the schistosity plane is generally larger than in the direction normal to the plane. The team also made three-dimensional simulations of the present groundwater flow during the rainy season around the No. 1 ore body. They used the finite element code GMF for a mesh corresponding to an area 700 m×400 m large with a depth of 200 m (from the ground surface). The modelled hydrogeologic unit was divided into three units, the weathered zone, the transitional zone, and the unweathered zone. Only the unweathered zone was assumed to be hydraulically anisotropic with respect to permeability, while the other two zones were assumed to be isotropic. For the unweathered zone a hydraulic tensor for each element was determined. The lower boundary and the boundary corresponding to the Koongarra Fault were given as no flow boundaries, the upper boundary was given as a constant head boundary (groundwater level was assumed to be at the ground surface), the other boundaries were given as constant heads. The choosen hydraulic conductivity for the weathered zone was $5 \cdot 10^{-4}$ m/d, for the transition zone $1 \cdot 10^{-2}$ m/d, and for the unweathered zone $6 \cdot 10^{-1}$ m/d. The calculated flow is from the northeast in the southwestern part of the No. 1 ore body and in the region to the south of the ore body, while the flow is from the north in the region to the northeast of the ore body. The flow velocities are extremely small in the region to the westsouthwest of the ore body.

The Pilot Group (ANSTO) gave a presentation about the approaches and finding in the transport modelling performed for the natural analogue. The major aims with the transport modelling performed has been to

- determine the extent of uranium transfer,
- assign the time scale,
- identify and classify transport and retardation processes, and
- determine the relevance of using the Koongarra analogue for the purpose of the assessment of a specific repository site.

The Koongarra ore body is located rather shallow, and has direct interaction with rain, climate effects, weathering and erosion. There are two different time scales, one very long as the climate has changed between desert and tropical during the years, and the present time scale with its seasonal variations between a very wet and a very dry climate. The modelling work performed includes many different processes, such as one dimensional advection and molecular diffusion. Matrix diffusion has not been considered. The K_d-concept has been adopted for sorption as well as surface sorption. Other processes looked at are secondary mineralisation, accessible and inaccessible mineral phases, nuclear recoil, and the occurrence of colloids. It has been found that transport with colloids are of minor importance although thorium and actinium have been observed on colloids. The time scale for development of the secondary uranium dispersion fan has been estimated to 1-2.5 Myr with a number of different models. It has also been concluded that during a time scale of about 0.5 Myr, 40% of the uranium in the weathered zone has moved 150 m, 20% moved 350 m and the remaining 40 % has not moved. The mobility of uranium is minimal in the unweathered zone.

Kemakta/SKI presented some modelling work performed with the aim to test the applicability of simple transport models used in the performance assessment of repositories. The migration of uranium and daughter nuclides in the weathered zone located below the water table of the No. 1 ore body has been simulated with a one dimensional advection-dispersion model with linear sorption (K_d-concept). The rock was assumed to be a saturated homogeneous and porous medium. Material properties (defined by present day conditions), water flux, and source concentration of uranium do not change with time. The codes used for the migration calculations were the finite difference codes TRUMP and TRUCHN, where the latter is an extended version of TRUMP including radionuclide chain decay. Scoping calculations show that a water flux less than 0.01 m/yr is required to match the observed migration distance, and a source concentration of uranium in the water of ~10 mg/l is needed to match the observed concentration of uranium in solid phase, assuming a K_d-value of 0.1 m^3/kg for uranium and a migration time of 2 Myr. To match the observed migration distance and solid uranium concentration, assuming a 100 times higher K_d-value for uranium, requires a water flux between 0.1 and 1 m/yr and a source concentration of uranium in the water of ~0.1 mg/l.

Calculations have also been performed to estimate the activity ratios $^{234}U/^{238}U$ and $^{230}Th/^{234}U$ in solid phase as a function of distance from the source. The calculations were performed both for constant and varying water fluxes over a time period of 2 Myr. The calculations of the activity ratios support the assumption of a migration time of the order of million years. Altering periods of flow and no flow during the last 200 000 years (2 periods with 75 000 years of no flow and 25 000 years of flow) seems to be of importance for the decrease in $^{230}Th/^{234}U$ activity ratio with distance. In addition to these calculations a very simple mass balance calculation has been performed to estimate the water flux needed to dissolve the uranium dispersed in the weathered zone. The mass of uranium in different depth intervals in the weathered zone was estimated from observed data. With a uranium solubility of 1 mg/l and a dissolution time of 1 Myr the water flux was calculated to be of the order of 0.1-0.3 m/yr.

The Project Team from JAERI presented their modelling of the uranium migration, considering the weathering, i.e. alteration of chlorite. Because of the weathering of chlorite, the mineral composition of the rock changes, which results in an increase of distribution coefficients and rock porosities with time. The retardation of the radionuclides increases with time, whereas the groundwater velocity decreases. The model used was a one dimensional advection-dispersion model with time dependent rock porosities and retardation. The water flux in the rock is kept constant and the uranium is released at a constant concentration from the source (the primary ore body) until the end of weathering. The domain modelled was a 300 m long section across the No. 1 ore body (between borehole DDH52 and DDH4). The results from the modelling are the uranium concentration and the $^{230}Th/^{234}U$ ratio in the bulk rock. A number of calculations have been performed, where the Darcy velocity was varied between 0.5 and 10 m/yr, and the dispersion length between 0.5 and 10 m. The simulations represent trends of observed data and it was concluded that the weathering of chlorite is important for the uranium migration. In future work two dimensional simulations are foreseen to be performed.

The Pilot Group (ANSTO) presented their work on the development of sorption models. The goal has been to develop a mechanistic description of U(VI) adsorption on typical minerals present in the weathered zone. Experiments indicate the presence of multiple types of sorption sites, some which are strong and some which are weak. A simple surface complexation model has been used to simulate the experimental results from batch experiments of the sorption on ferrihydrite of U(VI) at different concentrations as a function of pH. The concentration of strong and weak sorption sites was varied until good fits were obtained. It was concluded that this simple surface complexation model, involving two site types and one major surface species, satisfactorily describes U(VI) adsorption to ferrihydrite and quartz over a wide range of solution conditions.

The Project Team from USNRC presented their modelling of the chemical evolution of the present-day groundwaters. Aqueous speciation, saturation state and chemical mass transfer calculations were carried out using the codes EQ3NR and EQ6. The magnesium and aluminium contents of the soil and weathered rocks support the division of the site into different depth zones dependent on the degree of weathering. Close to the surface the schist is weathered which is reflected by a low Mg content and a high Al content. The transition at larger depths to unweathered rock is correlated with an increase in Mg content and a decrease in Al content of the bulk rock. This weathering profile is also supported by trends in the water chemistry, such as a sharp increase in pH in the top 25 m, followed by a more gradually increase with greater depths, and an overall trend of increasing Mg and HCO_3 concentration with depth. Speciation and state of saturation calculations suggest that the waters are part of a continuous spectrum of reaction progress extending from acidic relatively unreacted waters to slightly basic water near equilibrium with chlorite and kaolinite. Furthermore, it was concluded that the very strong dependence of all major chemical trends leads to a picture of essentially vertical recharge by rainwater that progressively evolves chemically by reaction with the chlorite schists.

The Project Team from RIVM presented their geochemical modelling work with the aim to study the formation of uranium phosphate in the weathered zone and uranium silicate in the unweathered zone just beneath the weathered zone. They used the codes EQ3NR and EQ6 to carry out observed system reaction paths calculations. The initial water was assumed to have a composition similar to the water sampled in borehole KD1, and the reactant minerals were chlorite, muscowite, quartz, pyrite, graphite, fluorapatite and U_3O_8. The output from the calculations shows that the most abundant uranyl phosphate mineral at Koongarra, saleeite, is formed, but under conditions which do not occur at Koongarra. The database used has, therefore, to be checked and data of relative abundance of minerals have to be included before further calculations will be performed.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20- 40- and 260-metres natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contribute hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations etc.

Analyses by the Project Teams

The Project Team from SNL/USNRC discussed the validation aspects for the Twin Lake study and presented data analysis of the tracer tests. The task for SNL as a contractor for USNRC is to develop both a validation strategy to address process model validation as well as site-specific model validation. The use of Twin Lake data could provide insight into the site-specific model validation process, specifically to determine the conservativeness of analyses relative to different models, different assumptions about existing data and the existence of data as well as the treatment of uncertainty. In the analyses of the Twin Lake data base the Project Team has applied a one dimensional advection-dispersion model. The input parameters are hydraulic conductivity, porosity, dispersivity, and hydraulic gradient. The dispersivity has been assumed to have an uniform distribution and is set to 10% of the travel distance. The hydraulic conductivity is evaluated from different tests, such as single well response tests, grain size analysis, and permeameter tests and is assumed to have a log-normal distribution. The gradient is determined from groundwater table levels and bedrock levels. The porosity which is assumed to have a normal distribution is evaluated from gravimetric analyses on core samples.

The analyses showed that the probability of obtaining a concentration larger than the maximum concentration steeply decreases at a certain value of the maximum concentration, but that this value of the maximum concentration always was larger than the measured maximum concentration (Figure 4). Furthermore, the calculated maximum concentration was insensitive to the choice of hydraulic conductivity. The probability of calculating a time at which the maximum concentration occurs which is larger than the corresponding time observed in the experiment changed from about 0.2 to about 0.85 depending on the characteristics of the log-normal distribution of hydraulic conductivity. Based on the results it was concluded that there is a very low probability of accepting a 'bad' site, but a high probability of rejecting a 'good' site based on the uses of conservative models combined with complete ranges of data.

The Pilot Group (AECL) informed about a new technique and methodology for characterisation of geologic heterogeneities. High energy emitting tracers are used to detect inhomogeneities and the dispersivity characteristics of a geologic structure. A gamma radiation detector which detects tracers within a circle with a radius of 0.1 m are used to get a vertical activity profile of the tracers. A local-scale dispersion model was used to simulate tracer tests, and it was concluded that this model is of universal nature and applicable to solving one-, two-, and three-dimensional problems. Furthermore, it was concluded that the most reliable approach to account for local heterogeneities is to measure velocities rather than conductivities.

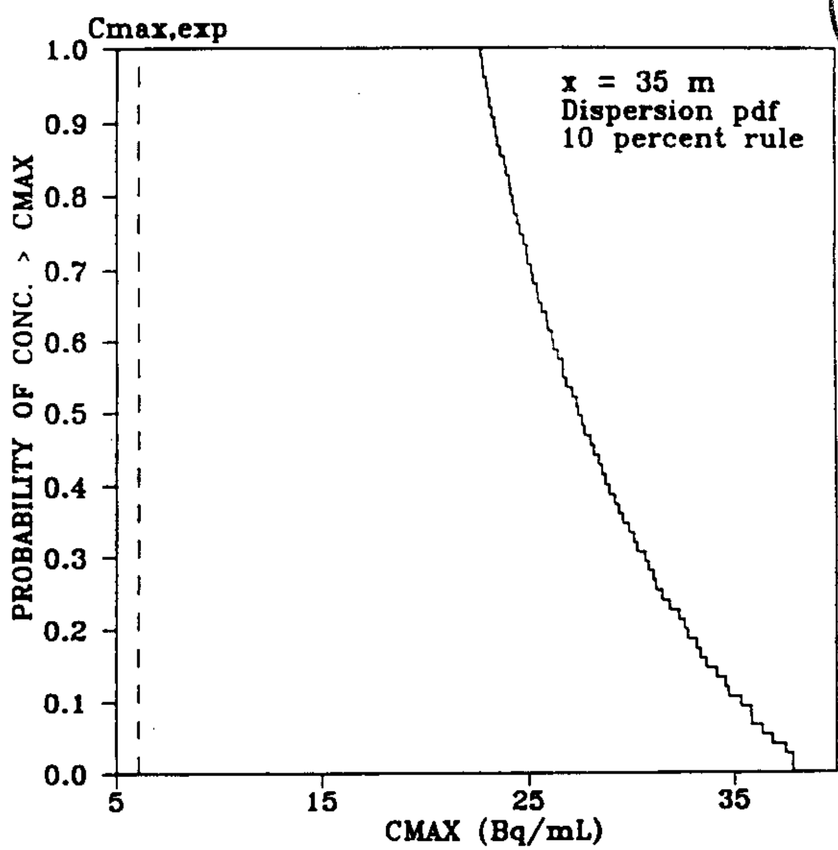

Figure 4. Probability of obtaining a modelled concentration larger than the measured maximum concentration.

Distribution of Background Information and Databases

Background information and databases are distributed to the INTRAVAL Participants either by the Secretariat or directly from the Pilot Groups according to Table 4. The information is distributed only on request from the Project Teams.

Table 4. Distribution of background information and databases.

Test Case	Distributor
Las Cruces Trench	Pilot Group, T. Nicholson, NRC[1]
Apache Leap	Pilot Group, T. Nicholson, NRC[1] and T. Rasmussen, UAZ[1]
WIPP 2	Pilot Group, E. Gorham, SNL[1]
Finnsjön	Secretariat[2]
Stripa	Secretariat[2]
Gorleben	Pilot Group, K. Schelkes, BGR[1]
WIPP 1	Secretariat[2]
Mol	Secretariat[2]
Alligator Rivers	Pilot Group, P. Duerden, ANSTO[1]
Twin Lake	Secretariat[2]

1) Full organisation name, see List of Intraval Participants in Appendix 1

2) Kemakta Consultants Co., P.O. Box 12655, S-112 93 Stockholm, SWEDEN

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

The organisation of INTRAVAL Phase 2 is similar to Phase 1. The study is directed by a Coordination Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Parties organise Project Teams for the actual project work. A Pilot Group has been appointed for each test case in order to secure the information transfer from the experimentalists to the Project Secretariat and Project Teams. At suitable intervals, about once a year, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group.

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 Inspectorate (SKI) acts as Managing Participant. 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 expenses, 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.

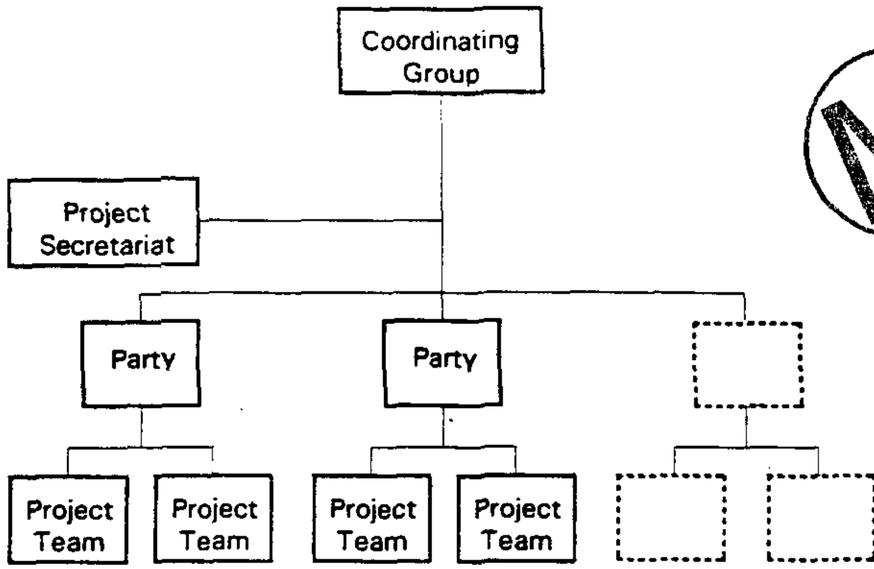

Figure 5. INTRAVAL Organisational Chart.

Managing Participant: SKI

Coordinating Group:

Chairman	J. Andersson, SKI
Vice Chairman	T. Nicholson, U.S. NRC
Secretary	B. Dverstorp, SKI

Principal Investigator: KEMAKTA Consultants Co.

Project Secretariat:

J. Andersson, SKI
B. Dverstorp, SKI
M. Ericsson, KEMAKTA
P. Jackson, AEA Technology
A. Larsson, KEMAKTA
J.P. Olivier, OECD/NEA
K. Pers, KEMAKTA
K. Skagius, KEMAKTA

List of INTRAVAL Participants

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Atomic Energy Control Board, Canada D. Metcalfe	(AECB)	Atomic Energy Control Board, D. Metcalfe	(AECB)
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		Bundesamt für Strahlenschutz H. Illi	(BfS)
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Gesellschaft für Reaktorsicherheit mbH, Federal Republic of Germany P. Bogorinski	(GRS)	Gesellschaft für Reaktorsicherheit mbH P. Bogorinski	(GRS)
Forschungszentrum für Umwelt und Gesundheit, Federal Republic of Germany R. Storck	(GSF)	Forschungszentrum für Umwelt und Gesundheit E. Fein	(GSF)

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National Radiological Protection Board, United Kingdom S. Mobbs	(NRPB)	National Radiological Protection Board S. Mobbs	(NRPB)
Power Reactor and Nuclear Fuel Development Corporation, Japan H. Umeki	(PNC)	Power Reactor and Nuclear Fuel Development Corporation, H. Umeki	(PNC)
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Swedish Nuclear Fuel and Waste Management Co., Sweden F. Karlsson	(SKB)	The Royal Institute of Technology I. Neretnieks	(SKB/KTH)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
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		Intera Information Technologies Ltd. D. Hodgkinson	(INTERA)
U.S. Department of Energy – OCRWM, United States of America C. Voss	(US DOE)	Pacific Northwest Laboratories C. Kincaid	(PNL)
		U.S. Geological Survey A. Flint	(US GS)
		Lawrence Livermore National Laboratory T. Busheck	(LLNL)
		Golder Associates Inc. C. Voss	(GOLDER)
U.S. Department of Energy-WIPP, United States of America P. Higgins	(US DOE)	Sandia National Laboratories E. Gorham	(SNL)
U.S. Environmental Protection Agency, United States of America W. Gunter	(US EPA)	U.S. Environmental Protection Agency C. Hung	(US EPA)
U.S. Nuclear Regulatory Commission, United States of America T. Nicholson	(US NRC)	U.S. Nuclear Regulatory Commission T. McCartin	(US NRC)
		Center for Nuclar Waste Regulatory Analyses B. Sagar	(CNWRA)
		Massachusetts Institute of Technology L. Gelhar	(MIT)
		Pacific Northwest Laboratories G. Gee	(PNL)
		Sandia National Laboratories E.J. Bonano	(SNL)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
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Organisation for Economic Cooperation and Development/Nuclear Energy Agency Member of Secretariat: J.P. Olivier	(OECD/NEA)		
Her Majesty's Inspectorate of Pollution, United Kingdom Member of Secretariat: P. Jackson			
International Atomic Energy Agency S. Hossain (observer)	(IAEA)		
Environmental Evaluation Group, United States of America L. Chaturvedi (observer)	(EEG)		
State of Nevada L. Lehman (observer)			

Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, U.S.A. Water and tracers were applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone was monitored. This test case was also included in INTRAVAL Phase 1. During Phase 1 data for site characterisation and model calibration were collected. In phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport in a new experiment (Plot 2b).

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 × 9 m and 1 × 12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium was applied at a controlled rate of 1.8 cm/day on the area sized 4 × 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracers below the surface of the soil. The movement of the water front was also observed visually on the trench wall. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1 × 12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) were added with the water on the area sized 1 × 12 m.

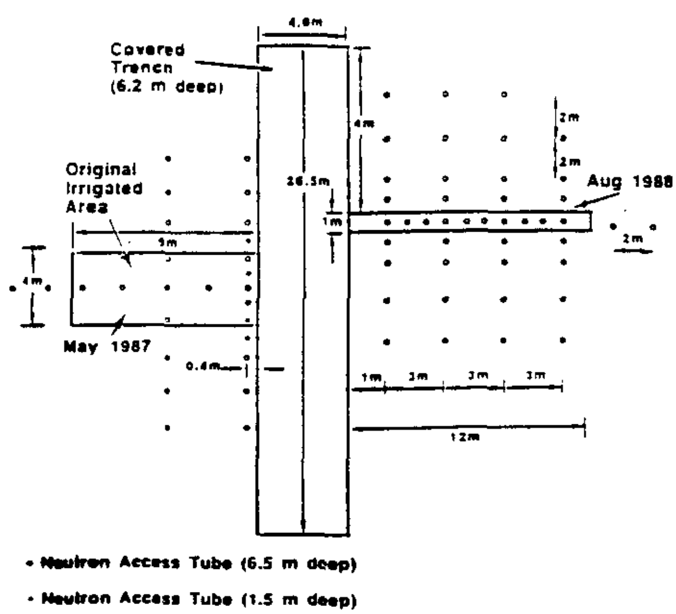

Figure 6. Top view of the trench with irrigated areas.

Available data

- water retention data
- density profiles
- particle-size analysis data
- saturated hydraulic conductivities (laboratory and in situ)
- water content
- tensiometer data
- solute concentration

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

The Apache Leap Tuff Site in tuffaceous rock is situated near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depths due to topography and to pumping associated with a nearby underground mine. The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source dramatically affect air, vapour, water and solute movement in geologic media, in particular unsaturated fractured rock , and to investigate the water and air transport properites of fractures and rock matrix of unsaturated rock.

The effects of a thermal source are studied wit laboratory nonisothermal core measurements, whereas the behaviour of fractures and other macropores are investigated in a series of laboratory measurements conducted on a block of Apache Leap Tuff having a single discrete fracture. In addition to these laboratory experiments there are plans to perform field investigations that will provide multiscale estimates of permeability at Apache Leap Site, information regarding mechanisms affecting the flow of fluids in fractured rock, and data for validation of flow models. The field experiment programme outline contributes to the characterisation of permeability distribution of a selected portion of the site using single-borehole pneumatic tests, pneumatic cross-borehole tests, gas tracer tests, and hydraulic tests. Most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Laboratory Nonisothermal Core Measurements

A cylindrically shaped core approximately 12 cm long and 10 cm in diameter was extracted from a block of Apache Leap Tuff (white unit). The large core, termed the 'mother' core, is used for the experiment, while smaller, 'daughter' cores were also extracted from the block for characterisation purposes. The mother core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses on all surfaces, and to minimise heat loss along the sides of the core.

During the experiment, a horizontal temperature gradient was established along the long axis of the core. Thirteen thermistors were situated along the core at approximately 1 cm intervals to record temperature over time (about twice weekly). A dual-gamma source was used to determine the water and solute content along the core over time.

The daughter cores were used to provide characterization data regarding porosity, moisture characteristic curves (including hysterisis effects), saturated and unsaturated hydraulic conductivity, and saturated and unsaturated air permeabilities. Similar data from 105 core segments at the Apache Leap Tuff Borehole Site were also available.

The simulation objective is to reproduce the core water content and solute concentration profiles using characterisation data and observed temperatures. The simulation output will consist of mean water contents and solute concentrations along 1 cm slices at 0.5 cm increments along the length of the core for selected times. The output will also consist of predicted temperatures at 1 cm intervals. The temperature measurement should be considered a point measurement.

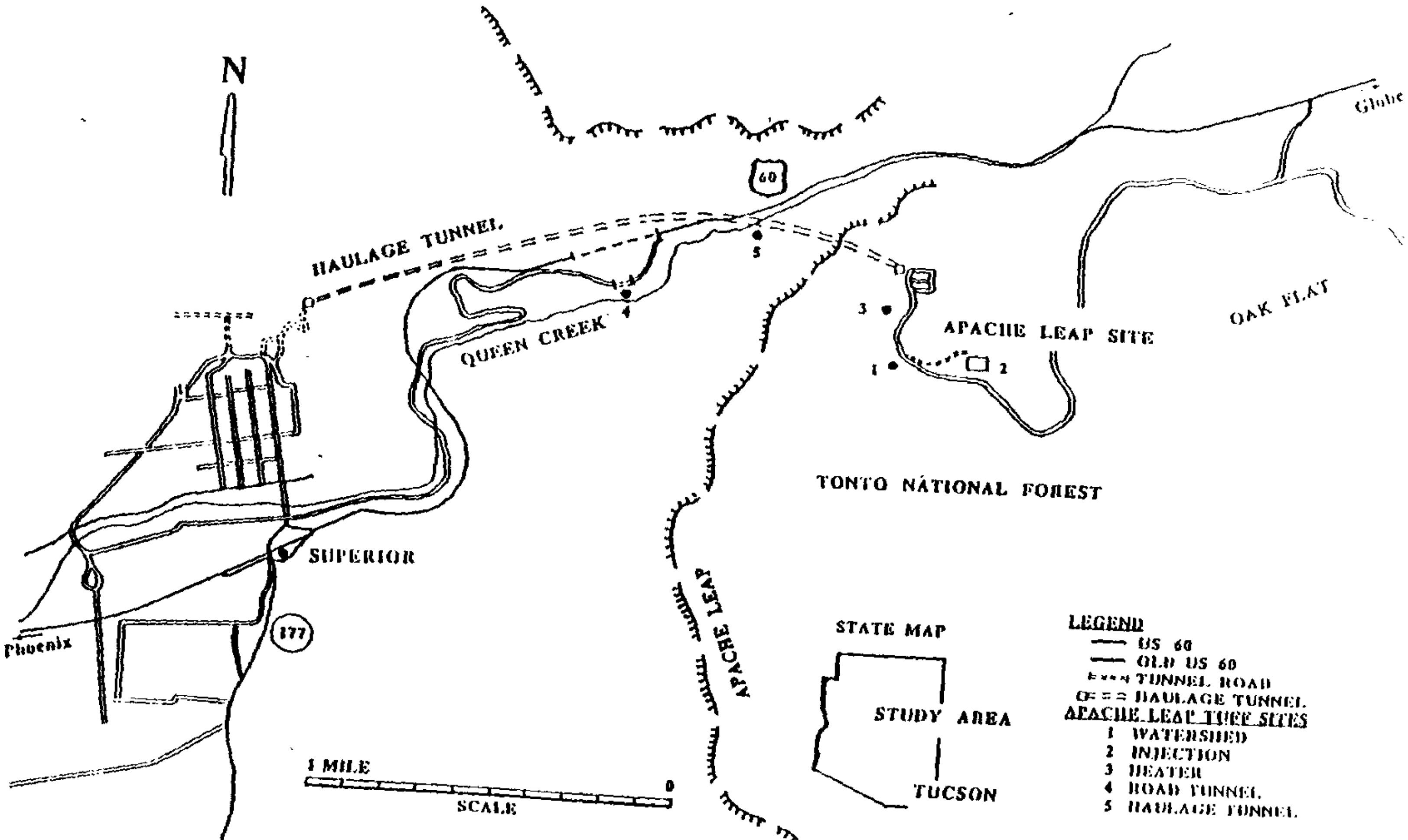

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Laboratory Isothermal Fractured Block Measurements

A block of Apache Leap Tuff (white unit) measuring 92.5 cm in length, 21.0 cm in height and 20.2 cm in width contains a fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent (−150 MPa). The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The positions of the wetting front in the fracture over time and the positions of the wetting front in the matrix over time were recorded.

The simulation objective of this problem is to reproduce the movement of a wetting front of water in a fractured, unsaturated rock using characterisation data and observed fracture inflow volumes over time. The simulation output should be wetting front positions in the fracture and rock matrix over time. Observed characterisation data can be used to calibrate the model, together with inflow data collected during the experiment.

Available data

Core Measurements

- rock matrix porosities
- initial water contents
- temperatures

A set of data collected prior to the heater experiment may also be useful for calibration purposes. Before the thermal experiments were conducted, the circumference of the mother core was sealed, while the two ends were left open. The core was fully saturated and then one end ot the core was placed on a pressure plate and a 5 bar (500 kPa) pressure was applied. The total weight of the core was measured on various dates, and used to develop a time series of core saturations. Additional data are also available from tests performed on daughter cores collected near the core used in the nonisothermal experiment.

Block Measurements

- rock matrix sorptivity coefficient
- rock matrix porosity
- rock fracture aperture
- cumulative inflow volume over time

Data from the Apache Leap Tuff Borehole Site related to rock matrix physical and hydraulic properties, including porosity, bulk density, rock matrix moisture characteristic curves and unsaturated hydraulic conductivity, are also available.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 - 2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involves detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used in modelling during INTRAVAL Phase 1. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8) at depths ranging between 100–350 m.

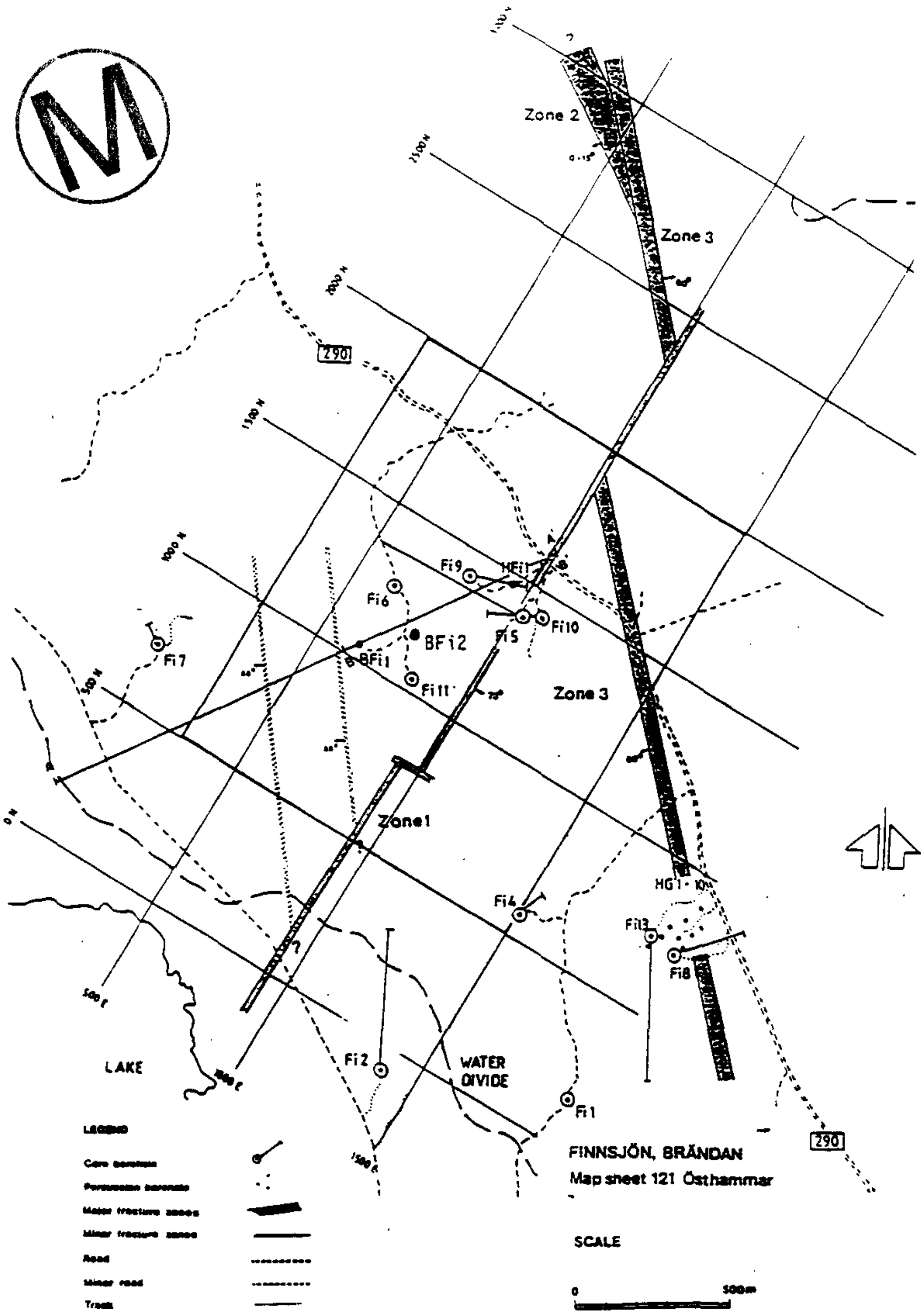

Figure 8. Borehole location in the Brändan area.

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment, tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. Three sections were packed off in each injection hole, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part in between. Non-sorbing tracers were injected in nine different intervals of the zone. Totally eleven different tracers were injected, eight of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test, a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test, a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

Available data

Interference Tests

- primary drawdown responses
- graphs of the recovery of groundwater head after pumping stops
- tracer injection information
- tracer breakthrough curves

Radially Converging Experiment

- tracer breakthrough curves
- tracer injection information
- groundwater levels
- relative hydraulic head differences
- temperature and electrical conductivity of pumped water

Dipole Experiment

- tracer breakthrough curves
- tracer injection information
- hydraulic heads and groundwater levels
- temperature, electrical conductivity and redox potential of the pumped water

In addition, geological data are available from a surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3D experiment, data from two other experimental programmes performed in the Stripa mine, the 'Site characterisation and Validation Programme' and the 'Channelling Experiments' are or will be made available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The 'Site Characterisation and Validation Programme' includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The 'Channelling Experiments' comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3D Experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. 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 (Figure 9).

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 pathways could thus be obtained.

Injections of conservative tracers were carried out from a total number of nine separate sections with increased permeability 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.

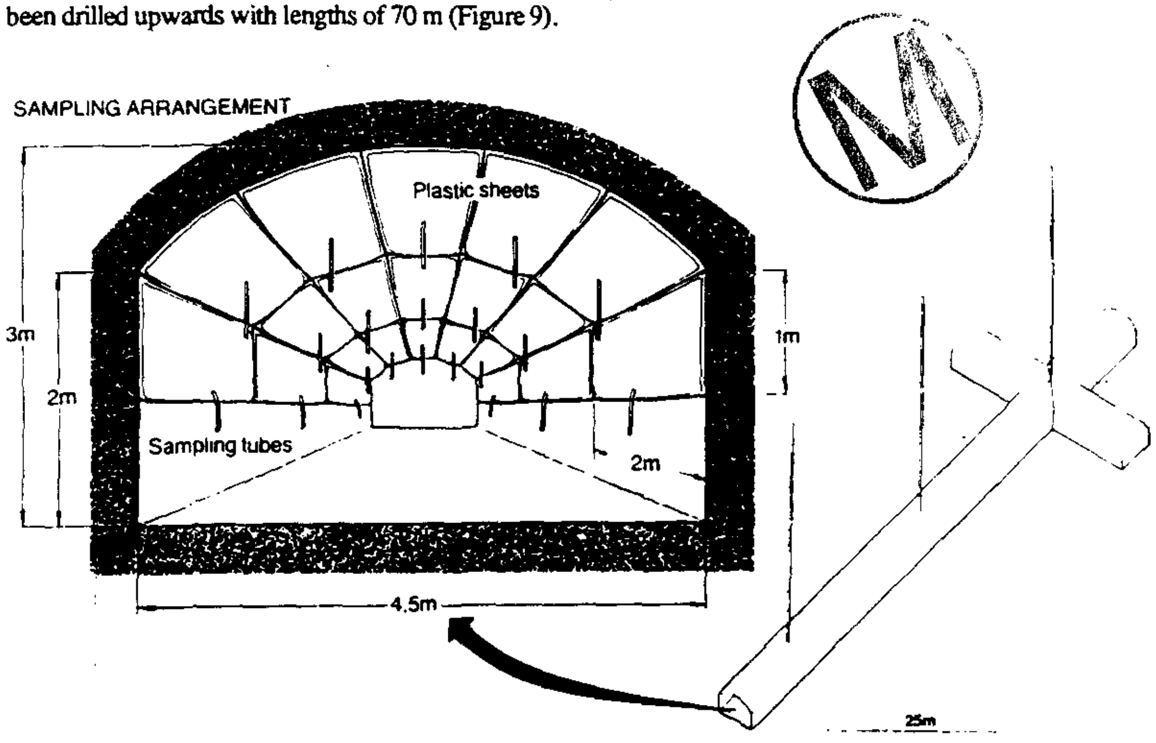

Figure 9. Layout of experimental 3D drift at Stripa and sampling arrangement.

The concentrations of the injected tracers were between 1000 and 2000 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.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show 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 six months of injection, tracers from at least five injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves were obtained. Each curve is based on several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

Site Characterisation and Validation Programme (SCV)

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125×125×50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics.

Thereafter three new 100–150 m long holes were drilled. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next six 100 m long boreholes, were drilled in the same direction as the new drift would be excavated. The water flow and its distribution were measured in these holes. The holes were also used for a tracer (salt) experiment.

Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut through one 5-10 m wide major fracture zone, which gave more than 99% of the total water inflow. Tracer experiments were performed in this fracture zone from seven spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two nonsorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

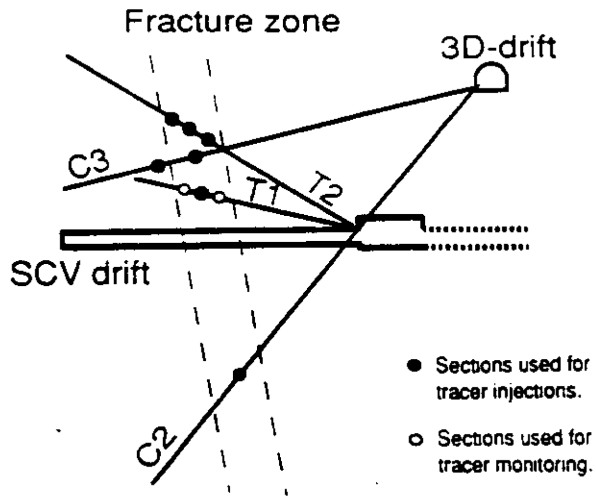

Figure 10. Layout of tracer experiment (SCV).

Channelling Experiment

The channelling experiments consist of three different types of test: the 'single hole experiment', 'the double hole experiment', and the 'tracer test'.

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (Figure 11) was used to inject water all along the fracture plane.

The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multipede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas in total 12 holes were drilled.

The double hole experiment was performed in a fracture, where the single hole test has shown that channels existed. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests, more coarse tests were performed. In the detailed pressure pulse tests, water was injected in one of the holes at a section of 50×50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was then reversed, i.e. injection was performed in the second hole and monitoring in the first hole.

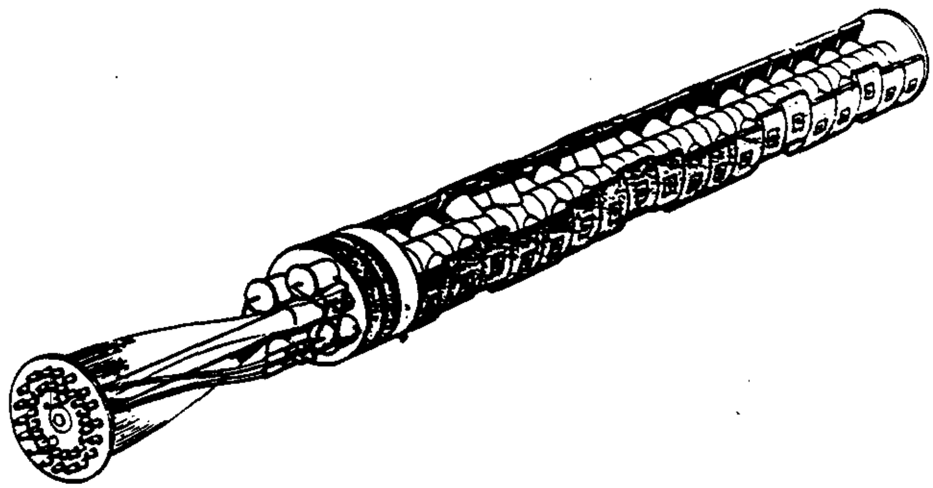

Figure 11. Design of the multiped packer (Channelling Experiment).

In the tracer test five non-sorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranine, Eosin Yellowish, Ebenyl Brilliant Flavin, Duasyn Acid Green V and Phloxine B were injected continuously during four weeks.

Summary of Available Data

3D Experiment

- water flow rates
- tracer concentration in water to test site
- rock characteristics and fracture data
- water chemistry
- injection pressures and injection flow rates
- hydrostatic pressures
- diffusivity and sorption data
- daily logs

Site Characterisation and Validation (SCV)

- core logging and fracture mapping in drifts
- geophysical single hole logging
- rock stress measurements
- borehole radar
- borehole seismics
- hydraulic investigations
- hydrochemisty
- water flow rates
- tracer breakthrough curves

Channelling Experiment

- number of fractures
- number of intersections
- information about infilling
- fracture lengths
- opening area of fractures
- pressure response
- tracer breakthrough

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite at the WIPP site. The WIPP, located in Carlsbad, New Mexico, U.S.A., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation (Figure 12).

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quarternary	Pleistocene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ochoian		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The test case will be focussed on the hydrology of this zone. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have been made including detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991-92 in order to get a better delineation of a hypothesised fractured region, a high transmissivity zone in the southeast corner of the site.

Sixty wells drilled to the Culebra dolomite at 41 locations provide information on the hydraulic properties (Figure 13). Large variations in transmissivity related to fracturing have been identified.

Test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra. These data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

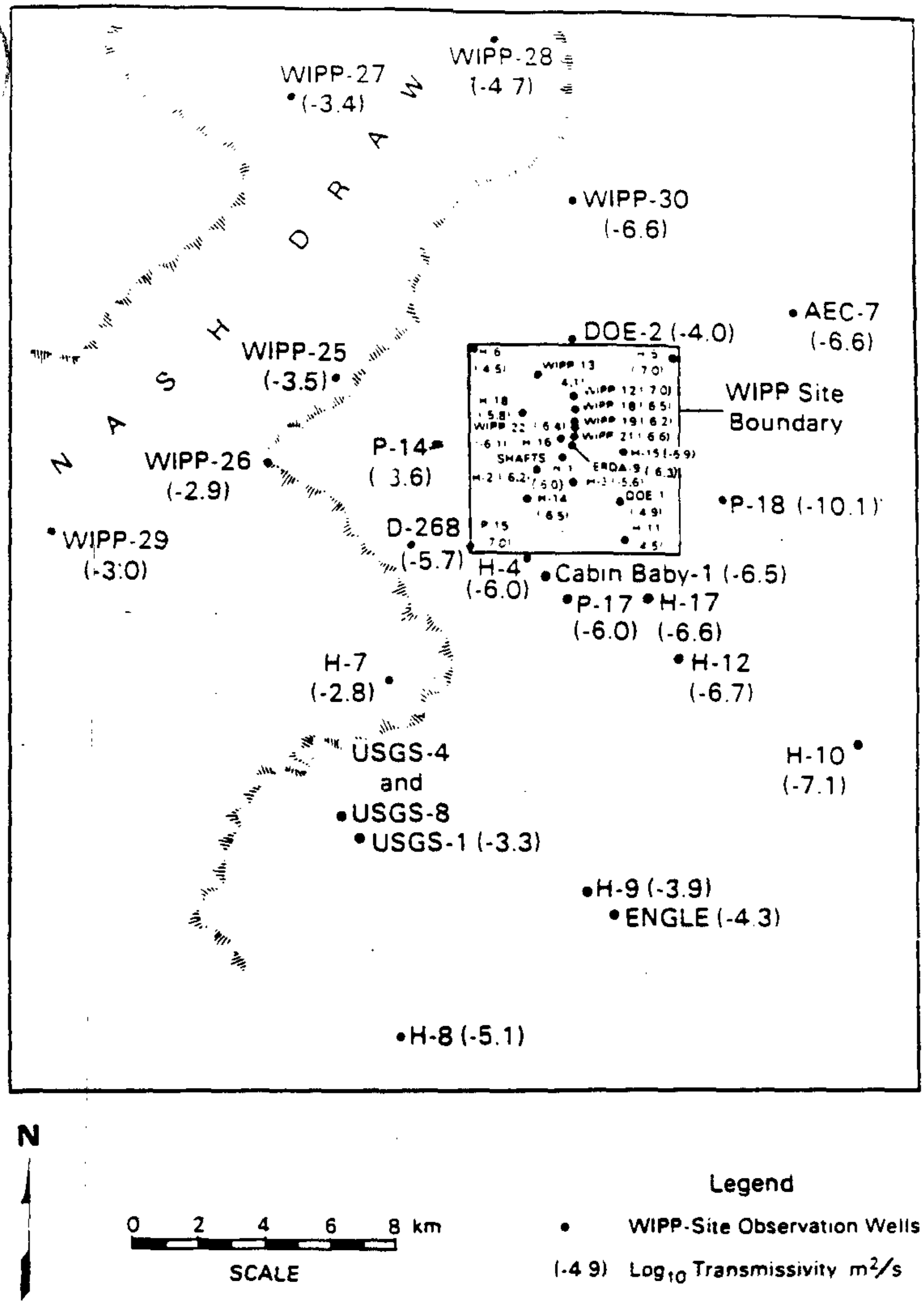

Figure 13. Culebra Wells and measured transmissivity near the WIPP site.

Objectives of the Test Case

A number of different objectives are identified:

- to determine if the hydraulic data support the derived transmissivity distribution and/or the model boundary conditions
- to evaluate the consequences of and the uncertainty in the derived transmissivity
- to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time
- to calculate the uncertainty in predictions of radionuclear travel time
- to determine if the paleoflow directions inferred from the geochemical/isotropic data could be reproduced using current transmissivity distribution and boundary conditions altered to simulate increased rainfall
- to determine if halite and gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration of the transmissivity distribution
- to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features

Available Data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic test data from all well locations
- raw and interpreted tracer test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well locations
- calibrated steady-state regional groundwater flow model
- calibrated transient regional groundwater-flow model

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the north-eastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1-2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock (a residue of the dissolution process of salt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

Experimental Design

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. During these tests information were obtained on boundaries, hydrogeological structure, connections between different aquifers, and hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the pumping tests the pumped well penetrated the entire deeper aquifer in the erosional channel (Figure 14).

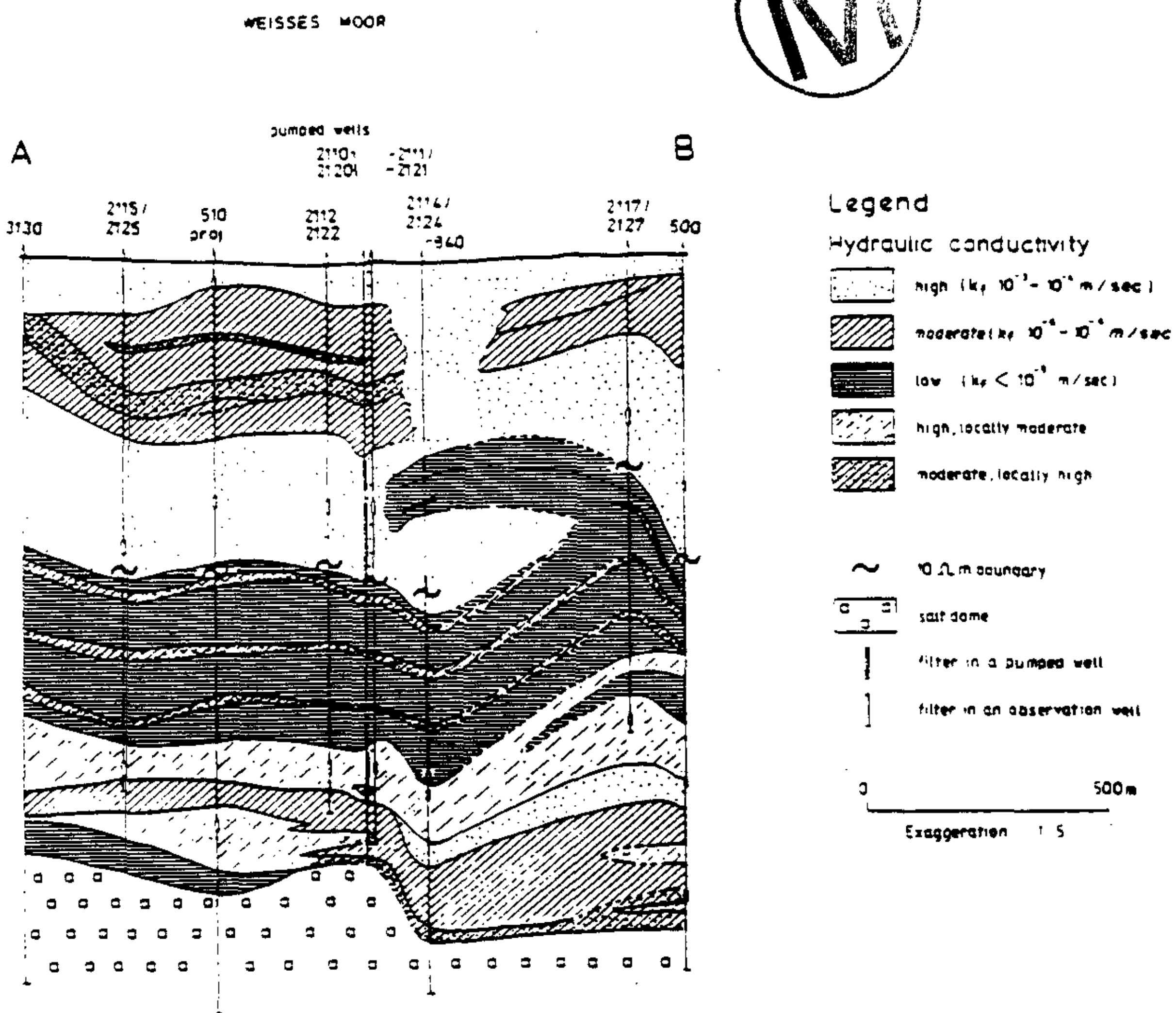

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the basis for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available Data

The data available from the selected pumping tests are:

- borehole locations (maps)
- hydrogeological data (groundwater levels etc.)
- pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed in the area.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository (Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation.

Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

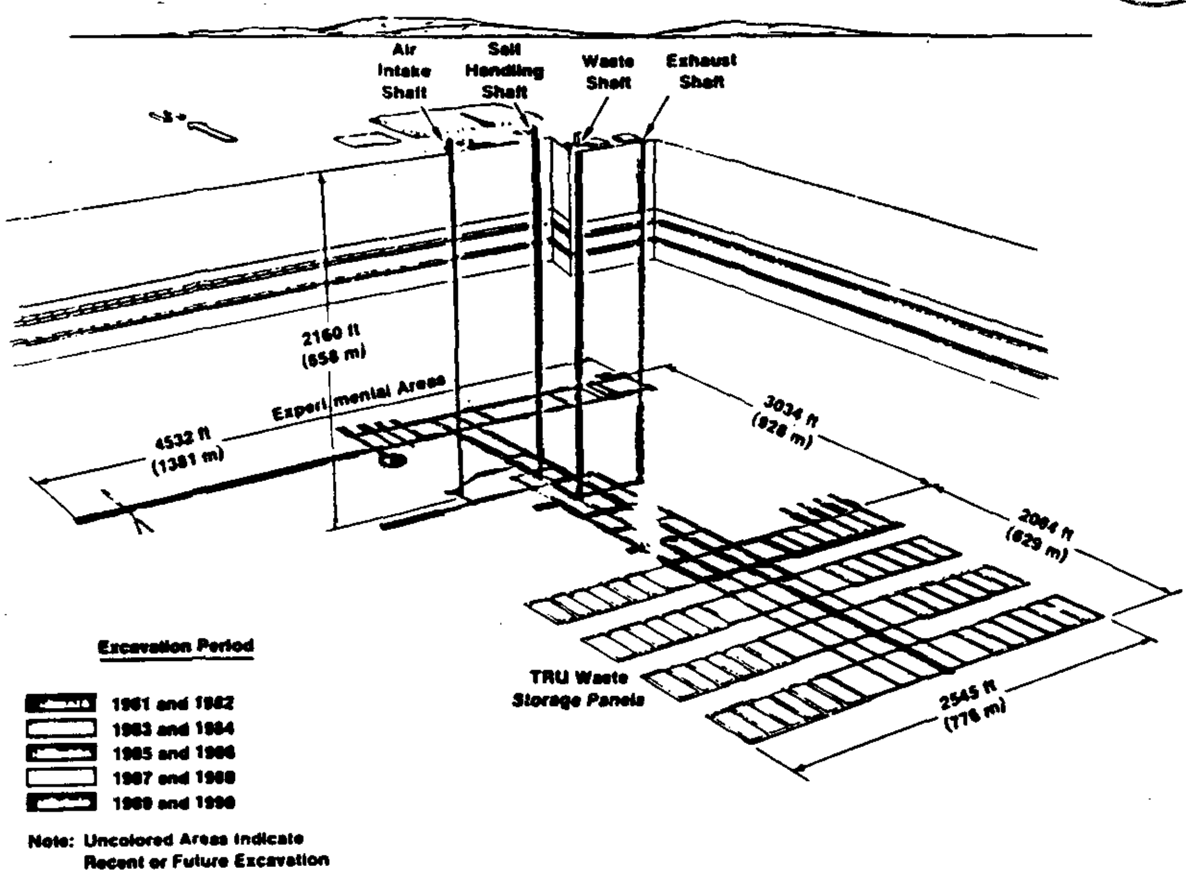

Figure 15. Schematic view of the WIPP site.

Experimental Design

Data from three types of experiments will form the bases for this test case:

- small scale brine-inflow experiments
- pore-pressure and permeability testing
- integrated, large scale experiment

Small Scale Brine-inflow Experiments

Brine-inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (Figure 16) and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole.

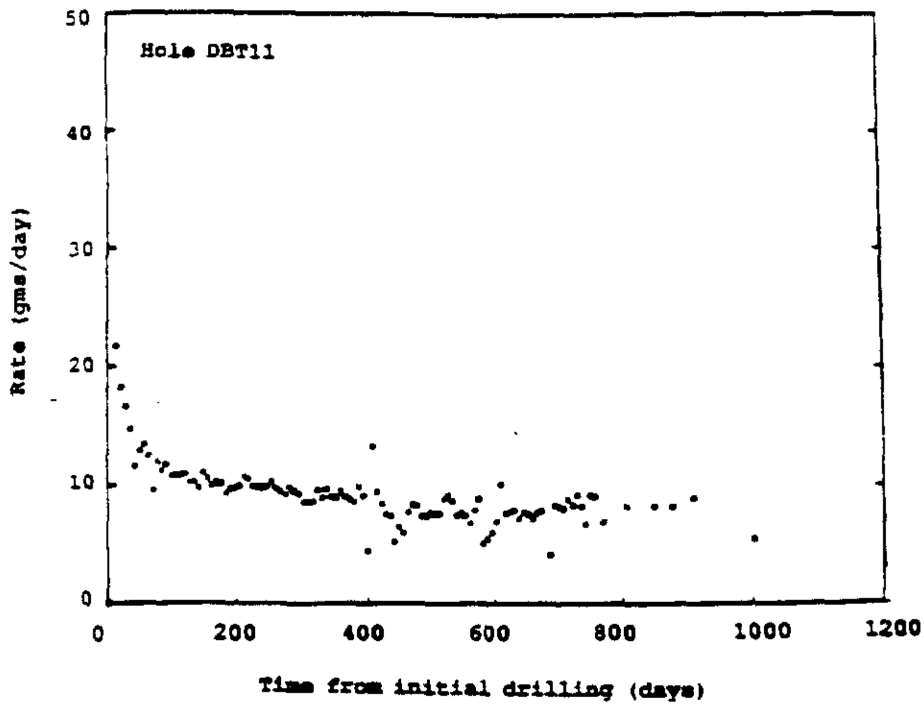

Figure 16. Brine inflow rate vs time in a borehole (Hole DBT11).

Chemical analyses of brine collected are also available. The brine-inflow measurements in the 10 cm diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore-pressure and Permeability Testing

Pore-pressure measurements are made in boreholes with a diameter of 10 cm and 2 to 27 m in length, drilled at a variety of orientations. Pore-pressure is measured in brine-filled, packer isolated intervals in the boreholes. Factors other than the formation pore-pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are also monitored. The boreholes are furthermore used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, Large-scale Experiments

A horizontal cylindrical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the room as well as the brine inflow into the room are now being measured. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore-pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore-pressure measurements, and measurements of borehole deformation and brine inflow.

Available Data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

- brine inflow rates
- humidity
- room closure, borehole deformation
- pore-pressure
- data from permeability tests
- rock property data
- general stratigraphic information
- core logs

Supporting Information

A number of technical issues that are important to the WIPP's performance are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

MOL

Migration experiment in Boom clay formation at the Mol site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

A number of piezometers, a so called piezometer-nest, have been installed in an underground research laboratory in the Boom Clay formation at a depth of 220 m (Figures 17 and 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand-pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand-pipe makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometer-nest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system was left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day during about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. The sampling was started 3 months after the start of the injection and continues at a two months' interval. To avoid disturbance of the HTO concentration, distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

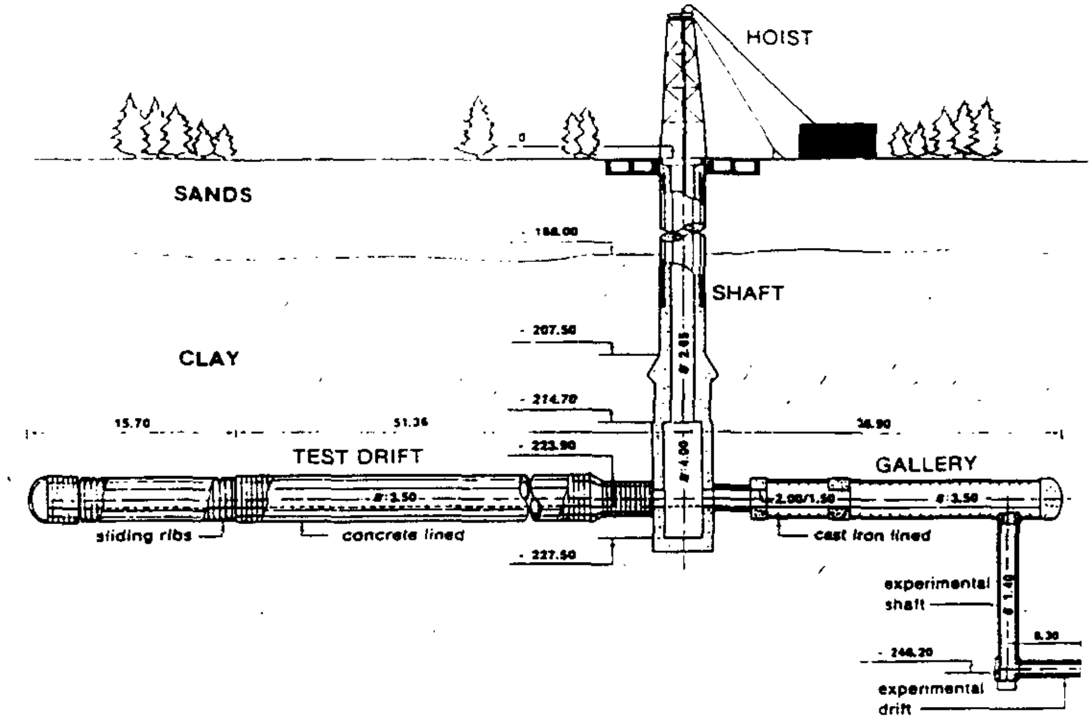

Figure 17. Scheme of the underground facility at Mol.

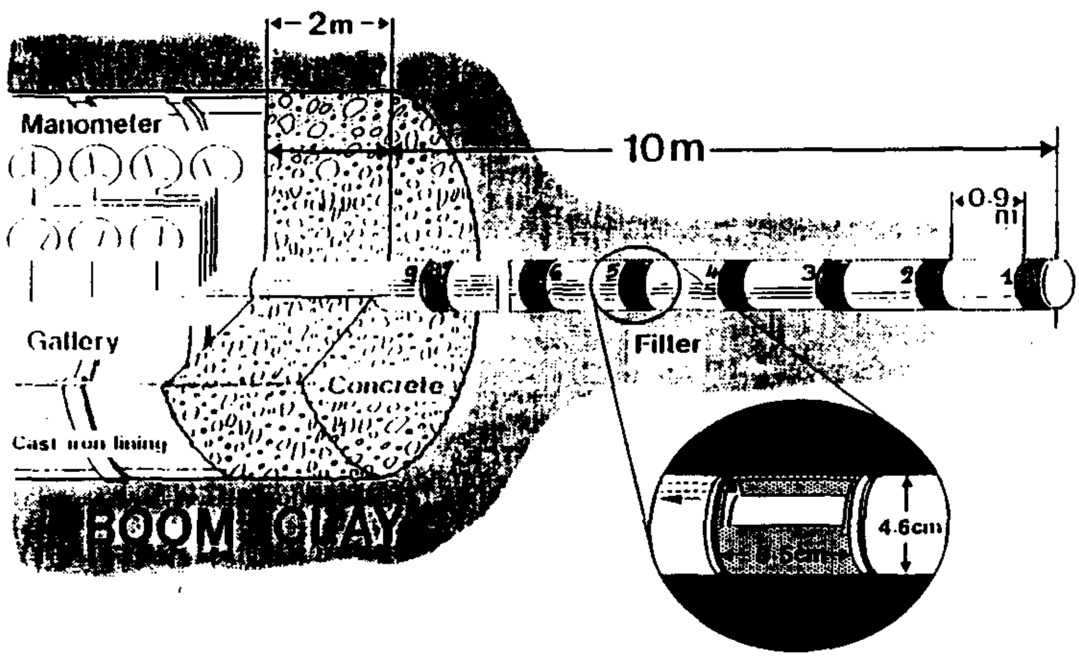

Figure 18. Conceptual view of the piezometernest.

Available Data

- steady state pressure distribution in the clay
- HTO concentration as a function time
- tracer injection data

Supporting Information

Supporting data are available from laboratory experiments and other in situ experiments. Transport parameters, e.g., the product of effective porosity and retardation factor, apparent dispersion constant, and diffusivity, have been estimated. A number of laboratory experiments have been performed, such as through-diffusion and percolation experiments with clay cores. The Boom clay is rich in organic matter which to a large part is linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

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

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participating organisations are the Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

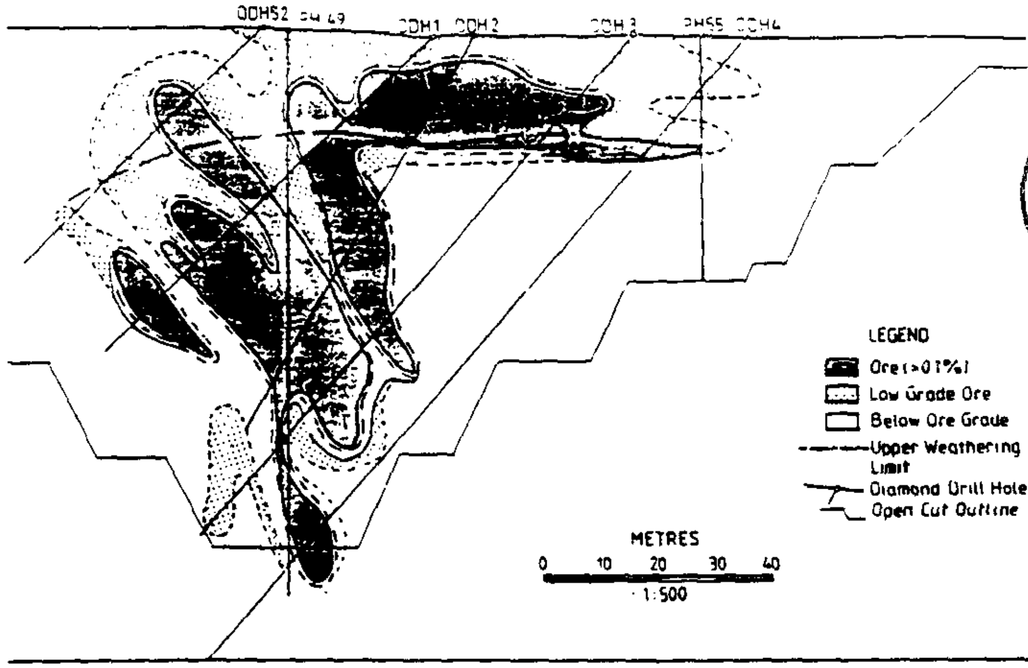

Figure 19. Cross section showing the dispersed zone at the Koongarra deposit.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses
- results from porosity and permeability measurements on drill core samples

Hydrochemistry

- pH, Eh, D.O., conductivity and temperature in groundwaters
- groundwater concentrations of cations and trace metals
- groundwater concentrations of uranium series nuclides and isotopes

Geology, Mineralogy, Radiochemical

- uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
- uranium series radioisotope activity ratios data for selected samples in the ore zone
- results from chemical analyses of core samples
- mineralogical composition of samples
- concentrations and activity ratios of uranium and thorium in different mineral phases
- concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20-40- and 260-metres natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Available Data

A large database is available, containing data both from field and laboratory experiments, such as:

- permeameter test data
- small-scale dispersion
- porosities
- grain size composition
- hydrogeological data
- geophysical data
- mapping of tracer migration (Figure 21)

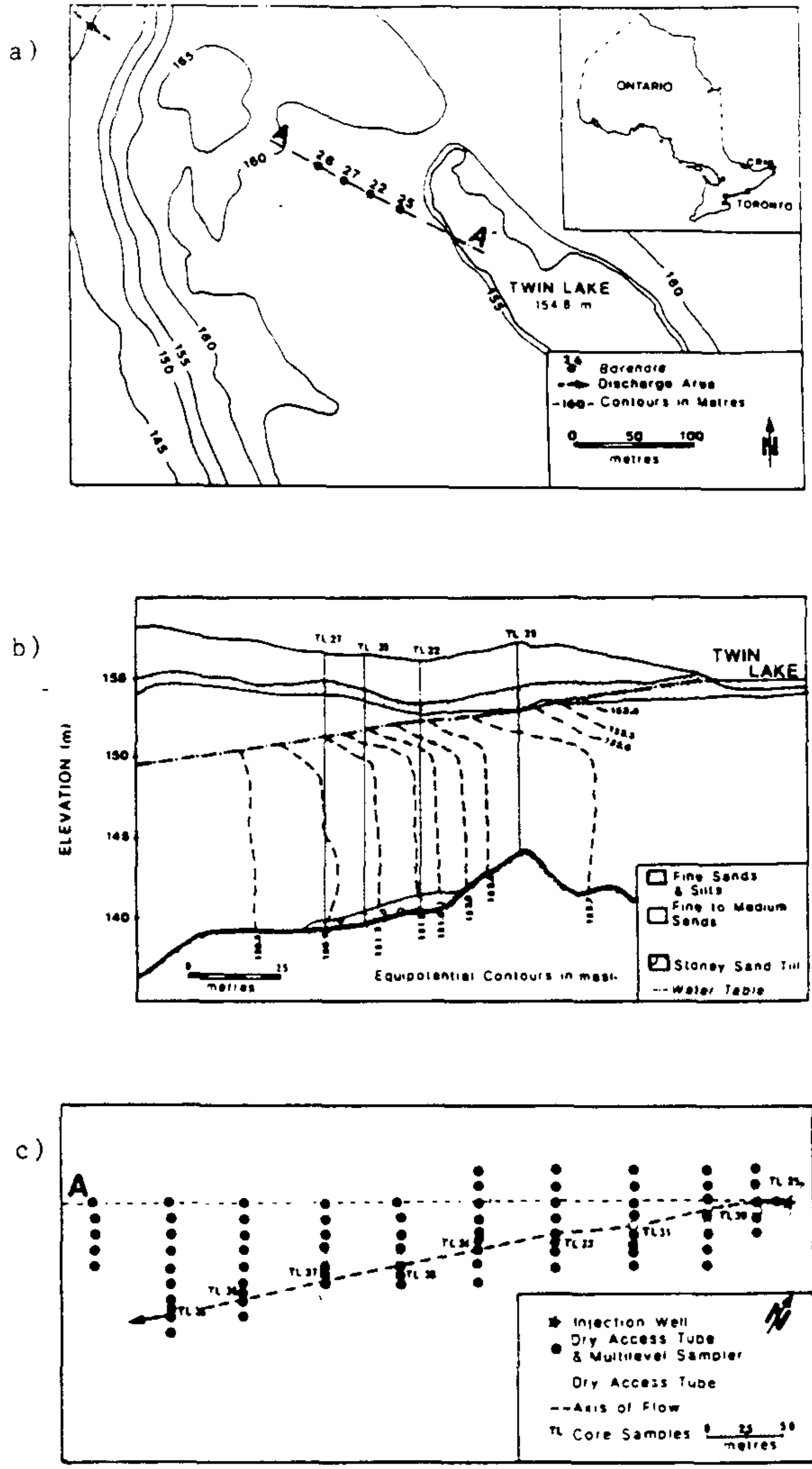

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A-A'). (c) Plan of field site showing instrumentation and tracer flow line.

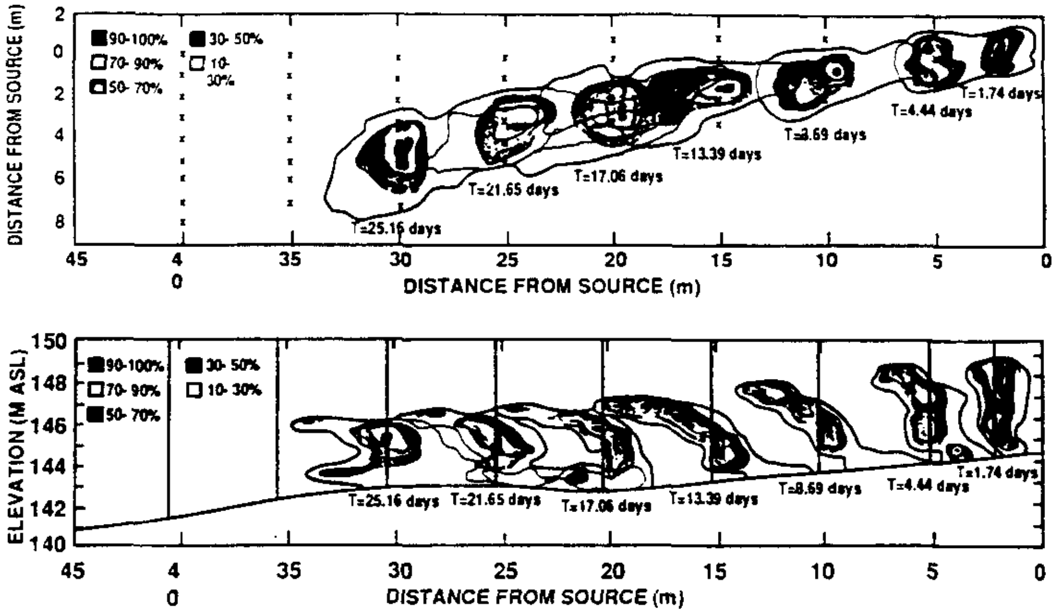

Figure 21. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke PJ., Gilling D., Jefferies NL., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a. INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

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INTRAVAL Parties:

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PROGRESS REPORT

9

March 1992 – November 1992

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

INTRAVAL
Progress Report Number 9, 1992

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.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL Progress Report Number 9

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990. The last workshop will be held in the autumn 1993.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both with regard to the processes and site-specific systems.

Eleven test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have 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 in such a way that it is possible to simulate the experiments with model calculations. 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.

Contact between the participants is maintained by arranging workshops which are followed by Coordinating Group meetings. Working Group meetings take place between the workshops.

Since the issue of the previous Progress Report, the eighth INTRAVAL workshop and the fourth Phase 2 Coordinating Group meeting have been held in San Antonio, USA. During the workshop the participants described the modelling work performed and discussed the results achieved so far. A full day session was dedicated to a general discussion of validation issues.

Most of the Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members. Two of the reports are in print and some minor editorial changes remain in another report. The Phase 1 Summary report is scheduled for printing in the spring 1993. The schedule for the Phase 2 reporting was discussed and it was concluded that draft versions of the Working Group reports have to be available in the summer of 1993 and final versions in December 1993.

The Eighth INTRAVAL Workshop and the Fourth Phase 2 Coordinating Group Meeting

The eighth INTRAVAL workshop and the fourth Phase 2 Coordinating Group Meeting were held in San Antonio, Texas, USA, on the 9th through 13th of November, 1992, with the Center for Nuclear Waste Regulatory Analysis (CNWRA) acting as host. At the workshop technical presentations of the modelling results achieved by the Project Teams were given. A full day session was dedicated to a general discussion of validation issues. The session was divided into a morning session with presentations from invited speakers and an afternoon session with discussions. The schedule for the final reporting of the project was discussed and it was concluded that draft versions of the Working Group reports have to be available in the summer of 1993 and final versions in December 1993. Extended outlines of the reports to be written were presented.

The Coordinating Group meeting was held on the 13th of November, 1992. The time schedule for the finalisation of the INTRAVAL project was agreed upon (see section about Phase 2 reporting). Because the leader of Working Group 4 was no longer available, it was decided to dissolve Working Group 4. A summary of the Alligator Rivers Test Case will be prepared by the Secretariat. The Twin Lake test case will be incorporated with Working Group 1 for the remaining part of INTRAVAL Phase 2.

The next, and final, INTRAVAL workshop will be held in Stockholm, Sweden, August 30 - September 3, 1993. It was suggested that each Working Group, together with the Secretariat, should organise a one-day plenary session that should follow the outline of the Working Group report. The next Coordinating Group meeting will be held in connection with the workshop in Stockholm. It was also decided to have an additional, and final, Coordinating Group meeting after the Stockholm meeting. Separate Working Group meetings are scheduled prior to the next INTRAVAL workshop.

The chairman informed that SKI will not be able to organise a third phase of INTRAVAL. However, SKI would be interested in the formation of a "Forum for flow and transport in rock in relation to performance assessment needs", but SKI would not take any specific initiative for its creation.

INTRAVAL Sub-Committee for Integration (ISI)

The second meeting of the INTRAVAL Sub-committee for Integration (ISI) was held on the 11th of November, 1992. A draft outline of the INTRAVAL integration and validation (summary) report was reviewed. A draft version of this report is to be completed by summer 1993, a second draft version by December 1993 and the final report in 1994. The aim is to get the ISI summary report published in a scientific journal.

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in a Summary Report and a series of technical reports. The technical reports cover descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports is a compilation of descriptions of the experiments on which the test cases are based. The technical reports have been prepared by six Working Groups. An editor was appointed for each test case with the responsibility to compile the test case analysis provided by the Project Teams.

All except four of the Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members. Two of the reports are in print and some minor editorial changes remain in one report. A draft version of the Phase 1 Summary report has been distributed to the Working Group leaders and the members of the Sub-committee for Integration for review. The final version of the Phase 1 Summary report is scheduled for printing in the spring of 1993.

Information from the Phase 2 Working Groups

Originally four Working Groups were set up addressing different types of test cases. Because of Mr. P. Duerdens, leader of Working Group 4, withdrawal from INTRAVAL, it was decided to dissolve Working Group 4. Two test cases were included in Working Group 4; Alligator Rivers and Twin Lake. A summary of the work on the Alligator Rivers Test Case will be prepared by the Secretariat. The Twin Lake test case will be incorporated in Working Group 1 for the remaining part of INTRAVAL Phase 2. Table 1 gives the test cases included in the three remaining Working Groups.

Table 1. Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap Twin Lake	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski

A chairman has been elected for each Working Group, sometimes aided by another person. The chairs of the Working Groups are responsible for the preparation of Working Group reports, which will form part of the final reporting of INTRAVAL Phase 2.

Since the previous workshop in Sydney, Australia, in February 1992, all Working Groups have arranged meetings. Minutes from most of these meetings are available on request from the Project Secretariat. Except for the meetings presented in Table 2, half a day was dedicated to Working Group meetings during the workshop in San Antonio.

Table 2. Working Group meetings held between March 1992 and November 1992.

Working Group	Date	Location	Test Case
1	June 1992	Las Cruces, USA	Las Cruces Trench
2	June 1992	Forsmark, Sweden	
3	June 1992	Traben-Trarbach, Germany	
4	October 1992	Toledo, Spain	Alligator Rivers

Prior to the next INTRAVAL workshop a number of Working Group meetings are scheduled (Table 3).

Table 3. Scheduled Working Group meetings.

Working Group	Date	Location	Test Case
1	December 1992	USA	Yucca Mountain
1	January 1993	Tucson, USA	Apache Leap
1	June 1993	USA	Yucca Mountain
2	March 1993	Berkeley, USA	
3	December 1992	SNL, USA	
3	March/April 1993	Bilthoven, Netherlands	
3	June 1993	Germany	Gorleben
4	No more meetings, Working Group has been dissolved		

INTRAVAL Phase 2 Reporting

The Secretariat will not take responsibility for publishing INTRAVAL Phase 2 Working Group reports. It is suggested that the technical work should be published in existing report series, journals etc. However, the Secretariat need a summary of the work within each Working Group to be included in the INTRAVAL Phase 2 Summary Report. In addition, a special report on integrated conclusions from the INTRAVAL Project will be prepared by the INTRAVAL Sub-committee for Integration (ISI).

Tentative schedule for the Phase 2 reporting:

Working Group reports:

- Extended outline, November 1992
- Draft, summer 1993
- Final draft, December 1993

Summary Report, INTRAVAL Phase 2:

- First draft, December 1993
- Final report, December 1994

Integrated conclusions (ISI) report for INTRAVAL Phase 1 and 2:

- Extended outline, November 1992
- First draft, summer 1993
- Second draft, December 1993
- Final Report, 1994

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 m × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 m × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 m × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in

INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from PNL/USNRC has used the Plot 2b experimental data for testing deterministic and stochastic models of water flow and solute transport through heterogeneous, unsaturated porous media. When evaluating the Plot 2b experiment it was found that the effects of spatial variations in hydraulic properties on solute transport during transient unsaturated flow are significant. The Plot 2b experiment was modelled using four scenarios: 1) isotropic conductivities and modified van Genuchten water retention function, 2) anisotropic conductivities ($K_x = 2K_z$) with constrained residual water content, 3) isotropic conductivities with water retention parameters determined using 1-D inverse solution and data from Las Cruces trench experiment 1, and 4) a single stochastic realisation of conductivities conditioned on data from the trench. It was found that simple uniform models predicted water flow better than the single stochastic realisation conditioned on data from the trench. Future work will investigate the use of generalised scaling analysis for describing the spatial variability of flow and transport properties.

The Project Team from CNWRA/USNRC have used the Plot 2b experiment to study the effect of model complexity on the accuracy of model predictions. The technical approach includes re-estimation of the van Genuchten model parameters from water retention data to ensure that initial suctions are consistent with measured initial water contents, kriging of the van Genuchten model parameters to quadrilateral zones, modelling of the movement of the moisture plume along three 2-D transects using the code PORFLOW, and finally, comparison of model predictions of water content to measured water content at different times up to 310 days by momentum analysis and point-to-point comparisons. All data available from the Plot 2b experiment were used in three models with different complexity regarding the discretisation. It was found that the most complex model provides the most accurate predictions, based on the sum of squared differences between computed and measured water contents. Analysis of the moments of the water content distribution does not aid in determining which of the three models is best. Analysis of the second moments indicates that there is less variation among the three models than between the models and the experimental results.

The Project Team from University of New Mexico/USNRC discussed the use of statistical inference to quantify the validity of different models applied to the Las Cruces experiments. Observations and, in most cases, blind predictions performed by different groups concerning water contents, first arrivals, fluxes and moments have been compared. The predictions made are based on 13 different conceptual models for the soil properties; five for a uniform isotropic soil, two for a heterogeneous isotropic soil, and six where the soil properties have stochastic distributions. The results varied, some models performing well for some measures and others performing well for other measures. For example, it was found that the models consistently predicted longer times for the first arrival than observed, implying that the models cannot be regarded as conservative. The applied stochastical models showed more preferential flow than observed in the experiment. It was pointed out that quantifying the uncertainty in the applied models requires models for probability distributions and correlation structure of the uncertainty. This suggests that stochastic models for uncertainty may be required to quantitatively validate deterministic models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source will affect air, vapour, water and solute movement in geologic media, especially unsaturated fractured rock, and the water and air transport properites of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory non-isothermal core measurements. A cylindrically shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimise heat loss along the sides of the core. During the experiment, a horizontal temperature gradient was established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to characterise water and air transport properites from fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which was 92.5 cm long, 21.0 cm high and 20.2 cm wide and contained a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The position of the wetting front in the fracture over time and the position of the wetting front in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are plans to perform field investigations. However, most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Analyses by Project Teams

The Project Team from the University of Georgia/USNRC presented laboratory experiments where water and gas flow behavior in unsaturated fractured rock were studied. A block of Apache Leap Tuff with a single discrete fracture was used to perform a series of tests to characterise the water and air transport properties of fractures and the rock matrix for a range of matric suctions. Fracture flow experiments were carried out to investigate the behavior of water and three gas mixtures: air, air plus a helium gas tracer, and air plus an argon gas tracer. In addition, coupled fracture-matrix fluid flow was addressed by studying the imbibition of water into the fracture and subsequent uptake and migration of water into the rock matrix bounding the fracture in an initially dry rock block. The rock fracture transmissivity was determined before and after the imbibition test using air flow, tracer and water injection experiments. Similar transmissivities were obtained in the different types of experiments even when using different pressure head gradients.

Equivalent fracture apertures were evaluated from six types of experiments. Three volumetric fracture aperture values were obtained using a pycnometer, tracer breakthrough volumes, and the ratio of fracture transmissivity to fracture hydraulic conductivity. Two Poiseuille apertures were calculated using a cubic aperture equation applied to gas and water flow rates, and using a quadratic aperture equation for the gas tracer breakthrough. A final estimate of fracture aperture was obtained using the air-entry potential of the saturated fracture.

The volumetric apertures, estimated using the pycnometer and the tracer breakthrough volumes, were found to be very close. The volumetric aperture determined using the ratio of fracture transmissivity to hydraulic conductivity gave smaller apertures, followed by the apertures determined using the cubic and quadratic equations, respectively. The smallest aperture observed was the capillary aperture. This progression is consistent with the hypothesis that fracture roughness will decrease the effective flow area for the Poiseuille flow and induce an ink bottle effect at fracture constrictions. The difference between apertures obtained using these six different methods was almost one order of magnitude.

The water imbibition rate was predicted using a model for a single horizontal fracture bounded by porous rock. The applied model include three stages in the fracture imbibition process. The first stage consists of rapid water imbibition into the dry fracture, the second stage of a lower imbibition rate into the fracture and rock matrix, and the final stage corresponds to an imbibtion rate where nearby fractures or rock matrix boundaries interfere and limit the lateral migration of flow away from the fracture. The model was found to provide a good fit of the shape of the observed data, but the model overestimated the fracture imbibition volume by a factor of twenty and the fracture wetting front advance by almost a factor of ten. The noted reduction in water inflow may be due to phenomena neglected in the theoretical model, such as fracture surface coatings or enhanced surface wetting and the inability to accurately determine fracture physical properties a priori, such as the fracture water diffusivity.

It was shown that fracture saturation behind the wetting front initially is very low, perhaps ten percent, but increases to complete saturation during the course of the experiment. This may indicate that fingers of saturation exist within the fracture during early times which expand laterally and dissipate over time. It seems that the fingering (channeling) is at least as pronounced in unsaturated fractures as in saturated.

Scale effects in air permeability determinations were studied by the Project Team from University of Arizona/USNRC. One borehole, Y2, has been tested at three different scales: 0.5, 1, and 3 m. Two other boreholes, X2 and V2, are currently being tested at a 1 m scale and another three boreholes, W2, Z2 and V2, will be tested at a 1 m scale. This will give a total borehole length of 180 m tested at a 1 m scale. High permeability intervals in these six boreholes will be retested at a 0.25 m scale to better define major fractures. The data obtained so far have been used for a preliminary geostatistical analysis to study the scale effect on the permeability determinations. The permeability based on the 0.5 m measurements has been found to vary over 11 orders of magnitude. The variability of the 1 and 3 m scale data is smaller, as expected, inferring that the measured permeability is a strong function of scale. The average permeability increased with increasing scale. Despite the large spatial variability of the permeability measurements, the underlying spatial structure has been found to be represented by a classical semi-variogram model. Thus, flow through the fractured porous material may be amenable to the theory of stochastic hydrology.

YUCCA MOUNTAIN

Yucca Mountain experiments.

Experimental Set-up

The objective of the Yucca Mountain test case is to compare predicted and observed moisture content as a function of depth in a borehole currently being drilled. The data set for the test case consists of composite transects of hydrologic properties at the site, detailed geohydrological data and moisture content data from boreholes UZN-53, UZN-54 and UZN-55, and topographic and structural geology information for the site. Data from the three UZN-boreholes will be used for prediction of the moisture content in a new borehole, UZ-16, that will be drilled to a depth of about 500 m at a distance of about 100 m from the UZN-boreholes. The drilling of this borehole is scheduled to be completed in March 1993 and the comparison between measured and predicted data is scheduled to be completed until next INTRAVAL meeting, in the autumn 1993.

Analyses by the Project Teams

The observer from the State of Nevada has studied the effects of variability in selected model inputs on modelled unsaturated water content profiles. 1-D, 2-D as well as fracture models were applied for simulations of the water content in the rock to a depth of almost 500 m. Some of the data used originate from boreholes at the Yucca Mountain site not included in the test case. The rock was modelled as consisting of seven hydrologic layers except for the 1-D case where the number of layers varied from 4 to 11. The results from the 1-D models showed a poor fit to measured data even though the number of layers as well as the infiltration rate were varied. The wet conditions within the upper high conductivity unit, co-existing with the unsaturated conditions in the low conductivity units, could not be modelled with 1-D geometry and infiltration. Like the 1-D simulations, the 2-D simulations were found to underestimate the measured water content in the upper unit. The fracture flow model showed considerably better match to observed data. In this model, water was recharged into a vertical fracture intersecting all seven hydrologic layers. The recharge rate was estimated based on ground surface material, topography, and climate data. The fracture density in the rock was set to about three fractures per metre. In this case, the very wet conditions in the upper permeable unit as well as the unsaturated conditions below are much better represented than either the 1-D or 2-D representations.

The Project Team from SNL/USNRC presented their initial work with geostatistics applied to the Yucca Mountain test case. The porosity between boreholes was simulated using a geostatistical simulator that can be used for 2-D as well as 3-D simulations and where each simulation is equally consistent with observed data. Observed correlations with porosity are used to generate other properties in a stochastic fashion. In this way, the saturated conductivity is generated from the porosity and the average pore size from the square root of the saturated conductivity divided by the porosity. Each simulation produces porosities on a local scale which are upscaled to the size of the element used in the grid followed by calculations of velocities and fluxes in the studied section.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of à fractured zone including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. The modelling is focussed on the dipole experiment.This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling, since it became available too late.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s; the middle 10^{-7}–10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water–salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbing tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Project Team from VTT/TVO discussed if breakthrough curves obtained from field tests using non-sorbing tracers reveal matrix diffusion. In tracer tests, like those performed in Finnsjön where a tracer is injected in one borehole and collected in another borehole, the breakthrough will be affected by hydrodynamic dispersion as well as matrix diffusion. When studying the Finnsjön tracer experiments it was found that the observed dispersion in the breakthrough curves was dominated by hydrodynamic dispersion rather than matrix diffusion because of the relatively high flow rates. Furthermore, if the flowpaths and velocity fields between the boreholes are unknown, which is the normal case, then transport in a number of individual channels can produce breakthrough curves similar to those that would be obtained for transport in a single path where the tracers interact with the rock matrix. Another effect that also might be misinterpreted as matrix diffusion is diffusion into stagnant volumes of water. The conclusion from the presentation was that matrix diffusion parameters cannot be determined from breakthrough curves obtained in field experiments. Instead, laboratory experiments and possibly also in in-situ experiments without any flow or with extremely low flow rates should be used for this purpose. Field tracer experiments, like the Finnsjön tests, should aim at studying flow and channeling concepts.

The Project Team from PNC has used a stream tube approach to study the effect of heterogeneity on tracer transport at the Finnsjön site. The rock was modelled as a high conductive layer with low conductive layers above and below. The mass transport in the high and low conductive zones were expressed by 1-D and 2-D advection-dispersion equations, respectively, for each streamtube. A hydraulic conductivity distribution was generated by using data from hydraulic tests at each borehole and the radially converging test. This hydraulic conductivity distribution was then used to simulate the dipole tests and to estimate the tracer transport parameters, dispersivity and porosity. Finally, the validity of the estimated parameters was confirmed by simulating breakthrough curves at the pumping hole in the radially converging test. These simulated breakthrough curves showed good agreement with measured curves, except for the tracer iodide which was explained with experimental problems during the iodide experiment causing disturbances in the breakthrough curves.

The Project Team from Conterra/SKB presented work regarding calibration and validation of a stochastic continuum model using data from the Finnsjön dipole tracer test. The main aim with this work was to investigate whether the stochastic continuum approach can successfully be used to describe tracer transport in fractured crystalline bedrock and specifically to explore whether a model calibrated on a local scale can be validated on a larger scale.

In the case of the Finnsjön tracer tests, only one scale of testing has been done and in view of the lack of a second measurement scale, a realistic generic case was created to test the ideas on calibration and validation of a stochastic continuum model. The problem was tackled by creating a reference transmissivity field represented by a 0.5 m thick 2-D confined aquifer with a size of 1200 m × 1200 m, corresponding to the upper highly conductive part of zone 2. All measured transmissivity data were used to construct a synthetic reference field as close as possible to the real situation. Dipole tracer tests, similar to the Finnsjön test, and a far-field (natural gradient) test were performed in this synthetic reference field for calibration and validation.

Eight boreholes penetrating fracture zone 2 have been hydraulically tested and several realisations were generated and conditioned on the data from these boreholes. One of the generated realisations was randomly chosen as the reference field. Two dipole experiments were simulated in the synthetic reference field, BFI01 to BFI02 and KFI11 to BFI02. In both experiments a total number of 900 particles, which were assumed to be conservative, were released. The movement of particles was analyzed using particle tracking techniques assuming no local dispersion, i.e. only advection was taken into account. These results were considered to be the real system response of the reference field and was used for calibration. The far field simulation in the synthetic reality was performed under natural gradient conditions. The tracer particles were instantaneously injected at a 20 m × 200 m area along the upstream boundary and the breakthrough at the downstream boundary of the model, more than 1000 m away, was recorded. The results from this far field simulation were used to validate the overall model, i.e. the validity of extrapolating a model calibrated and partially validated on a local scale to a larger, far field scale.

The team used the Monte-Carlo approach to generate 100 equally probable realisations having the same statistical structure as the observed data. The generated realisations are inherently unconditional since only the statistical parameters are the same as the measured data, whereas the actual transmissivity data at the boreholes are not honored. Comparing the breakthroughs in the dipole experiments it was found that individual realisations could be very different to the reference field due to uncertainty in transmissivity values, while the mean (assemble) breakthrough curve was very close to that of the reference field, especially for the BFI01 test. Based on a quantified measure of the deviation of the simulated breakthrough curve from that of the reference field, 3 of the 100 fields were chosen that captured the reference field quite well. The far field simulations were calculated under natural gradient conditions using the same transmissivity fields as for the local scale dipole test. The results from the three simulations show very different mean arrival times and dispersion patterns, indicating that calibration of the model on the local scale and subsequent prediction of far field transport phenomena can result in high uncertainty. To investigate the effect of the number of conditioning data on uncertainty, 28 new points were randomly selected from the reference field as new measurement data. Thus, a total of 36 measurement points were used for new conditional simulations. The calculation results on the local scale (dipole test) are similar to the results obtained when using only eight conditional points. In this situation, adding more measurement points on a larger scale does not improve the simulations on a local scale. However, the far field simulations were improved by adding these conditional points. It was thus concluded that calibration on a local scale is insufficient to validate a model for a larger transport scale and the model that gives the best fit on the local scale may not be the best model for far field predictions due to pronounced heterogeneity.

The Project Team from BRGM/ANDRA presented an analysis of the Finnsjön interference tests that accounted for boundary effects. The interference tests were performed by pumping in borehole BFI02, which intersects fracture zone 2, while the drawdown was monitored in the other boreholes at the site. Analysis of the interference tests was performed in two phases, with interpretations applying analytical solutions in the first phase and using a 3-D finite difference model in the second phase. In the first phase, the team evaluated transmissivities, storativities and distance to boundaries from the drawdown curves obtained from boreholes KFI05, KFI06, KFI09, KFI10 and KFI11. The transmissivities were found to be almost one order of magnitude larger when evaluating the drawdowns for early times compared to the whole test duration due to boundary effects. It was also observed that there are difficulties in correlating the estimated boundaries to the interpreted geometry of the main structural/geological features at the site.

In the second phase of the work the team calibrated a 3-D finite difference model on interference tests 1 and 2, performed in the lower and upper highly conductive subzones of fracture zone 2. The model was subsequently "validated" on test 3, performed in the entire fracture zone 2. It was found that the performed calibration on tests 1 and 2 gave a good representation of the data from test 3. The team will continue with tracer test interpretations using the calibrated hydrology.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiments, Sweden.

Experimental Set-up

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

In an experimental drift, excavated in the old iron ore mine in Stripa, the whole ceiling and upper part of the walls was 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 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 pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from supporting laboratory and field experiments. The experiment was a test case also during Phase 1 of INTRAVAL.

In addition to the results from the 3-D experiment, data from two other experiments performed in the Stripa mine, the "Channeling Experiments" and the "Site Characterisation and Validation program", are available to the INTRAVAL Participants during Phase 2. The Channeling Experiments consisted of two kinds of tests, single hole and double hole experiments. In the single hole experiments, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simple packer systems. In the double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole. The Site Characterisation and Validation program, with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, involved a number of investigation steps with modelling predictions. A few long boreholes were used to characterise the rock volume. Additional boreholes were drilled and used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the "Validation Drift", was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

The Project Team from BRGM/ANDRA analysed flow and tracer transport in the Stripa 3-D experiment and especially studied the influence of connectivity. The modelling was performed in steps, starting with building and conditioning of the stochastic fracture network model, followed by calibration of two types of channelling models, and finally simulation of the tracer breakthrough in these channel networks to check the physical meaning of the two tested models. The model contains the three main sets of fractures that were found at the 3-D site. The orientation of the fractures was assumed to be identical for fractures belonging to the same fracture set and was set to the peak density value. The disc diameter distribution was estimated from the observed trace length distribution. One of the main results obtained from a parameter study of the simulated fracture network was that the medium connectivity was not basically affected if fractures with a radius less than 2 m were excluded. This significantly reduces the number of fractures that have to be generated. The next step in the study was to reproduce the actual location of the fractures. This was achieved by conditioning the simulated fracture field to the observed fracture traces.

The flow through the generated fracture networks was calculated assuming that the flow takes place in a secondary network of one-dimensional hydraulic channels. Two models were calibrated to observed data in such a way that the global properties and the observed heterogeneities of the medium were described. Hence, the two models give by construction the same hydraulic response since calibrated to the same data. The Simplified Random Disk (SRD) model assumes that the nodes of the network are the centers of the fractures and flow occurs through "bonds" joining the center of each disk to the center of any intersecting disk. The Random Channel (RC) model assigns one or more sets of channels to each set of fractures. Inside the plane of a given fracture, each channel is defined by an orientation, a length, and a center. The channel centers are randomly located on the fracture planes. The flow simulations were performed in a 190×160×150 m volume, completely covering the 3-D drift. A zero constant head was imposed in the 3-D drift and a constant head derived from borehole measurements was imposed at the top of the studied volume. All the vertical box faces as well as the bottom of the flow domain were no-flow boundaries.

The calibrated flow models were used for transport modelling. The aim of the transport modelling was to reproduce the global transport properties rather than the exact location of each restitution point or the detailed breakthrough curves corresponding to these points. The breakthrough curve for one of the injected tracers, Eosin B, was chosen for calibration of the transport models. The usual advection-dispersion equation was solved within the channel network using a particle tracking method and the code TRIPAR.

There were only two transport parameters included in the transport models, the dispersivity and a shape factor defined as the ratio between the length and the width of each hydraulic channel. Although the two models by construction give the same hydraulic response, the SRD model is macroscopically less dispersive and transport solutes faster than the RC model. It therefore needs higher dispersivities and lower shape factors to conform to a given curve. In order to simulate correct arrival times with the SRD model, shape factors were needed which imply a generalised flow in the plane of the fractures and therefore basically no channelling effect. The shape factors obtained with the RC model are more compatible with the channel-like arrivals observed in the drift. The parameters calibrated from the Eosin B experiment were used to simulate the breakthrough for another tracer, Uranine. With the SRD model the predicted first arrival time of Uranine into the drift was too short and with the RC model the predicted concentrations were too low (Figure 1). Hence, the parameters determined from the breakthrough curve of one tracer could not be used directly to simulate the breakthrough curve of another tracer. It was suggested that the used parameter values may not be reliable estimates of global rock mass properties because of the no-flow boundary conditions used in the modelling and because of the low recovery of the tracer Uranine in the field experiment.

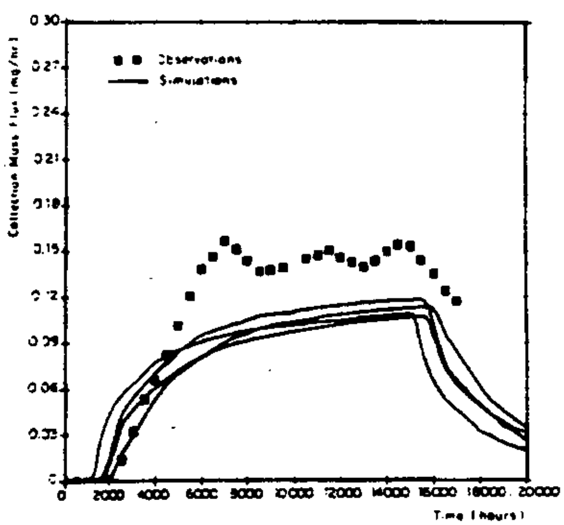

Figure 1. Stripa, BTGM/ANDRA. Observed and simulated mass flux curves for Uranine, Random Channel Model.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Project Team from BGR/BFS has performed some initial modelling regarding regional density dependent flow at the WIPP site. There are not many results or conclusions available so far, since the work has mainly been concentrated on the problem definition and the conceptual model. A vertical regional 2-D section extending almost east-west and intersecting the WIPP site has been chosen for the modelling of flow velocities and salt distribution. The first attempt of the modelling exercise was a simple system considered to be homogeneous. The next step in the work included the high conductive halite formation within the modelled plane. It was then found that the flow velocities within the halite formation were considerably higher than those in the surrounding formations. The latest modelling efforts involve a realistic permeability distribution based on available data and assumptions. The halite formation has not yet been included in the modelling using a realistic permeability distribution.

The Project Team from UPV/ENRESA used stochastic analysis for modelling of the groundwater flow and travel times at the WIPP site. A general problem with kriged fields is that they will become unrealistically smooth, since the variability of the original data will be lost to a large extent. Such smoothing may yield biased responses, particularly for transport problems. By adding perturbations determined at selected locations and interpolated to the remaining points, the spatial structure of the transmissivity field will be preserved. The team applied Monte Carlo methods to generate equiprobable maps of hydraulic conductivity that reflect the variability observed in the field. These conductivity fields are used in flow and transport modelling to obtain different equiprobable output responses. Instead of the turning band method, the common algorithm for stochastic conditional simulations, the team used their own developed conditional sequential simulation method (CSSM). When flow models are run for a series of conditional simulations, the obtained piezometric heads are in most cases found to compare very badly with the observed heads. It is therefore a need and advisable to honor the observed piezometric heads in the stochastical simulations. The following steps were performed to generate stochastic conditioned transmissivity fields honoring piezometric data: 1) application of CSSM to realise conditioning the transmissivity, 2) calculation of the head vector and compare this with the observed piezometric head and, 3) modification of the transmissivity field and boundary conditions within confidence limits, albeit preserving the measured transmissivity values and variability. An objective function was defined as the weighted square difference between observed and computed heads to optimise the solution to this problem. When comparing the heads it was found that the values were somewhat closer, but still quite far from the observed after optimisation (Figure 2). This remaining difference between observed and calculated heads represents the errors due to the applied linear optimisation, indicating that the linear optimisation fails. A more complex objective function will be introduced in future work.

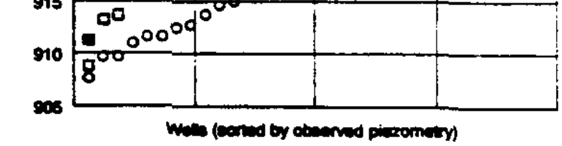

Figure 2. WIPP 2, UPV/ENRESA. Observed and calculated piezometric heads.

The Project Team from Intera presented an automated pilot point inverse technique to generate calibrated conditionally-simulated transmissivity fields. The present model for the Culebra formation uses kriged transmissivity fields to account for the spatial variability and can be calibrated to steady-state and transient pressure fields using the pilot point methodology. Conditional simulations are used to resolve the residual uncertainty not addressed by kriging and the travel time statistics are produced via Monte Carlo simulations. A total of 70 fields have been generated and used for transport calculations. The heads for all these fields were found to be close to those observed. Transport calculations, using the flow model SWIFT II, for these 70 fields indicate travel times between 10000 and 30000 years from the central part of the site to the southern boundary. Although different travel times, there does not seem to be any correlation between goodness of fit for the different fields and the predicted travel time.

The Project Team from SNL presented results from retardation experiments using cores from the Culebra formation. The formation has been found to be very heterogeneous. Different rock types and water chemistry has been found in boreholes separated by just a few meters. However, the team has successfully obtained samples on the Culebra formation water and intact horizontal cores that have been used in column experiments with sorbing and non-sorbing tracers. Core samples with a length of about 10 cm and a diameter of almost 15 cm were used in the column experiments. The samples were fragile and had to be coated with a polyurethane rubber prior to the repressurisation. The experiments started with brine injection until stable conditions were achieved followed by a simultaneous injection of non-sorbing and sorbing tracers. Due to practical considerations, the flow velocity in the laboratory samples were as large as 128 m/year compared to about 0.3 m/year for field conditions. The sorbing nuclides tested so far are: Pb, Eu, and Nd. Tests with U, Pu, Np, Th, Am, Pb, and Ra are being prepared. The experiments performed so far have shown an almost immediate response to the injected tracer, indicating that the primary flow through the Culebra samples is through fractures. Future experiments will be performed using lower flowrates in order to study effects, such as diffusion into the matrix.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental Set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire deeper aquifer in the erosional channel, forms the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The Project Team from BFS presented calculations performed on the Weisses Moor pumping test. The specific permeability (3.5×10^{-12} m^2), storage coefficient (5×10^{-4}), and aquifer thickness (44.6 m) have been estimated with an analytical model (Theis solution) using regression technique to minimise the draw-down residuals in the observation wells. The fitted drawdown curve was found to correspond well to that observed. The determined parameters were used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep rock was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed for both constant density of the water and a density increase with depth. The boundary conditions in the pumped well was either constant withdrawal along the entire well or constant withdrawal at one or both well screens. Almost identical drawdowns were obtained in the different calculations except for a small influence of the well screen location at early times. A conclusion is therefore that the effect of the well screen location is greater than the influence of taking density dependent flow into account. The density effect would probably have been larger if the duration of the pumping test had been longer than the actual three weeks.

The Project Team from RIVM has analysed the Weisses Moor pumping test. When comparing simulated and observed data on drawdown as function of time it was noted that there could in some cases be large discrepancies. Simulated and observed drawdowns were mostly quite close in the vicinity of the pumping well, but was found to be more deviating some distance away from the well. A few wells located close to the edge of the aquifer did not show any response to the pumping test. No pattern has, so far, been found between smaller/larger interpreted drawdowns compared to the observed. When studying the thickness of the aquifer it was found that it varies from 0 m up to about 90 m. Furthermore, samples taken in different parts of the aquifer indicate that the composition could be quite different at different locations. It was therefore suggested that one should carefully study the available geological data of the area and include observed heterogeneities when further analysing the pumping test.

The Project Team from SNL presented an evaluation of the hydraulic anisotropy from the Weisses Moor pumping test. Individual well responses were analysed to evaluate the validity of the distance-drawdown approach. This was done with the code INTERPRET/2 which provides an automatic fitting to Theis and other analytical solutions. Fitting of the transmissivity and storativity to the draw-down data generally gives very good fits to the entire draw-down period, but poor fits to the recovery period. The model generally underpredicts the pressure build up in the well during the recovery period, given that lower transmissivities and storativities are obtained if the recovery period is considered (Figure 3).

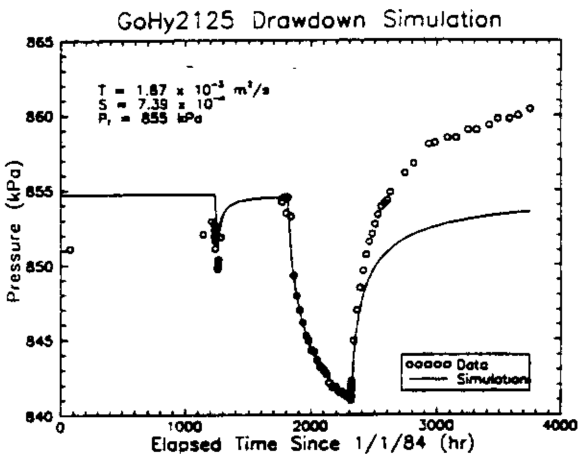

Figure 3. Gorleben, SNL. Fit of transmissivity and storativity to the drawdown data.

The anisotropy in the Gorleben channel was calculated for two groups each consisting of three wells. The horizontal anisotropy of the aquifer was found to be between three and nine, where the larger values were obtained when analyzing the recovery period. It was concluded that an undiscriminating application of the distance-drawdown approach to data from all observation wells does not provide a good indication of the validity of a Theis analysis of the Weisses Moor pumping test.

The Project Team from AEA/NIREX has applied indicator methods to the Gorleben data set. This modelling work include a binary indicator method and uses variograms and kriging for stratigraphic interpolations. The binary indicator approach uses data from boreholes and assigns a number 1 for conductive sections and a 0 for more or less impervious sections, such as clay. Using available data from boreholes in this way and interpolating the indicator function between boreholes by kriging gives estimates of the distribution and variability of the clay formation at the Gorleben site that significantly influences flow and transport predictions. Five boreholes in a vertical section almost perpendicular to the Gorleben channel were selected for comparison between kriged and geological interpretations. It was noted that the long connected features originating from the geological interpretation was not seen when the indicator kriging was applied. Future work with the indicator method will include conditioning by taking known geological structures into account in the model.

The Pilot Group (BGR) has performed numerical studies using the SUTRA code to investigate the density dependent groundwater movement in the Gorleben channel. The objective was to investigate whether steady-state conditions exist in the system today, and also to check the influence of hydrogeological and hydraulic parameters in the model calculations. A two dimensional, 15 km wide and 250 m deep cross-section was selected. The boundary conditions used were no-flow at the bottom, no-flow and no-flux at the sides, linear prescribed pressure at the top with free outflow, and fresh water infiltration. The permeability distribution was developed from a very simplified case in the first calculations to a more realistic description of the hydraulic system by introducing more and more of the observed heterogeneities in the system. A number of long-term (up to several hundred thousand years) simulations to predict the present day density distribution were conducted, starting with different initial conditions for the density distribution. So far the calculations indicate that steady-state conditions have not been reached in the groundwater system in the erosional channel even after a considerably long time. It was also concluded that a realistic picture of the geological setting is essential to be able to predict the present day density distribution. The results of the calculations are dependent on the time-scale of the simulation as well as on the selected initial density distribution, which indicate that additional paleoclimatic information is necessary. It was also concluded that the calculated density distribution is strongly dependent on the transverse dispersivity while an anisotropic longitudinal dispersivity is of secondary importance. The results from the travel time calculations were found to agree well with measured ^{3}H and ^{14}C data. Diffusion has been included in the calculations, but was found to have a negligible effect on the density distribution compared to advection. The work will continue with calculations in a new cross-section, but there are no plans to perform any 3-D calculations.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m.

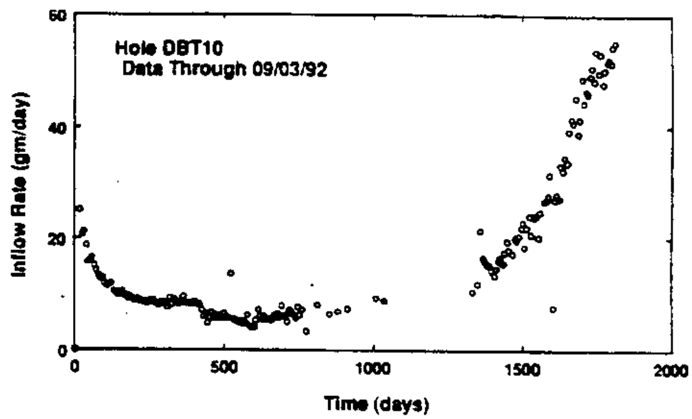

Figure 4. WIPP 1, SNL/WIPP. Brine inflow rate into borehole DBT10.

Analyses by the Project Teams

The Pilot Group (SNL/WIPP) presented the latest results concerning the small scale brine inflow experiments. The brine inflow is measured as function of time in a number of 3 to 5 m deep boreholes located in room D, room L4, and the Q access drift. It has been found that the inflow rates increase with time due to improved sealing and the quite heavy ongoing fracturing. The experiments have been going on for about five years and the brine inflow rate has in many of the observation holes more than doubled during the last year (Figure 4). Seismic tomography has been applied to determine the location and extent of fractures.

MOL

Migration experiment in Boom clay formation at the MOL Site, Belgium.

Experimental Set-up

This test case is based on an in situ migration experiment set-up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters.

The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are limited at the time being.

Analyses by the Project Teams

The Pilot Group (SCK/CEN) presented their modelling of the HTO tracer experiment that now has been running for about 5 years. The Boom clay has been modelled as a homogeneous anisotropic saturated porous medium. The considered governing transport mechanisms has been either advection-diffusion or diffusion only, as one question is whether advective transport is apparent from the existing data due to the very low hydraulic conductivity in the clay. The tracer transport is therefore almost entirely determined by diffusion. The best fit of the diffusion-only-model was obtained with a diffusivity of 4.05×10^{-10} m^2/s, and an almost identical value 4.03×10^{-10} m^2/s was obtained with the advection-diffusion model. Furthermore, almost identical values on diffusivity, conductivity and porosity has been evaluated from this in-situ experiment as found in supporting laboratory experiments. It was pointed out that the observed concentrations in filters 4 and 6 agree very well to those precalculated, giving confidence to the transport model used for prediction of the experimental outcome. The conclusion so far is therefore that the applied conceptual model is valid for prediction of field-scale concentrations and that laboratory scale parameters are valid for field-scale predictions. However, a drawback with the present experiment is that it is one-dimensional and can therefore not be used to study the expected anisotropy in the clay. A new type of experiment has recently been started with the aim to study the 3-D migration of the tracer $^{125}I^-$. As the distance between the filters is only 35 cm in this experiment, the first data point has already been achieved and was found to correspond well with the precalculated concentration at this location. The diffusion accessible porosity is assumed to be about half for I^- compared to HTO due to ion exclusion effects.

The Project Team from CEA-DMT/ANDRA presented modelling efforts and a sensitivity study of the Mol test case. A 3-D transport model that takes advection, dispersion, diffusion and radioactive decay into account was used. The influence of the piezometer pipe on the obtained concentrations was studied by comparing results using an analytical solution for a point injection with results from the 3-D transport model including the actual piezometer pipe. Using the same diffusivities in these two approaches resulted in a concentration difference of about a factor 2, which equals the error introduced when the experiment is evaluated with an analytical solution not taking the piezometer pipe into account.

The data from the HTO experiment have been fitted using linear as well as logarithmic concentrations. The best fits, based on the least square method, for these two approaches gave almost the same horizontal diffusivity (0.375 and 0.35 cm^2/d respectively), but a large difference in the vertical diffusivity (0.35 and 0.225 cm^2/d respectively). A sensitivity analysis including both logarithmic and linear concentrations showed that the experimental layout makes the determination of the horizontal (parallel with the piezometer pipe) diffusivity accurate, which was found not to be the case for the vertical diffusivity or the flow velocity.

ALLIGATOR RIVERS

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

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles present in Koongarra groundwaters.

Analyses by the Project Teams

The Project Team from RIVM presented some preliminary results of nuclide transport modelling at Koongarra. The aim with the work is to reproduce the shape of the dispersion fan in the unweathered zone. Contour plots of observed uranium concentrations in a horizontal plane are similar in shape at different depths in the weathered zone. Based on this it was suggested that uranium dispersion would mainly take place in the transition zone just above the weathering front. In the upper part of the weathered zone the rock is more heavily weathered and the weathering products, clays, reduces the water flow and increases the sorption in this part. The dispersion fan observed at higher levels should then be a more or less "frozen picture" except for any influences of diffusion processes. The similarity in shape of the dispersion fan at different depths also suggests that the groundwater pattern has not changed considerably in the past. The dispersion of uranium was simulated with a simple 2-D advection-dispersion-sorption model. With typical values of flow velocity, dispersivity and retardation factor it was possible to obtain a qualitatively acceptable dispersion fan. A model which takes into account the downward movement of the weathering front and transition zone is currently being developed and will be applied in future modelling work.

The Project Team from KEMAKTA/SKI used uranium and thorium data from the weathered zone at Koongarra to test the applicability of simple transport models generally used in performance assessment. In earlier work, the team simulated the migration of uranium and daughter nuclides using a 1-D advection-dispersion model with linear sorption (K_d-concept). The results showed a fair agreement between calculated and observed migration distance and concentration level of uranium in the solid phase. This model has now been extended to include phase transfer of radionuclides due to weathering and α-recoil. It is assumed that uranium and daughter nuclides in the groundwater are reversibly sorbed onto amorphous iron minerals and clays. By α-recoil and transformation of amorphous minerals to crystalline minerals, sorbed radionuclides are transferred from the accessible phase of the rock to the inaccessible phase of the rock. With parameter values from independent analyses carried out within the Alligator Rivers Analogue Project (ARAP), calculations were performed with two different values of the rate of transfer of radionuclides from accessible to inaccessible phase caused by weathering. The results were compared with observed uranium concentrations and activity ratios in the total rock as well as in the accessible and inaccessible phases of the rock. No significant improvement of the simulation of uranium concentration and activity ratios was obtained with the extended model and the assumed values of the phase transfer rate compared to the results of the simple model. However, it cannot be excluded that other combinations of phase transfer rate and sorption coefficient would give a better agreement between calculated and observed data.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20, 40 and 260 m natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contains hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations, etc.

Analyses by the Project Teams

The Pilot Group (AECL) has critically evaluated the usefulness of hydraulic conductivity data, determined on the basis of head measurements or empirical relationships, for heterogeneity characterisation and contaminant transport predictions. The conventional approach of quantifying aquifer heterogeneities is based on characterisation of the spatial pattern of hydraulic conductivity and it has been found that the inherent variability to a large extent is lost, since measured hydraulic conductivities are based on mean values for the medium. Furthermore, estimation of conductivity heterogeneities by calibrating a flow model against measured head data is deemed to be inappropriate, because heads are not particularly sensitive to conductivity variations. It was therefore suggested that the most reliable approach to account for local heterogeneities is to measure velocities and velocity variations rather than conductivities. The drawback is, however, that the velocities are usually very low implying measurement problems. A parameter set based on local scale dispersion was found to give good agreement to observed concentrations in a tracer test compared to another parameter set based on hydraulic conductivity values obtained from grain size analysis which gave rather poor agreement to the same data.

The Project Team from EDM/CEA/IPSN has used data from the Twin Lake tracer experiments to study mass transport with high Peclet numbers. Sharp fronts implying high Peclet numbers usually indicate modelling problems due to the small spatial and time steps that have to be used. The team presented a new numerical code that can be used for flow and mass transport in 2-D, where advection and dispersion are separated giving no Peclet number constraints. Unknowns, such as concentration and/or head, are approximated using arbitrary order Lagrange polynomials. The advective term is treated by backtracking along characteristic lines of flow. The advantage with this code using "spectral elements" compared to classical codes is that stable solutions are achieved even if large timesteps are used when the Peclet number is large. However, too long time steps will increase the time needed for the backtracking. The code can so far be used for 2-D simulations, but a 3-D extension is underway.

The Project Team from CEA/ANDRA raised the question whether stochastic modelling applied to the Twin Lake site can be performed. The team has analyzed the data from the 40 m tracer experiment and concluded that the experiment cannot be used to evaluate important parameters like the horizontal covariance of the hydraulic conductivity and the horizontal correlation length.

The Project Team from JAERI presented some preliminary modelling results of the Twin Lake tracer test. A 2-D vertical section has been modelled using an advection-dispersion model. The code MIGINT was used to generate hydraulic conductivities, porosities, retardation factors, as well as various statistical distributions and correlation lengths among these parameters. The data generated by MIGINT was used to calculate groundwater flow and nuclide transport with the finite element code MIG2DF. When conditioning the model to measured hydraulic conductivities, it was found that the observed tracer plume could not be reproduced which might be explained by heterogeneities in the system. The small dispersion length caused large computational problems, why the mesh size will be reduced in future calculations and a new numerical method will be applied.

Distribution of Background Information

Background information and databases are distributed to the INTRAVAL Participants either by the Secretariat or directly from the Pilot Groups according to Table 4.

Table 4. Distribution of background information.

Test Case	Distributor
Las Cruces Trench	Pilot Group, T. Nicholson, NRC[1)]
Apache Leap	Pilot Group, T. Nicholson, NRC[1)] and T. Rasmussen, UoG[1)]
WIPP 2	Pilot Group, E. Gorham, SNL[1)]
Finnsjön	Secretariat[2)]
Stripa	Secretariat[2)]
Gorleben	Pilot Group, K. Schelkes, BGR[1)]
WIPP 1	Secretariat[2)]
Mol	Secretariat[2)]
Alligator Rivers	Secretariat[2)]
Twin Lake	Secretariat[2)]
Yucca Mountain	Pilot Group, C. Voss, USDOE[1)]

1) Full organisation name, see List of Intraval Participants in Appendix 1

2) Kemakta Consultants Co., P.O. Box 12655, S-112 93 Stockholm, Sweden

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 Inspectorate (SKI) acts as Managing Participant. 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 expenses, 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.

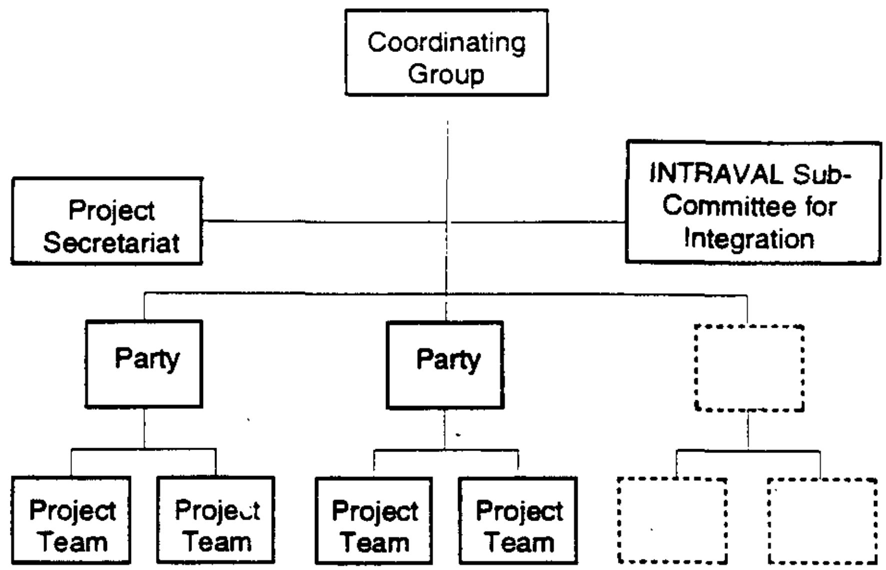

Figure 5. INTRAVAL Organisational Chart.

Managing Participant:	SKI
Coordinating Group:	
Chairman	J. Andersson, SKI
Vice Chairman	T. Nicholson, U.S. NRC
Secretary	B. Dverstorp, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	
	J. Andersson, SKI
	L. Birgersson, KEMAKTA
	B. Dverstorp, SKI
	M. Ericsson, KEMAKTA
	P. Jackson, AEA Technology
	A. Larsson, KEMAKTA
	J.P. Olivier, OECD/NEA
	K. Pers, KEMAKTA
	K. Skagius, KEMAKTA

List of INTRAVAL Participants

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
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		Bureau de Recherches Géologiques et Minières J.P. Sauty	(BRGM/STO)
Atomic Energy of Canada Ltd., Canada T. Chan	(AECL)	Atomic Energy of Canada Ltd. T. Chan (AECL-WR) G. Moltyaner (AECL-CRL)	(AECL)
Atomic Energy Control Board, Canada D. Metcalfe	(AECB)	Atomic Energy Control Board, D. Metcalfe	(AECB)
Australian Nuclear Science and Technology Organisation, Australia	(ANSTO)	Australian Nuclear Science and Technology Organisation	(ANSTO)
Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz, Federal Republic of Germany K. Schelkes	(BGR/BfS)	Bundesanstalt für Geowissenschaften und Rohstoffe K. Schelkes	(BGR)
		Bundesamt für Strahlenschutz H. Illi	(BfS)
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Empresa Nacional de Residuos Radioactivos, S.A., Spain J.C. Mayor	(ENRESA)	Universidad Politécnica de Valencia J. Gómez-Hernández A. Sahuquillo	(UPV)
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Forschungszentrum für Umwelt und Gesundheit, Federal Republic of Germany R. Storck	(GSF)	Forschungszentrum für Umwelt und Gesundheit E. Fein	(GSF)
Her Majesty's Inspectorate of Pollution, United Kingdom K. Butter	(HMIP/DoE)	Atkins Engineering Sciences T. Broyd	(AES)
		Intera Information Technologies Ltd. N. Chapman	(INTERA)

List of INTRAVAL Participants (cont.)

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		Central Research Institute for the Electric Power Industry M. Kawanishi	(CRIEPI)
		Hazama-gumi A. Kobayashi	(HAZAMA)
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Power Reactor and Nuclear Fuel Development Corporation, Japan H. Umeki	(PNC)	Power Reactor and Nuclear Fuel Development Corporation, H. Umeki	(PNC)
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Swedish Nuclear Fuel and Waste Management Co., Sweden F. Karlsson	(SKB)	The Royal Institute of Technology I. Neretnieks	(SKB/KTH)
Swedish Nuclear Power Inspectorate, Sweden J. Andersson (Chairman) B. Dverstorp (Secretary)	(SKI)	The Royal Institute of Technology B. Dverstorp	(SKI/KTH)
U.K. Nirex Ltd., United Kingdom D. George (P. Jackson)	(NIREX)	AEA Technology P. Jackson	(AEA)
		Intera Information Technologies Ltd. D. Hodgkinson	(INTERA)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
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		U.S. Geological Survey A. Flint	(US GS)
		Lawrence Livermore National Laboratory T. Busheck	(LLNL)
		Golder Associates Inc. C. Voss	(GOLDER)
U.S. Department of Energy–WIPP, United States of America P. Higgins	(US DOE)	Sandia National Laboratories E. Gorham	(SNL)
U.S. Environmental Protection Agency, United States of America W. Gunter	(US EPA)	U.S. Environmental Protection Agency C. Hung	(US EPA)
U.S. Nuclear Regulatory Commission, United States of America T. Nicholson	(US NRC)	U.S. Nuclear Regulatory Commission T. McCartin	(US NRC)
		Center for Nuclar Waste Regulatory Analyses B. Sagar	(CNWRA)
		Massachusetts Institute of Technology L. Gelhar	(MIT)
		Pacific Northwest Laboratories G. Gee	(PNL)
		Sandia National Laboratories E.J. Bonano	(SNL)
U.S. Nuclear Regulatory Commission, United States of America T. Nicholson	(US NRC)	University of Arizona T. Rasmussen (University of Georgia) P. Wierenga (UAZ-SWS)	(UAZ)
Organisation for Economic Cooperation and Development/Nuclear Energy Agency Member of Secretariat: J.P. Olivier	(OECD/NEA)		
Her Majesty's Inspectorate of Pollution, United Kingdom Member of Secretariat: P. Jackson			

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)
International Atomic Energy Agency S. Hossain (observer)	(IAEA)	
Environmental Evaluation Group, United States of America L. Chaturvedi (observer)	(EEG)	
State of Nevada L. Lehman (observer)		

Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, USA. Water and tracers were applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone was monitored. This test case was also included in INTRAVAL Phase 1. During Phase 1 data for site characterisation and model calibration were collected. In Phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport in a new experiment (Plot 2b).

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep has been dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium was applied at a controlled rate of 1.8 cm/day on the area sized 4 m × 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracers below the surface of the soil. The movement of the water front was also observed visually on the trench wall. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1 m × 12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) were added with the water on the area sized 1 m × 12 m.

Available data

- water retention data
- density profiles
- particle-size analysis data
- saturated hydraulic conductivities (laboratory and in situ)
- water content
- tensiometer data
- solute concentration

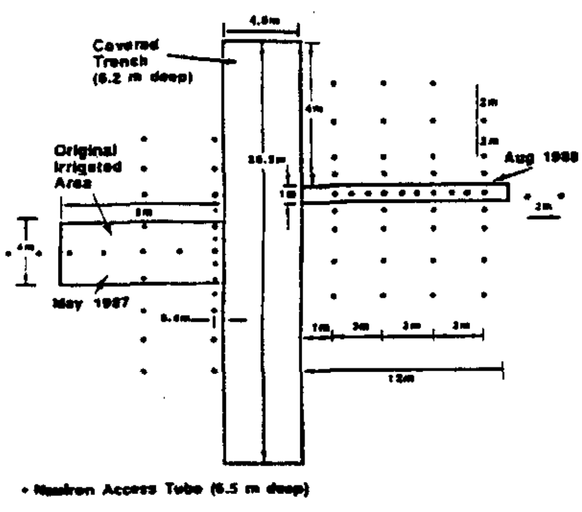

Figure 6. Las Cruces. Top view of the trench with irrigated areas.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

The Apache Leap Tuff Site in tuffaceous rock is situated near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depths due to topography and to pumping associated with a nearby underground mine. The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source dramatically affect air, vapour, water and solute movement in geologic media, in particular unsaturated fractured rock, and to investigate the water and air transport properites of fractures and rock matrix of unsaturated rock.

The effects of a thermal source are studied with laboratory nonisothermal core measurements, whereas the behaviour of fractures and other macropores are investigated in a series of laboratory measurements conducted on a block of Apache Leap Tuff having a single discrete fracture. In addition to these laboratory experiments there are plans to perform field investigations that will provide multiscale estimates of permeability at Apache Leap Site, information regarding mechanisms affecting the flow of fluids in fractured rock, and data for validation of flow models. The field experiment programme outline contributes to the characterisation of permeability distribution of a selected portion of the site using single-borehole pneumatic tests, pneumatic cross-borehole tests, gas tracer tests, and hydraulic tests. Most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Laboratory Nonisothermal Core Measurements

A cylindrically shaped core approximately 12 cm long and 10 cm in diameter was extracted from a block of Apache Leap Tuff (white unit). The large core, termed the "mother" core, is used for the experiment, while smaller, "daughter" cores were also extracted from the block for characterisation purposes. The mother core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses on all surfaces, and to minimise heat loss along the sides of the core.

During the experiment, a horizontal temperature gradient was established along the long axis of the core. Thirteen thermistors were situated along the core at approximately 1 cm intervals to record temperature over time (about twice weekly). A dual-gamma source was used to determine the water and solute content along the core over time.

The daughter cores were used to provide characterization data regarding porosity, moisture characteristic curves (including hysterisis effects), saturated and unsaturated hydraulic conductivity, and saturated and unsaturated air permeabilities. Similar data from 105 core segments at the Apache Leap Tuff Borehole Site were also available.

The simulation objective is to reproduce the core water content and solute concentration profiles using characterisation data and observed temperatures. The simulation output will consist of mean water contents and solute concentrations along 1 cm slices at 0.5 cm increments along the length of the core for selected times. The output will also consist of predicted temperatures at 1 cm intervals. The temperature measurement should be considered a point measurement.

Laboratory Isothermal Fractured Block Measurements

A block of Apache Leap Tuff (white unit) measuring 92.5 cm in length, 21.0 cm in height and 20.2 cm in width contains a fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent (~ 150 MPa). The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The positions of the wetting front in the fracture over time and the positions of the wetting front in the matrix over time were recorded.

The simulation objective of this problem is to reproduce the movement of a wetting front of water in a fractured, unsaturated rock using characterisation data and observed fracture inflow volumes over time. The simulation output should be wetting front positions in the fracture and rock matrix over time. Observed characterisation data can be used to calibrate the model, together with inflow data collected during the experiment.

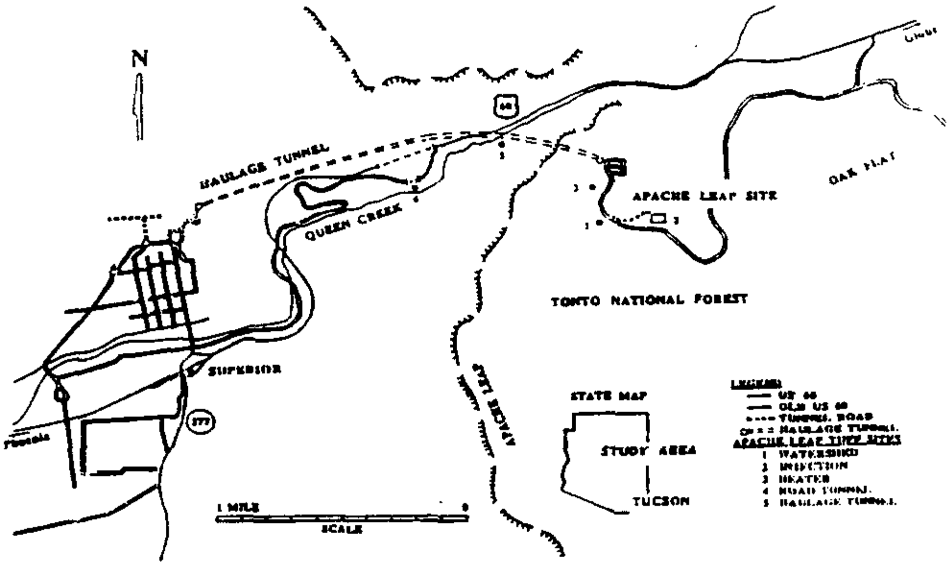

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Available data

Core Measurements

- rock matrix porosities
- initial water contents
- temperatures

A set of data collected prior to the heater experiment may also be useful for calibration purposes. Before the thermal experiments were conducted, the circumference of the mother core was sealed, while the two ends were left open. The core was fully saturated and then one end of the core was placed on a pressure plate and a 5 bar (500 kPa) pressure was applied. The total weight of the core was measured on various dates, and used to develop a time series of core saturations. Additional data are also available from tests performed on daughter cores collected near the core used in the nonisothermal experiment.

Block Measurements

- rock matrix sorptivity coefficient
- rock matrix porosity
- rock fracture aperture
- cumulative inflow volume over time

Data from the Apache Leap Tuff Borehole Site related to rock matrix physical and hydraulic properties, including porosity, bulk density, rock matrix moisture characteristic curves and unsaturated hydraulic conductivity, are also available.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 – 2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involves detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used in modelling during INTRAVAL Phase 1. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8) at depths ranging between 100–350 m.

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment, tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. Three sections were packed off in each injection hole, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part in between. Non-sorbing tracers were injected in nine different intervals of the zone. Totally eleven different tracers were injected, eight of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test, a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test, a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

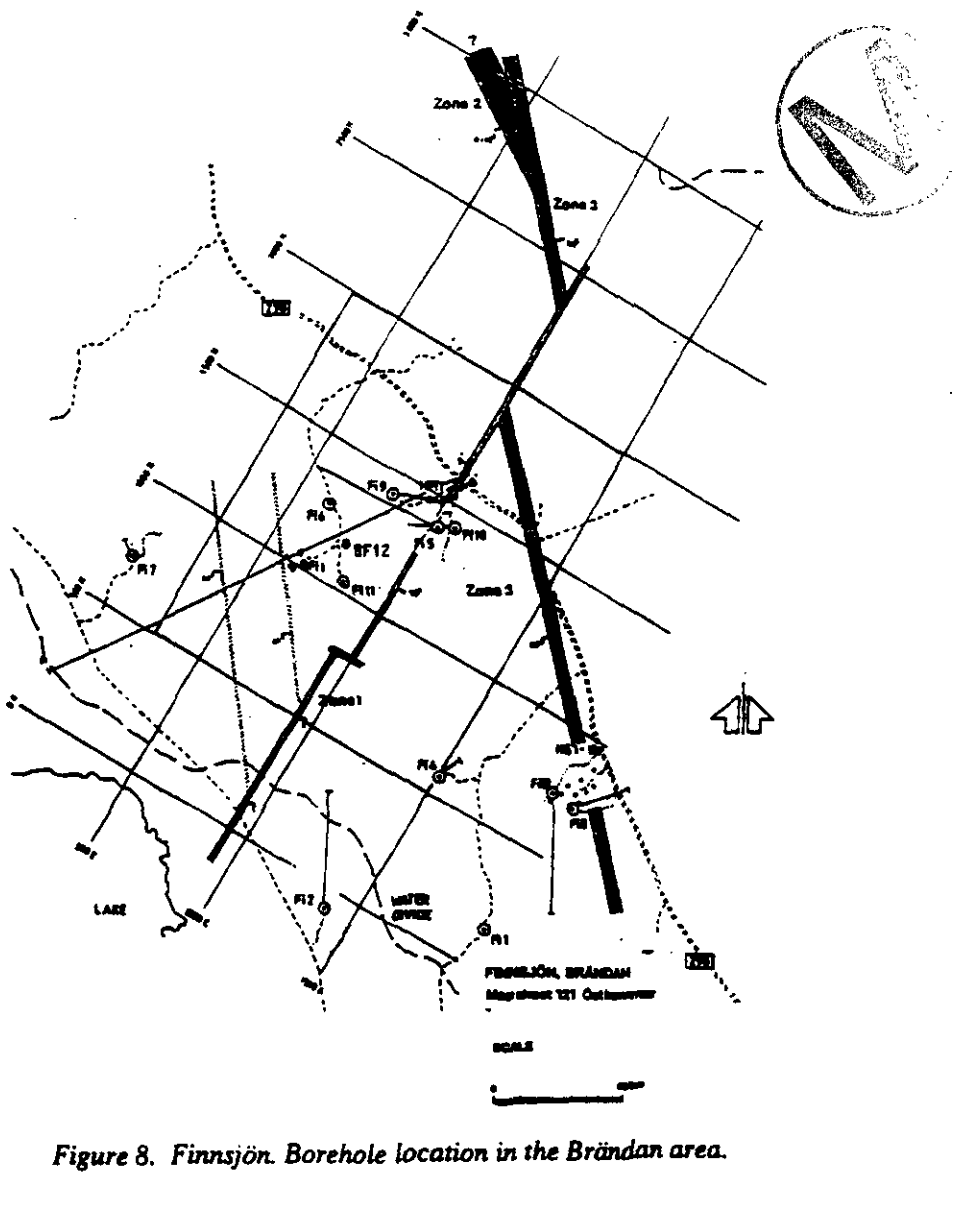

Figure 8. Finnsjön. Borehole location in the Brändan area.

Available data

Interference Tests

- primary drawdown responses
- graphs of the recovery of groundwater head after pumping stops
- tracer injection information
- tracer breakthrough curves

Radially Converging Experiment

- tracer breakthrough curves
- tracer injection information
- groundwater levels
- relative hydraulic head differences
- temperature and electrical conductivity of pumped water

Dipole Experiment

- tracer breakthrough curves
- tracer injection information
- hydraulic heads and groundwater levels
- temperature, electrical conductivity and redox potential of the pumped water

In addition, geological data are available from a surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3-D experiment, data from two other experimental programmes performed in the Stripa mine, the "Site characterisation and Validation Programme (SCV)" and the "Channelling Experiments" are available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3-D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3-D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The Site Characterisation and Validation Programme includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The Channelling Experiments comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3-D Experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. 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 (Figure 9).

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 pathways could thus be obtained.

Injections of conservative tracers were carried out from a total number of nine separate sections with increased permeability 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 1000 and 2000 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.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show 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 six months of injection, tracers from at least five injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves were obtained. Each curve is based on several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

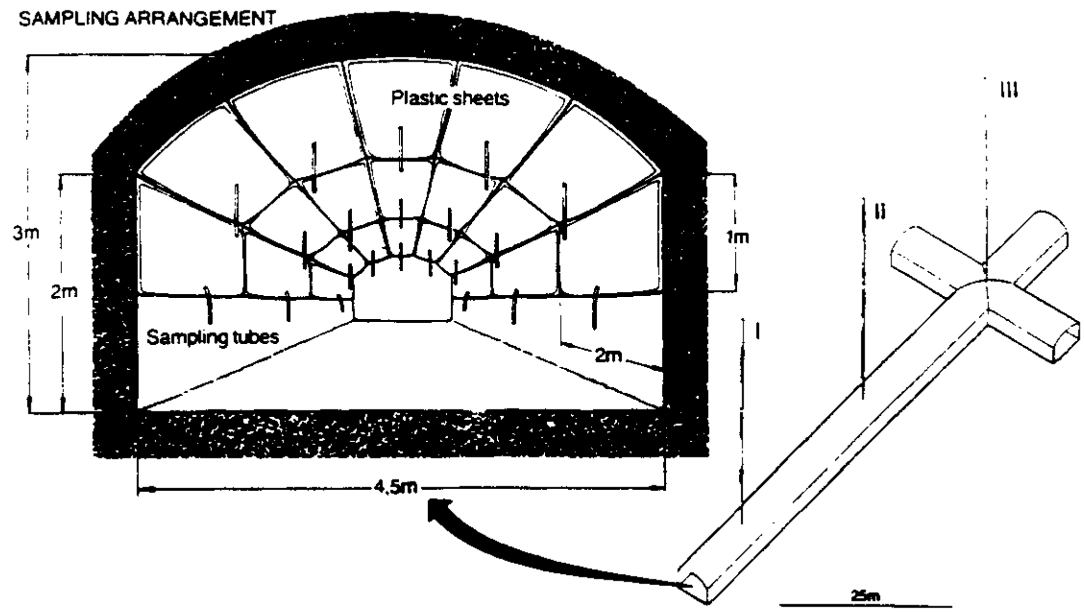

Figure 9. Layout of experimental 3-D drift at Stripa and sampling arrangement.

Site Characterisation and Validation Programme

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125×125×50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics.

Thereafter three new 100–150 m long holes were drilled. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next six 100 m long boreholes, were drilled in the same direction as the new drift would be excavated. The water flow and its distribution were measured in these holes. The holes were also used for a tracer (salt) experiment.

Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut through one 5-10 m wide major fracture zone, which gave more than 99% of the total water inflow. Tracer experiments were performed in this fracture zone from seven spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two non-sorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

Channelling Experiments

The channelling experiments consist of three different types of test: the "single hole experiments", the "double hole experiment", and the "tracer test".

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (Figure 11) was used to inject water all along the fracture plane.

The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multi-pede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas in total 12 holes were drilled.

The double hole experiment was performed in a fracture, where the single hole test has shown that channels existed. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests, more coarse tests were performed. In the detailed pressure pulse tests, water was injected in one of the holes at a section of 50 mm × 50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was then reversed, i.e. injection was performed in the second hole and monitoring in the first hole.

In the tracer test five non-sorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranine, Eosin Yellowish, Ebenyl Brilliant Flavin, Duasyn Acid Green V and Phloxine B were injected continuously during four weeks.

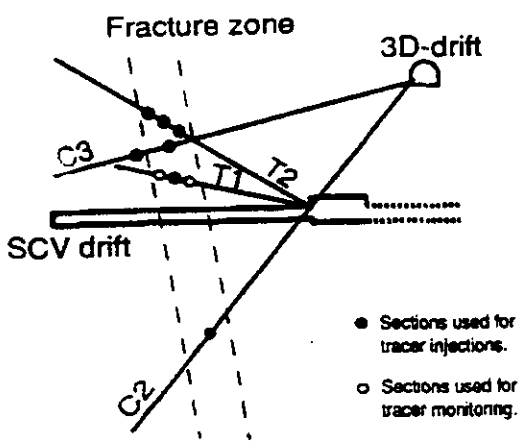

Figure 10. Stripa. Layout of tracer experiment (SCV).

Summary of Available Data

3-D Experiment

- water flow rates
- tracer concentration in water to test site
- rock characteristics and fracture data
- water chemistry
- injection pressures and injection flow rates
- hydrostatic pressures
- diffusivity and sorption data
- daily logs

Site Characterisation and Validation

- core logging and fracture mapping in drifts
- geophysical single hole logging
- rock stress measurements
- borehole radar
- borehole seismics
- hydraulic investigations
- hydrochemisty
- water flow rates
- tracer breakthrough curves

Channelling Experiments

- number of fractures
- number of intersections
- information about infilling
- fracture lengths
- opening area of fractures
- pressure response
- tracer breakthrough

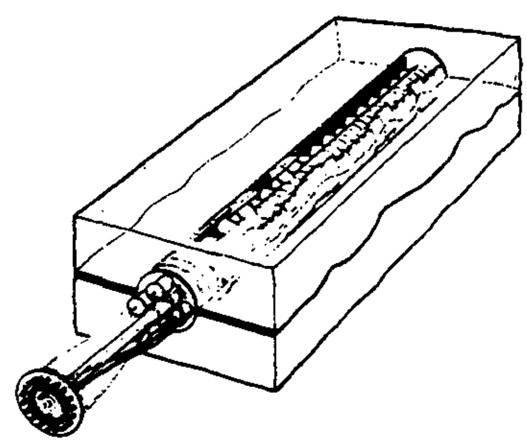

Figure 11. Stripa. Design of the multiped packer (Channelling Experiments).

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite at the WIPP site. The WIPP, located in Carlsbad, New Mexico, USA., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation (Figure 12).

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quarter-nary	Pleisto-cene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ochoian		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guada-lupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The test case will be focussed on the hydrology of this zone. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have been made including detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra.

Sixty wells drilled to the Culebra dolomite at 41 locations provide information on the hydraulic properties (Figure 13). Large variations in transmissivity related to fracturing have been identified.

Test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra. These data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

Objectives of the Test Case

A number of different objectives are identified:

- to determine if the hydraulic data support the derived transmissivity distribution and/or the model boundary conditions
- to evaluate the consequences of and the uncertainty in the derived transmissivity
- to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time
- to calculate the uncertainty in predictions of radionuclear travel time
- to determine if the paleoflow directions inferred from the geochemical/isotropic data could be reproduced using current transmissivity distribution and boundary conditions altered to simulate increased rainfall
- to determine if halite and gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration of the transmissivity distribution
- to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features

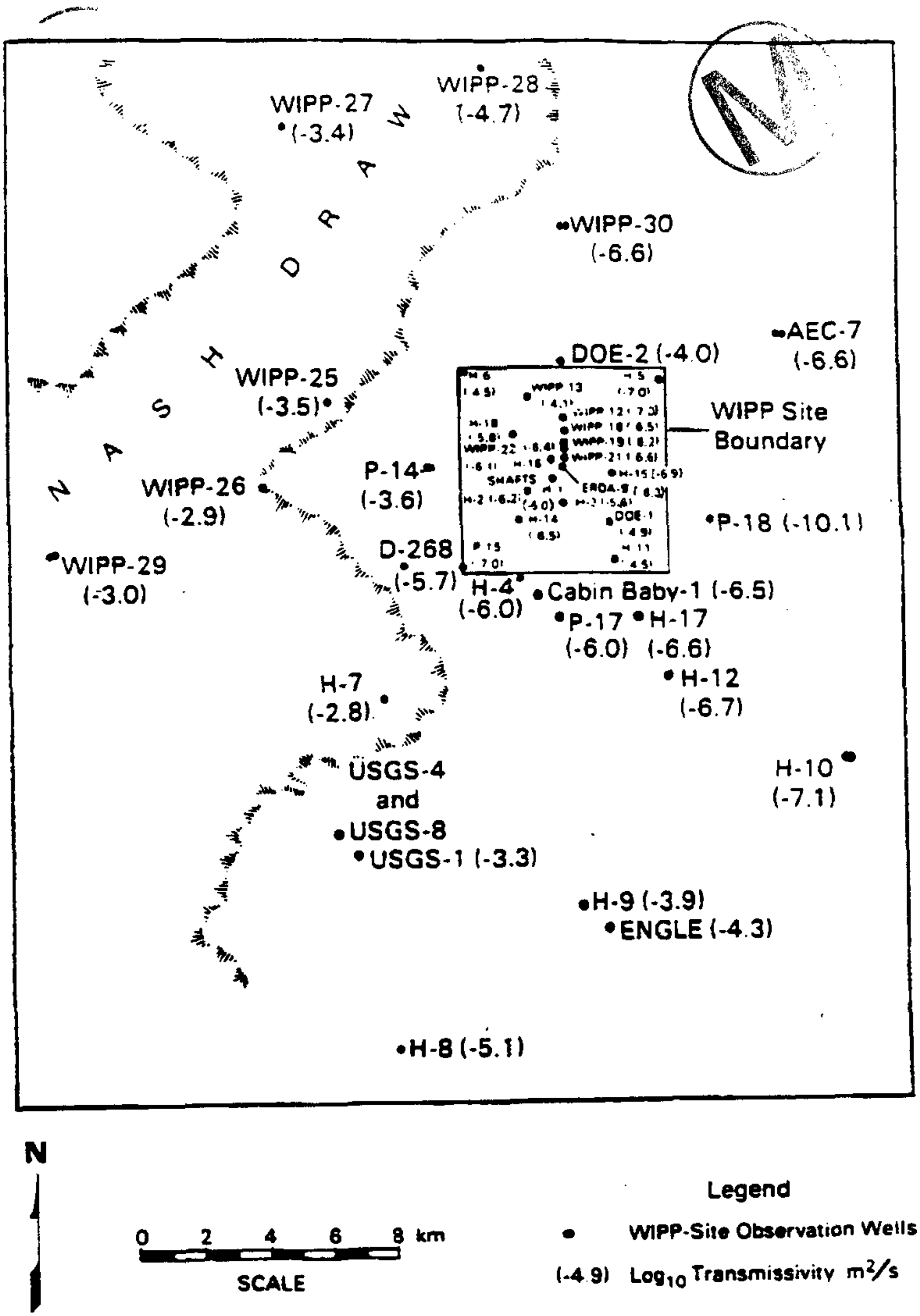

Figure 13. WIPP 2. Culebra Wells and measured transmissivity near the WIPP site.

Available Data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic test data from all well locations
- raw and interpreted tracer test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well !ccations
- calibrated steady-state regional groundwater flow model
- calibrated transient regional groundwater-flow model

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1–2 km wide, crosses the salt dome from south to north. Erosion along the channel .tends down to the cap rock (a re lue of the dissolution process o :alt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

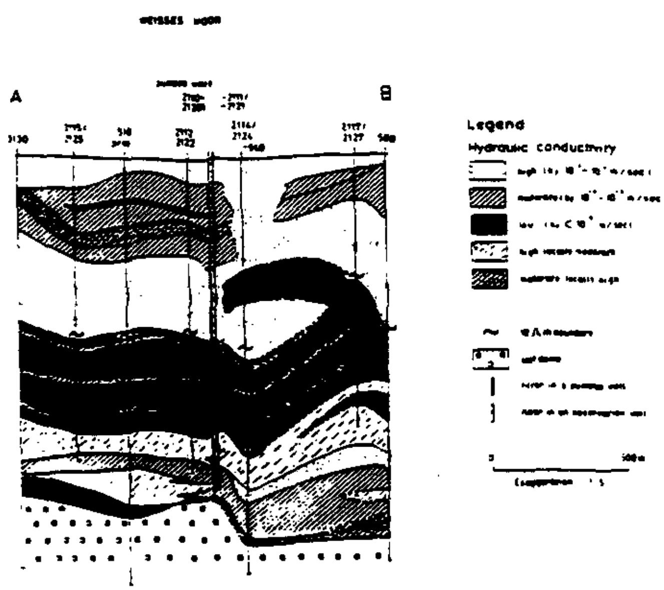

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

Experimental Design

Hydrogeological investigations have been conducted in an area of about 300 km² around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. During these tests information were obtained on boundaries, hydrogeological structure, connections between different aquifers, and hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the pumping tests the pumped well penetrated the entire deeper aquifer in the erosional channel (Figure 14).

The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the basis for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available Data

The data available from the selected pumping tests are:

- borehole locations (maps)
- hydrogeological data (groundwater levels etc.)
- pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed in the area.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository (Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation.

Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Experimental Design

Data from three types of experiments will form the bases for this test case:

- small scale brine inflow experiments
- pore pressure and permeability testing
- integrated, large scale experiment

Small Scale Brine Inflow Experiments

Brine inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (Figure 16) and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole.

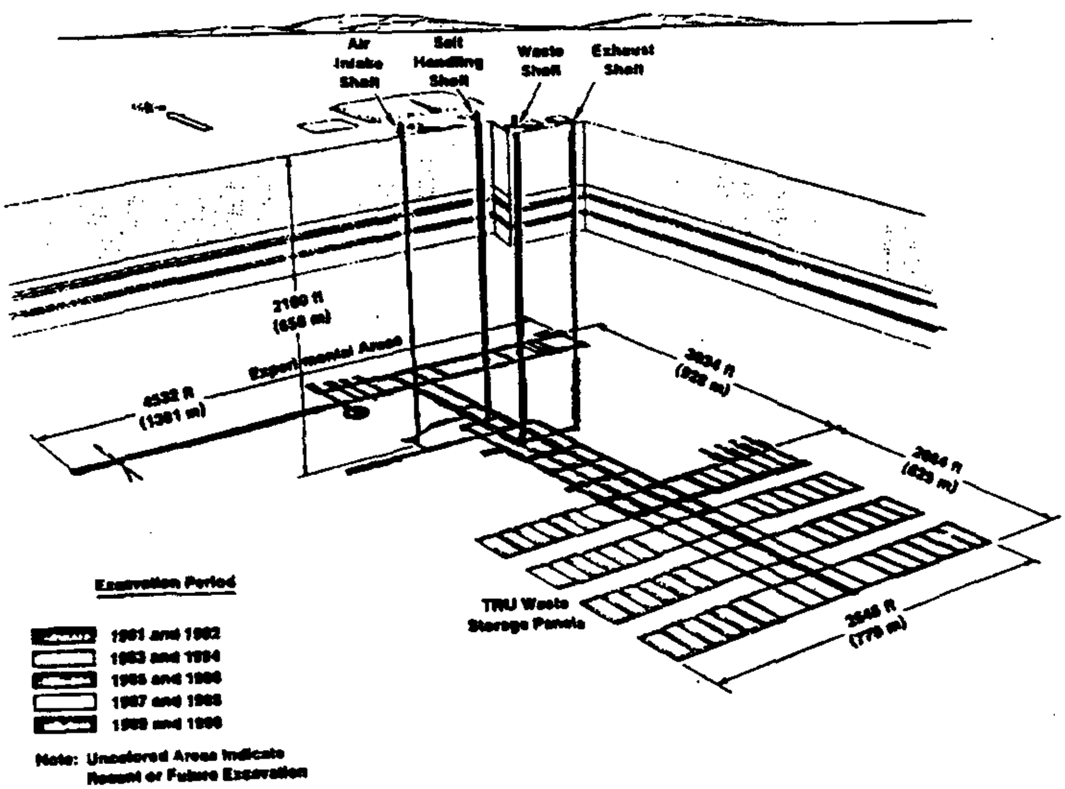

Figure 15. WIPP 1. Schematic view of the WIPP site.

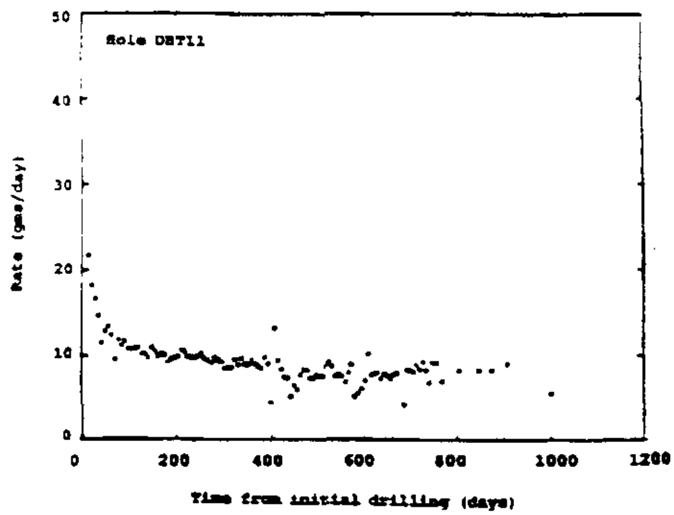

Figure 16. WIPP 1. Brine inflow rate vs time in a borehole (Hole DBT11).

Chemical analyses of brine collected are also available. The brine inflow measurements in the 10 cm diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore Pressure and Permeability Testing

Pore pressure measurements are made in boreholes with a diameter of 10 cm and 2 to 27 m in length, drilled at a variety of orientations. Pore pressure is measured in brine-filled, packer isolated intervals in the boreholes. Factors other than the formation pore pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are also monitored. The boreholes are furthermore used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, Large-scale Experiments

A horizontal cylindrical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the room as well as the brine inflow into the room are now being measured. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore pressure measurements, and measurements of borehole deformation and brine inflow.

Available Data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

- brine inflow rates
- humidity
- room closure, borehole deformation
- pore pressure
- data from permeability tests
- rock property data
- general stratigraphic information
- core logs

Supporting Information

A number of technical issues that are important to the performance of WIPP are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

MOL

Migration experiment in Boom clay formation at the Mol site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The

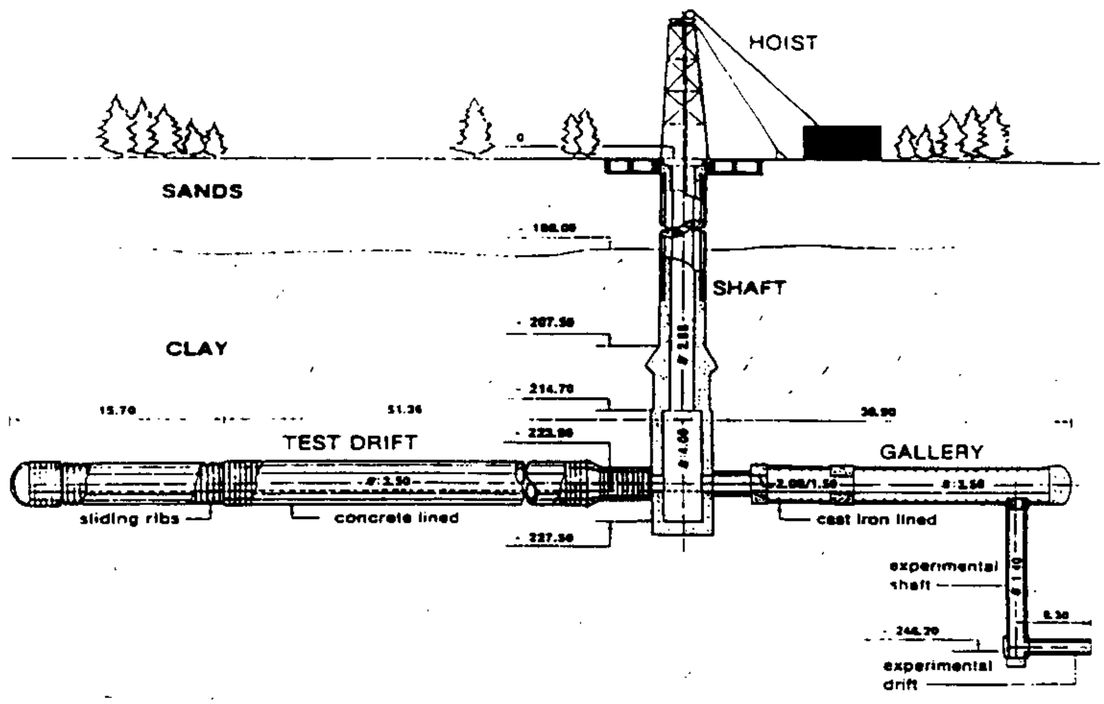

Figure 17. Scheme of the underground facility at Mol.

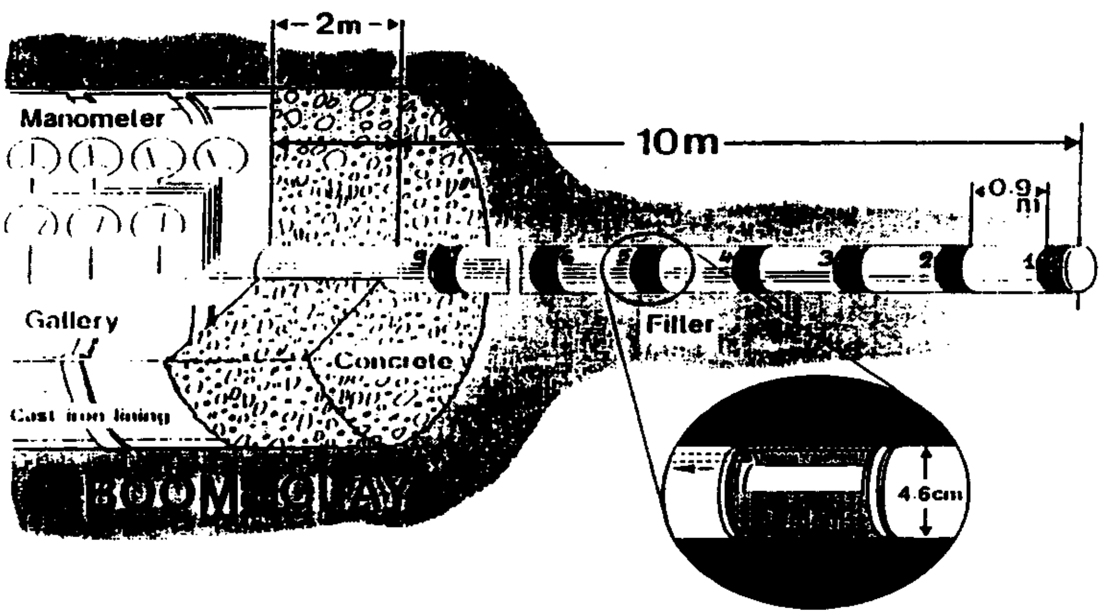

Figure 18. Mol. Conceptual view of the piezometernest.

experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

A number of piezometers, a so called piezometernest, have been installed in an underground research laboratory in the Boom Clay formation at a depth of 220 m (Figures 17 and 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand-pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand-pipe makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometer-nest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system was left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day during about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. The sampling was started 3 months after the start of the injection and continues at a two months' interval. To avoid disturbance of the HTO concentration, distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

Available Data

- steady state pressure distribution in the clay
- HTO concentration as a function time
- tracer injection data

Supporting Information

Supporting data are available from laboratory experiments and other in situ experiments. Transport parameters, e.g., the product of effective porosity and retardation factor, apparent dispersion constant, and diffusivity, have been estimated. A number of laboratory experiments have been performed, such as through-diffusion and percolation experiments with clay cores. The Boom clay is rich in organic matter which to a large part is linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

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

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participating organisations are the Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more

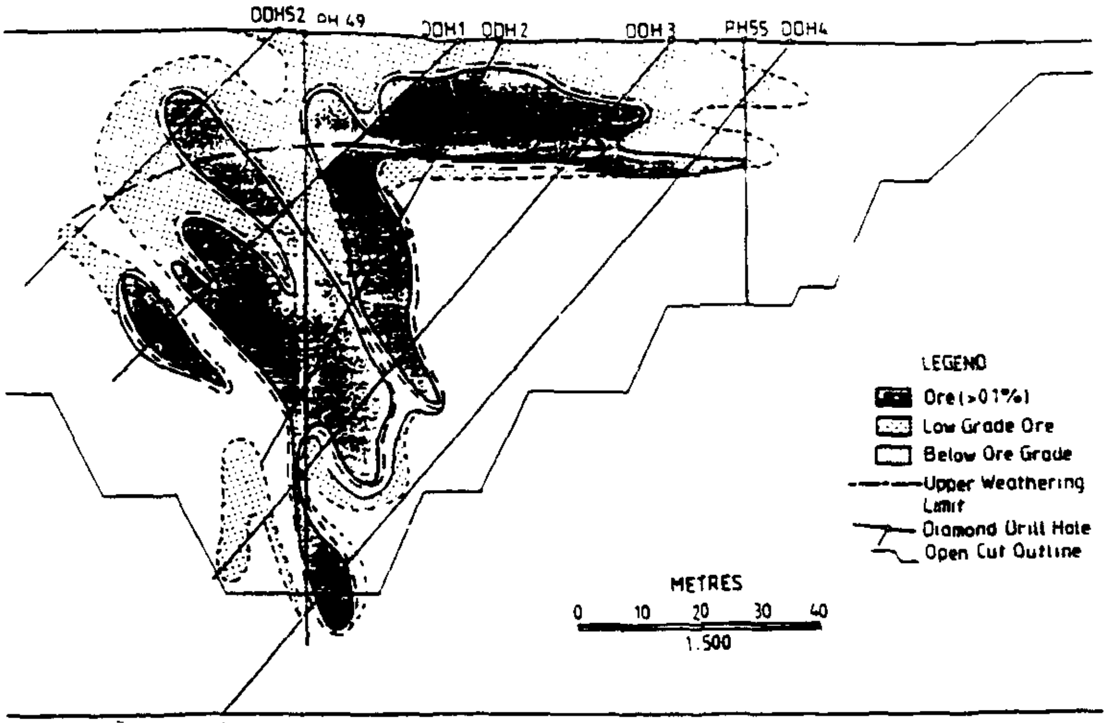

Figure 19. Alligator Rivers. Cross section showing the dispersed zone at the Koongarra deposit.

than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses
- results from porosity and permeability measurements on drill core samples

Hydrochemistry

- pH, Eh, D.O., conductivity and temperature in groundwaters
- groundwater concentrations of cations and trace metals
- groundwater concentrations of uranium series nuclides and isotopes

Geology, Mineralogy, Radiochemical

- uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
- uranium series radioisotope activity ratios data for selected samples in the ore zone
- results from chemical analyses of core samples
- mineralogical composition of samples
- concentrations and activity ratios of uranium and thorium in different mineral phases
- concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20, 40 and 260 m natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Available Data

A large database is available, containing data both from field and laboratory experiments, such as:

- permeameter test data
- small-scale dispersion
- porosities
- grain size composition
- hydrogeological data
- geophysical data
- mapping of tracer migration (Figure 21)

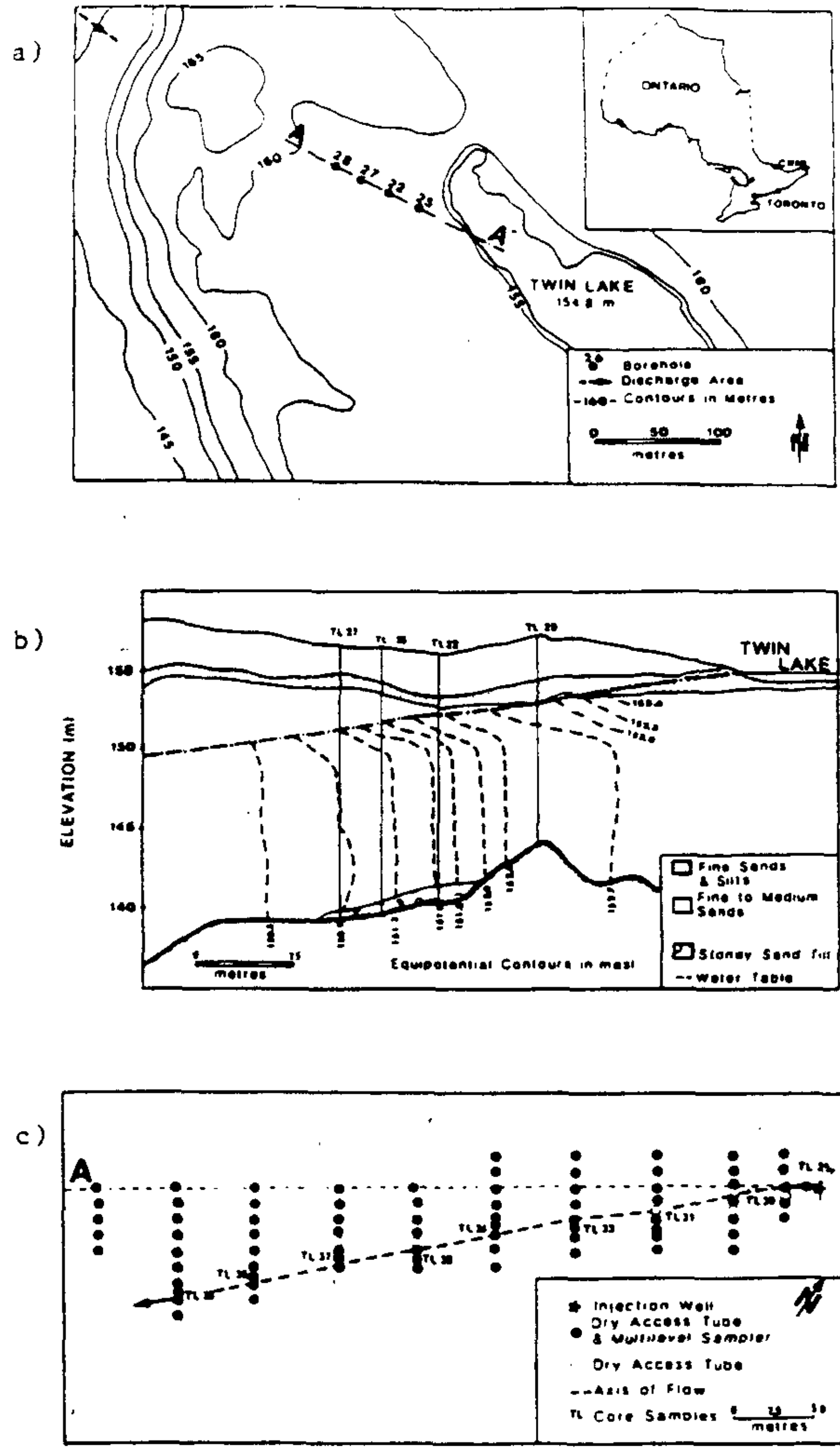

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

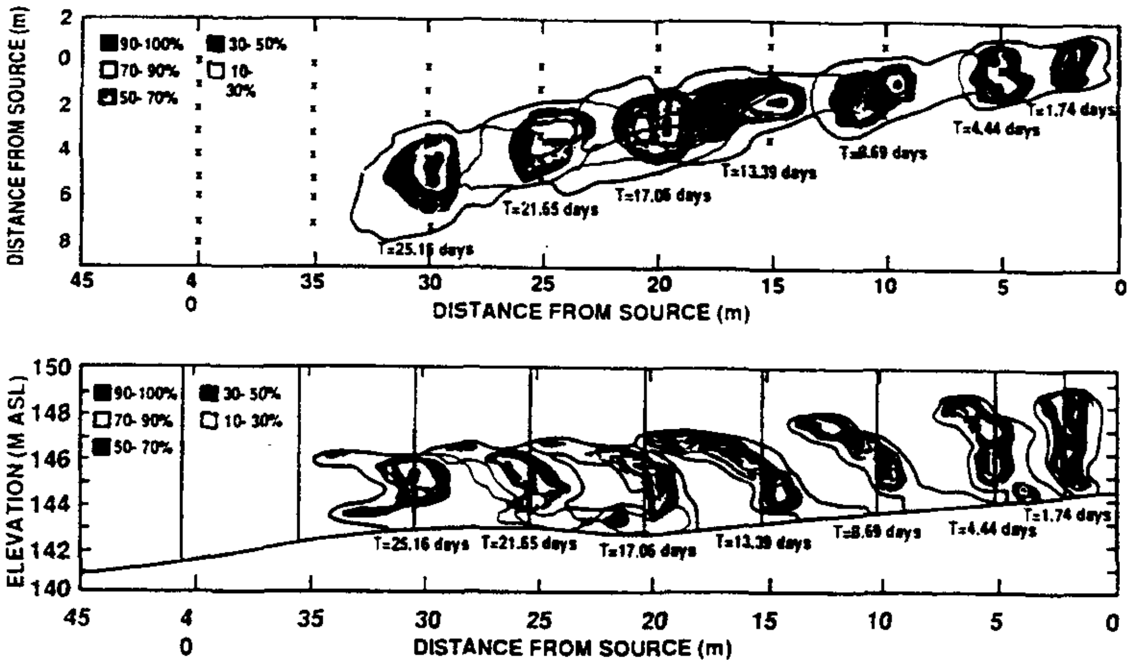

Figure 21. Twin Lake. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration)

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a, INTRAVAL, INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P., and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., and Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries, INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E., and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J., and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J., and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L., and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

Radionuclide Migration in Single Natural Fissures in Granite (TEST CASE 2)

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R., and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

Tracer Tests in a Deep Basalt Flow Top (TEST CASE 3)

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Idemitsu K., and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H., and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Flow and Tracer Experiments in Crystalline Rock Based on Stripa 3D Experiments (TEST CASE 4)

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B., and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W., and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W., and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W., and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

Tracer Experiments in a Fracture Zone at the Finnsjön Research Area (TEST CASE 5)

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P., and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A., and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Katsuragi T., and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

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Agence Nationale pour la Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Atomic Energy Control Board (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/ Bundesamt für Strahlenschutz (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 mbH (Federal Republic of Germany), Forschungszentrum für Umwelt und Gesundheit (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 Protection (The Netherlands), National Radiological Protection Board (United Kingdom), Power Reactor and Nuclear Fuel Development Corporation (Japan), Studiecentrum voor Kernenergie (Belgium), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy–OCRWM (United States of America), U.S. Department of Energy–WIPP (United States of America), U.S. Environmental Protection Agency (United States of America), U.S. Nuclear Regulatory Commission (United States of America).

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PROGRESS REPORT

10

December 1992 – August 1993

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

INTRAVAL
Progress Report Number 10, 1993

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.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat 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 model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
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Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both with regard to the processes and site-specific systems.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990.

Eleven test cases are included in Phase 2. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have 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 in such a way that it is possible to simulate the experiments with model calculations. 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.

Contact between the participants has been maintained by arranging workshops which were followed by Coordinating Group meetings. Working Group meetings have taken place between the workshops.

Since the issue of the previous Progress Report, the ninth and last INTRAVAL workshop and the fifth and last Phase 2 Coordinating Group meeting were held in Stockholm, Sweden. During the workshop the participants described the modelling work performed and discussed the achieved results. Since this was the last workshop, the presentations were focussed on summarising the results from each Working Group.

The Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members except the Phase 1 Summary report which is scheduled for printing late 1993. The schedule for the Phase 2 reporting was discussed and it was concluded that draft versions of the Working Group reports have to be available in the spring of 1994 and final versions in June 1994.

The Ninth INTRAVAL Workshop and the Fifth Phase 2 Coordinating Group Meeting

The ninth INTRAVAL workshop and the fifth Phase 2 Coordinating Group Meeting were held in Stockholm, Sweden, on the 30th of August through the 3rd of September, 1993, with the Swedish Nuclear Inspectorate (SKI) acting as host. The objective of the workshop was to summarise and conclude the INTRAVAL Project. All Working Groups had plenary sessions with a summary of the work performed within the group followed by technical presentations of recent work.

The Coordinating Group meeting was held on the 3rd of September, 1993. The plan for reporting (see section about INTRAVAL Reporting) was agreed upon. INTRAVAL will be formally concluded as the INTRAVAL Phase 2 Summary report has been approved by the Parties.

INTRAVAL Sub-Committee for Integration (ISI)

The purpose of the INTRAVAL Sub-committee for integration (ISI) is to assist the Secretariat by integrating the activities of the Working Groups, the validation approaches and the lessons learned. The

ISI had their third meeting on August, 31 in connection with the INTRAVAL workshop in Stockholm. A revised outline of the ISI INTRAVAL Phase 1 and 2 integrated conclusions report was developed during the meeting. A first draft of the report will be available by May, 1994 and the final report will be published early 1995.

Information from the Phase 2 Working Groups

Four Working Groups have been set up addressing different types of test cases, see Table 1. Each Working Group has a chairman, possibly aided by another person. The chairs of the Working Groups are responsible for the preparation of Working Group reports, which will constitute the base for the final reporting of INTRAVAL Phase 2.

Table 1. INTRAVAL Phase 2 Working Groups.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap Twin Lake Yucca Mountain	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski
	Alligator Rivers	Secretariat (K. Skagius)

INTRAVAL Reporting

All INTRAVAL Phase 1 technical reports have been printed and distributed. The final draft of the Phase 1 Summary report was distributed in June, 1993 to the INTRAVAL Parties for formal approval and is scheduled for publication at the end of 1993.

The Secretariat will take responsibility for publishing INTRAVAL Phase 2 Working Group reports prepared by the Working Group leaders with help from appointed editors. In addition, the Secretariat will prepare an INTRAVAL Phase 2 Summary report based on test case summaries from each of the Working Groups.

The time schedule for the INTRAVAL Phase 2 reporting is according to Table 2. Final reports from all Working Groups will be available in June 1994. A first draft of the INTRAVAL Phase 2 Summary report is scheduled for October, 1994 and a final report for spring 1995. The INTRAVAL Sub-committee for integration (ISI) will publish a report concerning Integrated Conclusions in early 1995. In addition, there are plans for publication in scientific journals during 1995.

Table 2. Schedule for INTRAVAL Phase 2 Reporting.

Report	First Draft	Final Draft	Final Report
Working Group 1	Jan. 1994	April 1994	June 1994
Working Group 2	Jan. 1994	April 1994	June 1994
Working Group 3	Feb. 1994	April 1994	June 1994
Alligator Rivers	Jan. 1994	March 1994	June 1994
Phase 2 Summary	Oct. 1994		Spring 1995
ISI Report	May 1994	Oct. 1994	Early 1995

Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 m × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 m × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 m × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models were used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data were made available to the Project Teams.

Analyses by the Project Teams

The following Project Teams have been working with the Las Cruces trench test case during INTRAVAL Phase 2:

- New Mexico State University (NMSU)/USNRC
- CNWRA/USNRC
- PNL/USNRC
- MIT/USNRC
- Bureau for Economic Geology, Univ. of Texas (BEG)/USNRC

During Phase 2 of INTRAVAL some teams modelling the second experiment (Plot 2b) have done blind predictive modelling of water content and solute concentrations at various points using data from previous laboratory and field experiments, and some teams have done predictions based on data from the second experiment. The Pilot Group has then gathered all results and performed comparative analyses. They have used a series of comparative plots, tables and simple non-parametric tests to assess model performance, see Figure 1 where populations of tritium prediction errors for the different models are illustrated. No rigorous statistical model testing were performed.

The models used for predictions of water flow and solute transport in the Plot 2b experiment are summarised in Table 3. Different types of 2-D models have been used ranging from simple models assuming homogeneous isotropic soil profiles to complex models considering heterogeneous anisotropic soil profiles.

Table 3. Summary of 2-D models used by the Project Teams for the Las Cruces Trench test case.

Project Team	Approach	Predicted value(s)	Soil properties
BEG1	not blind	water flow	uniform, isotropic
CNWRA1	blind	water flow	9 layers, isotropic
CNWRA2-3	blind	water flow	heterogeneous, isotropic
MIT1	blind	water flow	homogeneous, anisotropic
NMSU1	not blind	water flow, tritium migration	homogeneous, isotropic
NMSU2-5	not blind	water flow, tritium migration	heterogeneous, isotropic
PNL1-4	blind	water flow, tritium migration	uniform, isotropic

All model predictions of first arrival times of the water plume were non-conservative at latter times, whereas several of the models with heterogeneous soil profiles provided predictions of first arrival times of the tritium plume that were conservative at latter times. The results of the model predictions show that models that assumed heterogeneous soil profiles did not necessarily perform better than those that assumed homogeneous soil profiles. Furthermore, it was shown that models with anisotropic property fields did not perform better than those that assumed isotropic property fields.

When comparing the results from the different Project Teams it was found that models that performed best by one measure were out performed by other models using other measures. As a result of the comparisons it could be concluded that simple models seems to predict the measured values with as good result as the more complicated models. A number of

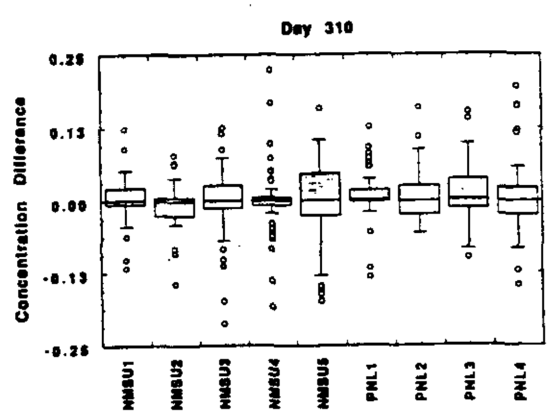

Figure 1. Las Cruces Trench. Populations of tritium prediction errors.

topics were identified that has to be developed: better techniques to condition soil property models on local observation, techniques to scale local observations to larger scales, better understanding of the relative importance of various physical processes. Concerning the model testing it has been identified that the models must be tested at different sites on larger scales and that more rigorous mathematical/numerical model testing techniques using field data have to be developed.

What concerns performance assessment, the work with the Las Cruces test case has illustrated the need of a test site characterisation methodology as well as a better understanding of when simple models are truly conservative compared to more complex models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap test case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source will affect air, vapor, water and solute movement in geologic media, especially unsaturated fractured rock, and the water and air transport properties of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory non-isothermal core measurements. A cylindrical shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimise heat loss along the sides of the core. During the experiment, a horizontal temperature gradient was established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to characterise water and air transport properties of fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which was 92.5 cm long, 21.0 cm high and 20.2 cm wide and contained a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The position of the wetting front in the fracture and in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are some results available from field investigations. However, much of the data from the field experiments will not be available during the course of INTRAVAL Phase 2.

Analyses by Project Teams

The following Project Team has been working with Apache Leap Tuff site test case during INTRAVAL Phase 2:

- UAZ/USNRC

The Pilot Group (UAZ) gave some comments on the Apache Leap test case which includes five hierarchical scale experiments, from core characterisation to field air permeability tests. The validation strategy has been to use field characterisation data to provide model predictions with confidence intervals. Each experiment should be conducted in such a way that the observed behaviour is known with sufficient confidence and to ensure that it is not artifacts one is studying. If models based on alternative concepts show identical behaviour then the experiment is not properly designed. The strategy used for comparison of model predictions and observed data has been to propagate parameter uncertainties to forecast uncertainties in predicted values. If the predicted values lie outside the forecasted confidence interval the model is found to be inadequate. It was also pointed out that experimental uncertainties should be used to evaluate the degree of significance between model prediction and experimental observations. The core characterization studies showed that hysteresis significantly altered the drying and wetting curves. Therefore, the wetting history at the site must be known if matric suctions are estimated from field measurements of water content. The fracture imbibition experiment indicated that fingers of saturation existed within the fracture during early times and that those fingers expanded laterally and dissipated with time. Furthermore, it seems that the fingering (channeling) is at least as pronounced in unsaturated fractures as in saturated.

The Project Team from UAZ has studied scale effects in air permeability determinations. Three boreholes, Y2, V2, and X2 have been completely tested at a 1 meter scale. The borehole Y2 has as well been tested at 0.5 and 3 m scales. Two other boreholes, W2A and Z2, are currently being tested at a 1 m scale. When the testing program is completed, a total borehole length of 180 meters will have been tested at a 1 m scale. An important conclusion from the analysis performed so far is that air permeability is a strong function of applied pressure. Values quoted without such pressures are therefore ambiguous. The average permeability has been found to increase with increasing scale. Another major finding is that the data indicate that flow through the fractured porous material may be amenable to the theory of stochastic hydrology.

YUCCA MOUNTAIN

Yucca Mountain experiments.

Experimental Set-up

The objective of the Yucca Mountain test case is to compare predicted and observed moisture content as a function of depth in a borehole currently being drilled. The data set for the test case consists of composite transects of hydrologic properties at the site, detailed geohydrological data and moisture content data from boreholes UZN-53, UZN-54 and UZN-55, and topographic and structural geology information for the site. Data from the three UZN-boreholes have been used to predict the moisture content in another borehole, UZ-16, that will be drilled to a depth of about 500 m at a distance of about 100 m from the UZN-boreholes.

Analyses by the Project Teams

The following Project Teams have been working with the Yucca Mountain test case during INTRAVAL Phase 2:

- Golder/USDOE
- USGS/USDOE
- CNWRA/USNRC
- State of Nevada
- SNL/USNRC
- USNRC

The Project Team from USGS has used a 1-D finite difference matrix model (TOUGH) to predict the water content in the core from borehole UZ-16. The model parameters were calibrated using data from nearby shallow boreholes. The parameters were particle density, porosity, permeability and van Genuchten parameters for unsaturated hydraulic conductivity from filled moisture retention curves for different microstratigraphic units at different depth. The problem with this modelling was that the applied rock properties were from another location than UZ-16 and no fracture or fault properties were available. The team has used past climate conditions to estimate earlier infiltration and noted that the saturation measured today is not sensitive to earlier climatic changes.

The Project Teams from CNWRA and USNRC applied a 1-D steady state, composite porosity model and a dual continuum fracture-matrix model for 1-D steady-state infiltration to predict the water saturation in the core from borehole UZ-16. The predictions were based on hydraulic characteristics of rocks from transects and other boreholes, neutron logs from other boreholes and porosity and lithologies from the borehole to be predicted (UZ-16). The first model (composite porosity) predicted the water content profiles rather well except in a few geological units. The predicted saturation appear to be less accurate than the predicted water content. The second model (dual-continuum) which represents fractures and matrix as two continua interconnected trough a transfer term gave a proper description of the saturation behaviour of the fracture continuum. The effect of fracture coatings may be seen in flow regimes where there is a transition between fracture and matrix flow.

The observer from the State of Nevada has studied the effects of variability in selected model inputs on modelled unsaturated water content profiles. 1-D, 2-D as well as fracture models have been applied for simulations of the water content in the rock to a depth of almost 500 m. Some of the data used originate from boreholes at the Yucca Mountain site not included in the test case. The rock has been modelled as consisting of seven hydrologic layers except for the 1-D case where the number of layers were varied from 4 to 11. The results from the 1-D models showed a poor fit to measured data even though the number of layers as well as the infiltration rate were varied. The wet conditions within the upper high conductivity unit, co-existing with the unsaturated conditions in the low conductivity units, could not be modelled with 1-D geometry and infiltration. Like the 1-D simulations, the 2-D simulations were found to underestimate the measured water content in the upper unit. The fracture flow model showed considerably better match to observed data. In this model, water was recharged into a vertical fracture intersecting all seven hydrologic layers. The recharge rate was estimated based on ground surface material, topography, and climate data. The fracture density in the rock was set to about 3 fractures/meter. In this case, the very wet conditions in the upper permeable unit as well as the unsaturated conditions below are much better represented than the 1-D and 2-D representations.

Different Project Teams applied different modelling approaches to predict the water saturation in the core from borehole UZ-16. The test case provided insufficient data to discriminate between the models used but it seems that the stratigraphy is the most important aspect in modelling unsaturated flow at Yucca Mountain. It was not possible to reach any conclusions concerning fracture vs. matrix flow models because of the large differences in model geometries and boundary conditions. Another aspect that makes model comparison dubious is the difference in applied initial conditions. No conclusions concerning infiltration from the saturation profile could be drawn because of the fractured nature of the tuffs.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The main experiments carried out are a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. The modelling is focused on the dipole experiment. This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling, since it became available too late.

Geological Structures

The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometers.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s, the middle 10^{-7}–10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water–salt water interface is located in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbing tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Finnsjön experiments has been studied by the following Project Teams:

- Geosigma/SKB
- VTT/TVO
- PNC
- PSI/NAGRA
- New Mexico State University (NMSU)/SNL/US-DOE
- Hazama/JAERI
- Conterra/KTH/SKB
- BRGM/ANDRA
- UPV/ENRESA

These Project Teams applied different approaches for the analysis of the experiments.

The Geosigma team performed a porous media advection-dispersion analysis applying the same concept for the whole sequence of flow and transport experiments. The team also studied the effects of the natural gradient and anisotropy. 1-D as well as 2-D models were applied and the classification of model simulations was based on regression statistics.

The VTT team applied a channel concept for the whole sequence of tests. The main objectives were to obtain a model which was as realistic as possible for the description of groundwater flow and tracer transport and to test if the same concept could be applied to all three tracer tests in zone 2. The modelling approach was to consider flow in a 2-D network of channels and transport in just one or two routes. The channels were assumed to be non-interacting and having variable apertures. The team concluded that all experiments could be described with the same concept. Furthermore, 50–100 % of the transport could be explained by just considering one channel. The team found that the effect of hydrodynamic dispersion was clearly noted in the experiments contrary to the effect of matrix diffusion.

The PNC team performed a porous media analysis with the main objective to study the effect of heterogeneity on the tracer transport. The system was assumed to be a dual porosity porous medium and the modelling approach included generation of hydraulic conductivity distributions by trial and error as well as applying a geostatistical approach. Stream tube and 2-D finite difference models were used. The procedure was to fit the transport parameters from the dipole test and to check the validity by simulating the radially converging test. The objectives were to statistically estimate transmissivities in the high conductive zone in the upper part of zone 2 and to identify transport parameters by considering least square errors. The validity of the model was examined by comparing calculated and observed data. The team concluded that the tail part of the breakthrough

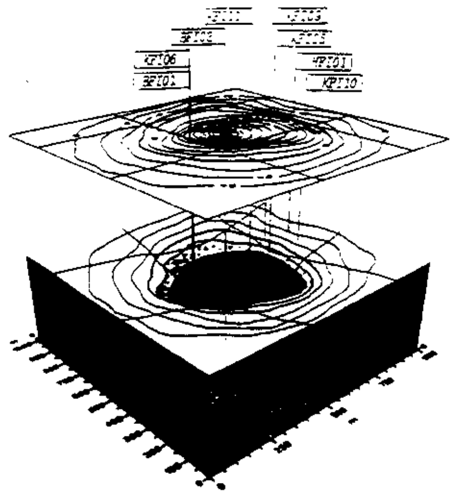

Figure 2. Finnsjön, PNC. Calculated hydraulic heads in the radially convergent test.

curve of each tracer could be explained by considering the mixing between the low conductive and the high conductive zone. Furthermore, the parameters identified from the dipole tracer test simulation could explain the general characteristics of the breakthrough curve obtained from the radially converging tracer test. Figure 2 illustrates the calculated hydraulic heads in the radially convergent test.

The PSI team did not use the same data as the other teams, but performed a porous media analysis of a radially converging tracer test from another part of the Finnsjön site. The main modelling objectives were to determine the geometrical assumptions needed to reproduce the breakthrough curves and to determine the dominant transport processes in the Finnsjön experiments. The modelling approach was to assume a 2-D dual porosity homogeneous system. The team concluded that the concept of the dual

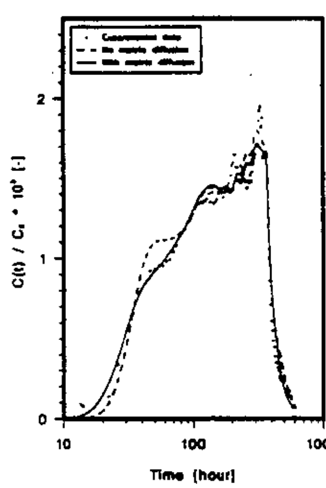

Figure 3. Finnsjön, PSI. Experimental data and calculated breakthrough curves with and without matrix diffusion.

porosity medium has proven to be a versatile, efficient and highly appropriate "tool" for analysing the Finnsjön migration experiments. Furthermore, no serious limitation of the model was identified, i.e. no indication for further mechanisms that ought to be included could be recognized. One of the main goals of the investigations was to find an answer to the question of the minimum number of independent flow paths that had to be included in the calculations. It was found that models with a single flow path reproduced the break-through curves in a grossly averaged way. Introducing a second flow path improved the fits. Furthermore, the concept with a further flow path complies with in-situ observations. An inspection of the measured data showed that the signature of matrix diffusion could not be identified in the tailing part of the breakthrough curves. However, calculations for both concepts (one/two flow path systems) demonstrated that this mechanism cannot be neglected. It effectively influences the shape of the breakthrough curves and strongly improves the fits (Figure 3).

The NMSU team used a layered porous media model and a double porosity model to analyse the radially converging test and the dipole test. The modelling approach included a description of a vertical cross-section representing the flow paths. The thickness and hydraulic conductivity distribution was interpreted from individual borehole data. The results showed a reasonable agreement with most breakthrough curves for both single and double porosity models. It was therefore not possible to judge which model that best represented the fracture zone.

The Hazama team performed a flow and transport analysis of the radially converging and the dipole tracer tests. The modelling approach included the use of a REV from the Crack Tensor Theory. Values of the apparent aperture were assigned using conditional simulation followed by a transport analysis in a continuum model by means of a particle tracking method. The modelling included particle releases from simulated test sections and calculation of ensemble breakthrough curves. These calculated breakthroughs were found to give good as well as bad fits to the measured breakthrough curves.

The Conterra/KTH team applied a stochastic continuum model to analyse the dipole test and a conceived far-field natural gradient test. The main objective in this modelling exercise was to determine if a stochastic continuum model calibrated on a local test scale also is valid on a larger, far-field scale.

The team tackled this problem by creating a reference transmissivity field represented by a 0.5 m thick 2-D confined aquifer with a size of 1200 m × 1200 m, corresponding to the upper permeable part of zone 2. All measured transmissivity data were used to construct a synthetic reference field as close as possible to the real situation. Dipole tracer tests, similar to the Finnsjön test, and a far-field (natural gradient) test were performed in this synthetic reference field for calibration and validation.

Eight boreholes penetrating fracture zone 2 have been hydraulically tested and several realisations were generated and conditioned on the data from these boreholes. One of the generated realisations was randomly chosen as the reference field. The results from "tracer tests" using a particle tracking technique were considered to be the real system response of the reference field. The far field simulation in the synthetic reality was performed under natural conditions.

The team used the Monte-Carlo approach to generate 100 equally probable realisations having the same statistical structure as the observed data. Comparing the breakthroughs in the dipole experiments it was found that individual realisations could be very different to the reference field due to uncertainty in transmissivity values, while the mean(assemble) breakthrough curve was very close to that of the reference field. Based on a quantified measure of the deviation of the simulated breakthrough curve from that of the reference field, 3 of the 100 fields were chosen that captured the reference field quite well. The far field simulations were calculated under natural gradient conditions using the same transmissivity fields as for the local scale dipole test. The results from the three simulations show very different mean arrival times and dispersion patterns, indicating that calibration of the model on the local scale and subsequent prediction of far field transport phenomena can result in high uncertainty. This indicates that there are not enough conditioning points on the far-field scale to recapture the characteristics of the far-field reference case transport response. Therefore, calibration of a model on a local scale is insufficient to also validate the model on a larger transport scale. This conclusion implies that measurement data should be collected on scales relevant to the studied transport problem.

The BRGM team performed an analytical and numerical porous media analysis of the interference tests and the radially converging tracer test. The boundary effects as well as the multi-layering of zone 2 were taken into account in the modelling. The model was calibrated using data from two of the tests and subsequently validated on a third test. A 3-D analysis showed a good fit between measured and calculated drawdown during the complete test sequence. Furthermore, it was possible to simulate the behavior of the five high-recovery tracers. Another finding was that a homogeneous porosity could not be employed.

The UPV team analysed the implications of selecting a multiGaussian model based on the parsimony principle. The modelling approach included a demonstration of the impact of extreme values on travel times by applying two stochastic models, multiGaussian and non-multiGaussian, in a stochastic continuum study. The team concluded that a Gaussian histogram does not imply that the only multivariate model must be multiGaussian. Furthermore, it was pointed out that a multiGaussian model implies a very low connectivity of extreme values and might therefore be too optimistic from a regulatory point of view.

The analysis of the Finnsjön experiments includes a variety of different approaches including stochastic modelling even though the porous medium concepts seems to dominate. An important conclusion is that the dimensionality of the applied model was not decisive for the ability to reproduce the field responses. It was furthermore noted that a relatively simple model could reproduce the experimentally obtained breakthrough curves. The effect of matrix diffusion seems to have been very small in the experiments mainly due to the high induced flow velocities. The tracer migration has therefore been governed by advection and it was noted that hydrodynamic dispersion was needed to explain the breakthrough curves measured in field.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiments, Sweden.

Experimental Set-up

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

In an experimental drift, excavated in the old iron ore mine in Stripa, the whole ceiling and upper part of the walls was 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 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 pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from supporting laboratory and field experiments. This so called 3-D experiment was as well a test case during Phase 1 of INTRAVAL.

In addition to the results from the 3-D experiment, data from two other experiments performed in the Stripa mine, the "Channeling Experiments" and the "Site Characterisation and Validation program", were available to the INTRAVAL Participants during Phase 2. The Channeling Experiments consisted of two kinds of tests, single hole and double hole experiments. In the single hole experiments, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simple packer systems. In the double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole.

The Site Characterisation and Validation program, with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, involved a number of investigation steps with modelling predictions. A few long boreholes were used to characterise the rock volume. Additional boreholes were drilled and used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the "Validation Drift", was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

The data set from the Stripa 3-D migration experiment has been studied in INTRAVAL Phase 1 and 2. Four Project Teams studied the test case in Phase 1:

- KTH/SKB
- Lawrence Berkely Laboratory (LBL)/USDOE
- KTH/SKI
- INTERA/AEA/NIREX

Two other Project Teams have analysed the Stripa 3-D data as part of Phase 2:

- VTT/TVO
- BRGM/ANDRA

The experimental findings from the Stripa 3-D experiment clearly indicated that:

- the water flow into the drift was very unevenly distributed
- there seems to be a correlation between fracture intersections and high water flow rates
- also the tracer migration properties were unevenly distributed since experimental breakthrough curves in adjacent sheets for the same tracer were in many cases quite dissimilar.

To reproduce such observations, most Project Teams based their analysis upon the assumption of flow and transport within one-dimensional channels. The channeling concepts considered by the different Project Teams were:

- one-dimensional models assuming no mixing of tracer between the channels over the migration domain
- models of interconnected one-dimensional channels assuming a perfect mixing at each channel intersection
- and finally, one team did not assume any mixing and flow dimension a priori, but considered the flow dimension as the main unknown.

Different teams considered different transport properties in the individual channels. The KTH/SKB team considered channels that only had advective transport as well as channels having transport properties based on a combination of advection-dispersion-matrix diffusion. The Project Teams from KTH/SKB, KTH/SKI, BRGM and LBL considered channels having transport properties due to advection and dispersion.

Different channel arrangements were as well considered by the Project Teams. All teams analysed transport in a single channel. The LBL team assumed an arrangement consisting of several discrete parallel channels. Each channel had a variable aperture along its length, and the hydraulic conductivity in the channel was controlled by constrictions. Such channels does not represent physical pipes, but rather channels that arise naturally as paths of low resistance through the fracture planes. The LBL team used this arrangement coupled with the advection-dispersion model.

The KTH/SKB team also considered an arrangement consisting of a large number of parallel channels that conduct the flow from the inlet to the outlet without mixing between the channels. Thus, this arrangement is very close to the one used by the LBL team, but the KTH/SKB team assumed that dispersion in the direction of flow was caused by channeling, so that the "advection only" single channel property was applied. A further assumption was that the channel properties obeyed a lognormal distribution function. The flow rate through each channel was calculated using the cubic law.

The Project Teams from KTH/SKI and BRGM considered a network of one-dimensional channels located in a three-dimensional network of interconnected disc-shaped fractures. Both teams considered a channel geometry where flow was assumed to occur through "bonds" joining the center of each disc to the center of the adjacent disc. In addition to this concept, the BRGM team also used a "Random Channel Model" where one-dimensional channels were randomly located on the fracture discs and where fracture intersections may or may not be considered as channels.

The LBL and VTT teams used deconvolution techniques to analyse the experimental breakthrough curves. The impulse responses obtained by LBL were composed of distinct peaks. These peaks were considered as the result of solute transport in independent channels and the solution of the one-dimensional advection-diffusion equation, for a delta pulse injection, was fitted to each peak. The VTT team focused on the detailed analysis of the impulse responses given by deconvolution of the experimental breakthrough curves and injection pulses, taking into account the effects of measurement errors and other disturbances on the deconvolution results. The impulse responses obtained by the VTT team were also composed of various peaks. These peaks did not necessarily correspond to those previously identified by the LBL team. The LBL team used the Toeplitz method and the VTT team the Extreme Value Estimation method (EVE) to perform the deconvolution. The EVE method estimates the lower and upper bounds of the unknown or any user-defined linear expression formed from them. The analysis by the VTT team indicated that the experimental breakthrough data could be explained by hydrodynamic dispersion.

The geometry of the system was estimated in the approach employed by the INTERA/AEA team. The team calculated fractional dimensions of the flow paths and noted that the slopes of the fitted lines were generally close to unity suggesting that the basic premise of transport through a simple geometric structure is appropriate and that the dominant structure is pipelike.

The Project Teams, except for KTH/SKI, used the tracer breakthrough curves to fit the transport parameters. However, a problem was that the tracer injections had been time-varying. Because of this, the teams had to use either the real data and compute what the response would have been if a simple (pulse) injection had been performed or compute the responses of the system to the time-varying injection. The first approach which involves a deconvolution technique was used by the LBL and VTT Project Teams and the second approach which involves a convolution technique was used by the KTH/SKB and BRGM teams. Two other approaches were as well used. The LBL team studied the first peak early arrival data and modelled the time-varying injection flow rates by an exponential decay curve followed by a period of stabilization. The KTH/SKI team generated synthetic breakthrough curves with the channel network model using a pulse injection and integrated the simulated curves over time in order to simulate a constant step injection of tracer.

One of the more important experimental observation from the 3-D experiment was that the flow and tracer transport seemed to be localized to a few preferential flowpaths, channels. The definition and incorporation of channels and channel properties has therefore been a common theme for the Project Teams. Although the Project Teams applied quite different assumptions, the various channel models were able to reproduce most of the trends observed in the experiment. Such a finding therefore points out that the experimental data could not be used to validate or invalidate any of the various channel models. Furthermore, several mechanisms were probably unmodelled. Indeed, it is true that these models have allowed to reproduce some of the field observations, nevertheless it can hardly be seen how they could have predicted them. Mechanisms such as diffusion into stagnant pools of water, matrix diffusion, mixing between channels, flow channel geometry and disturbances, as two-phase flow, due to the drift will have to be studied further.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The test case has been studied by the Project Teams from:

- AEA/NIREX
- UPV/ENRESA
- AECB
- BGR
- SNL/USDOE

The main data used in the studies undertaken within INTRAVAL were the hydrogeological properties of the Culebra dolomite. The Culebra dolomite is quite thin, approx 8 m, but extends for many kilometers and is highly fractured. A large number of hydraulic tests have been performed in the dolomite including transmissivity measurements, steady-state measurements of heads and cross-hole tests. The modelling has mainly addressed the issues involved in treating the heterogeneity of the transmissivity of the Culebra dolomite. The effects of the varying salinity of the groundwater in the Culebra dolomite has also been analysed. There are large variations in the transmissivities of the Culebra leading to uncertainties in quantities of importance in a repository performance assessment such as travel times. Therefore, there seems to be a generally-agreed approach to use stochastic models. The conceptual models include two as well as three dimensional descriptions of the Culebra dolomite. Furthermore, continuum porous media as well as fracture network models have been studied.

The teams from AEA and UPV tackled this test case by using stochastic models. The AEA team applied the Turning Band algorithm for generation of realizations. The finite element groundwater and transport code NAMMU was used to solve the problem. The team examined the uncertainties in the pathlines, travel time, head and Darcy velocity that resulted from the uncertainties in the parameters. Furthermore, the statistical behavior of the variogram estimators was studied using Monte-Carlo simulations. The team considered four different stochastic models, all isotropic, and concluded that if the correlation length was comparable to, or greater than, the size of the domain investigated it was not possible to determine the correlation length from the measured data. However, this did not have a significant impact on the uncertainties in quantities such as the travel time, provided that the model was conditioned on a reasonable number of transmissivity measurements. The team applied three different approaches to condition the head data. None of these approaches were found to be entirely satisfactory. Furthermore, the performed work gave some evidence that conditioning on head data is not as strong constraint as conditioning on transmissivity data.

The UPV team used a sequential Gaussian simulation for the generation of realizations. The finite difference codes MODFLOW and MODPATH were used to compute the flow and particle paths. An optimization method was used to condition the head data. The team found that the anisotropic variogram gave best fits. The conditioning on the heads implied some significant improvement, but some discrepancies were still remaining. Gaussian models imply lack of connectivity of regions with higher (or lower) than average transmissivity. Therefore, they might not take into account fast flow paths from the repository which are responsible for the main radiological consequences. Furthermore, the modelling performed by the team indicated that variable density has a large impact on the results and should therefore be included.

The AECB team studied the effects of salinity on the groundwater flow. This was done by comparing the groundwater flow and head data using three different salinity distributions. The problem was solved using the finite difference code SWIFT. The results indicated that there was not any strong evidence for a trend, the variations were consistent with the correlated spatial process. The match to the heads were not good even with conditioning. The calculations with different salinity indicated that the flow paths in the Culebra from the center of the site are relatively insensitive to the uncertainties in the salinity distribution.

The BGR team addressed issues relating to the choice of conceptual model. The AEA, UPV and AECB teams all considered two-dimensional areal models of the Culebra dolomite and assumed that the permeabilities of the units above and below are sufficiently small so that vertical flow can be neglected. The BGR team examined this assumption by including different approaches for the density variations due to variations in salinity and the effect of permeability differences.

The SNL team has applied different conceptual models to study the importance of vertical flow between the Culebra dolomite and the overlying units. Calculations using the preliminary conceptual model indicate that leakage from the Culebra may be of importance.

This test case provided a very valuable focus for the development and study of stochastic models for the treatment of heterogeneity in hydrogeological properties. The applied stochastic models have proven to be valuable tools in assessing the effect of uncertainty due to heterogeneity on the performance of a repository.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental Set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire deeper aquifer in the erosional channel, forms the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The following Project Teams have been working with the Gorleben test case during INTRAVAL Phase 2:

- BGR
- AEA/NIREX
- BfS
- GRS
- RIVM
- SNL/USDOE

The different teams have worked with a number of different tasks. The Project Team from AEA have applied geostatistics on the Gorleben data set and the quantity of interest has been the distribution of clay at the site. The pumping test has been evaluated by BfS, SNL and RIVM and the regional flow situation has been studied by GRS and BGR.

The Project Team from AEA has applied an indicator kriging method to study the Gorleben data set. The modelling work include indicator methods and the use of variograms and kriging for stratigraphic interpolations. Qualitative data from boreholes logs were used in a statistical framework to estimate the distribution and variability of the clay formation at the site. The analysis was conditioned by taking stratigraphic information into account. Information from five boreholes in a vertical section perpendicular to the Gorleben channel were selected for comparison between kriged and geological interpretation and a reasonable degree of agreement was observed.

The Project Team from RIVM made an interpretation of the Weisses Moor pumping test. The drawdown during the pumping period was analytically evaluated with the THEIS model, but the team concluded that the analytical solution could not be used. The drawdown in the boreholes during pumping but also during recovery were then calculated numerically. The varying density of the water observed in different boreholes were not included in the calculations as the density effect was judged to have minor influence on the flow during the short time period for which the calculations were performed (500-2000 hr). A reasonable estimate of the hydraulic conductivity and storage coefficient could be obtained with a 2-D constant density mode, taking into account anisotropy and global heterogeneities. The fit for boreholes located close to the pumping well is usually good, whereas, the fit is usually less good for boreholes further away. The issue of validation has not been addressed yet since the work has been concentrated on data evaluation and parameter fitting.

The Project Team from BfS presented calculations on the Weisses Moor pumping test. The specific permeability, storage coefficient, and aquifer thickness were estimated with an analytical model, THEIS, using regression technique to minimise the residuals in draw-down in the observation wells. The so fitted drawdown curve corresponded well to that observed. The determined parameters were then used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep crossection was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed for both constant density of the water and density dependent flow, i.e an increased density with depth. The boundary conditions in the pumped well were either constant withdrawal at one or at each well screens. Almost identical drawdowns were observed in the different calculations except for a small influence of the well screen location at early times. A conclusion is therefore that the effect of the well screen location is greater than taking the influence of density dependent flow into account.

The Pilot Group (BGR) performed numerical transient calculations with the code SUTRA to study density dependent groundwater movements in the erosional channel above the salt dome. The aim was to reproduce the density distribution and to check if the flow situation in the channel today is in a steady-state situation. Calculations were performed for a cross-section intersecting the channel. The modelled 2-D cross-section is 15 km wide and 250 m deep. Three different initial conditions were applied for the density distribution: linear density distribution, density distribution from measured data, and a narrow density transition zone (between 220 and 240 m depth). The conclusion from these calculations were that steady-state conditions have not been reached in the system yet. The sensitivity to the channel outlet has also been studied by performing calculations of the density distribution after 10 000 years. The calculations differ mainly in the hydraulic properties at the northern channel outlet. The outlet was modelled in three different ways: a closed outlet, an open outlet, and a very small outlet. These calculations gave almost identical results.

The Project Team from GRS presented simulation of the salt transport in the Gorleben channel with the finite element code NAMMU. They started to perform 3-D fresh water simulations followed by 2-D salt transport calculations for a cross section of the channel. They presented salt concentration profiles and pressure contours at different times. The calculations are very time consuming and advanced numerical solvers are required for the problem. One concluding remark was that more information about the initial conditions, boundary conditions as well as the time evolution of the site would have been appreciated.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. In the large scale experiments, brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m are measured.

Analyses by the Project Teams

The following Project Teams have been working with the WIPP 1 test case during INTRAVAL Phase 2:

- SNL/USDOE
- EDM/CEA/IPSN
- RIVM

The Pilot Group (SNL) presented their conclusions and unresolved issues regarding brine inflow through evaporities. The permeability testing on halite and anhydrite interbeds gave the following permeabilites: for pure halite less than 10^{-23} m^2 (no response observed), impure halite ranges from $2 \cdot 10^{-21}$ to $5 \cdot 10^{-20}$ m^2, permeability of anhydrite interbeds is controlled by sub-horisontal bedding-plane fractures and ranges from $2 \cdot 10^{-20}$ to $6 \cdot 10^{-18}$ m^2. The transmissivities of anhydrite interbeds (8 to 96 cm thick) ranges from $5 \cdot 10^{-14}$ to $7 \cdot 10^{-12}$ m^2/s. Pore pressure in halite are generally lower than in anhydrite at the same distance from an excavation, possibly due to combined effects of stress relief and pore dilation caused by creep. The small-scale brine inflow tests showed: no inflow from pure halite, inflow rates consistent with permeabilites for impure halite and heterogeneous fracturing cause large variations for anhydrite (inflow rate varies two order of magnitude between boreholes 1 to 2 metres apart). The inflow of brine to boreholes through multiple layers of impure halite decreased for the first two years and increased thereafter (the increase may be caused by creep and other forms of deformation). The brine inflow rates to bore holes in anhydrite increase with time, possibly due to shear deformation and creation of new storage volumes beneath the excavations. The large-scale brine inflow testing (Room Q) showed an up to 25% increased permeability in boreholes in anhydrite interbeds after mining of the room. The stress relief from mining caused pore pressure in anhydrite interbeds to decrease by up to 5.5 MPa. Halite with no measurable permeability or distinct pore pressure prior to mining showed clear permeability and pore pressure after mining. A total of 150 litres of brine has been collected in the room over 2 years. Future plans for the permeability experiments are one additional test of an anhydrite interbed to evaluate the pressure dependence of permeability, and two additional tests of argillaceous halite (one in the far field). It was concluded that Darcy's flow model has not been validated for evaporites. It may be valid for anhydrites under natural low-gradient conditions, but is probably invalid for fractured anhydrites under large hydraulic gradients because permeability will change as pressure changes. Darcy's flow model is probably also invalid in a medium such as halite in which plastic deformation of pores occurs over long time scales.

The Project Team from EDM presented their evaluation and modelling of the small scale brine inflow experiment. They used the law of conservation and Darcy's law to describe the flow of brine through the salt. The salt was assumed to be a homogeneous and isotropic material, and the team excluded the impact of mechanical and thermal effects. Brine inflow data from bore holes DBT10, 11, 12, and 13 were used to estimate the storativity and the permeabilities. The conclusion from these simulations were that good agreement with the inflow experiments was observed and that the permeability in argillaceous halite is about 50 times larger than in pure halite.

It can be concluded from the WIPP 1 experiments and evaluations that the pressurisation of a repository due to gas generation depends on the amount of available brine. However, the validation of brine flow in salt under natural gradients is still an open issue, since the tests were carried out with order of magnitude higher gradients. The question was raised whether it is possible to use coupled hydro-mechanical models for this purpose.

MOL

Migration experiment in Boom clay formation at the MOL Site, Belgium.

Experimental Set-up

This test case is based on an in situ migration experiment set-up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2.

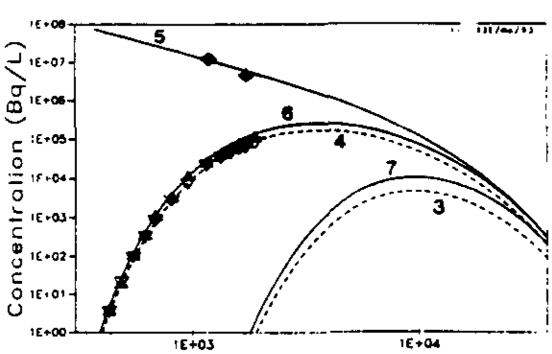

Figure 4. Mol, SCK/CEN. Measured tracer concentration points and the precalculated lines in the HTO experiment.

Analyses by the Project Teams

The following Project Teams have been working with the MOL test case during INTRAVAL Phase 2:

- SCK/CEN
- BRGM
- EDM/CEA/IPSN
- RIVM
- SNL/USDOE

The Pilot Group (SCK/CEN) presented some new concentration values obtained from filters 4 and 6 in the HTO experiment, which now has been running for more than 5 years (Figure 4). These new concentration values were found to be close to precalculated values. The pressure gradient in the system is slightly lower today compared to when the experiment was started about five years ago. The Pilot Group has modelled the Boom Clay as a homogeneous anisotropic saturated porous medium. The governing transport mechanism has then been diffusion-advection or diffusion only, since it is doubtful whether advective transport can be evaluated from the existing data due to very low hydraulic conductivity in the clay. The tracer transport is almost entirely determined by diffusion. Almost identical values on diffusivity, conductivity and porosity has been evaluated from the in-situ experiments as found in supporting laboratory experiments. It was concluded that the conceptual model is valid for predictions of field-scale concentrations and that the parameters determined in the laboratory are valid for field-scale predictions. The anisotropy of the clay cannot be studied with this one-dimensional tracer monitoring and a new type of experiment has therefore been started with the aim to study 3-D migration of the tracer $^{125}I^-$. The distance between the filters in this new experiment is only 0.35 m and the first data points achieved was found to agree with those precalculated.

ALLIGATOR RIVERS

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

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the mobilisation and transport of uranium in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data from more than 70 boreholes have been collected. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles present in Koongarra groundwaters.

Analyses by the Project Teams

The following Project Teams have been working with the Alligator Rivers test case during INTRAVAL Phase 2:

- RIVM
- KEMAKTA

The primary orebody at Koongarra is estimated to be $1 \cdot 10^9$ yr old. Geomorfological information indicate that weathering started some $1 \cdot 10^6$ to $6 \cdot 10^6$ years ago. The base of weathering is at present at a depth of 25–30 m below the surface and a dispersed fan of uranyl phosphates as well as dispersed uranium is found in the weathered zone. A partly weathered transition zone with higher permeability than in both the unweathered zone and the weathered zone is located just above the base of weathering. The groundwater flow direction in the area is at present towards the south.

The Secretariat (KEMAKTA) summarised the analyses performed within INTRAVAL and the Alligator Rivers Analogue Project (ARAP) by the Project Team from RIVM and KEMAKTA. Both teams started with an analyse of data from the field and laboratory experiments. The solid phase uranium concentrations and the uranium concentration in the water indicate an extension of the dispersed fan of about 350 m towards the south and about 100 m towards southeast from the fault. A similar dispersion pattern is obseved at all depths in the weathered zone. This is an interesting observation, since if the rate of weathering is assumed to have been constant with time, then the shape of the dispersion pattern could be explained by the assumption that the transport of uranium is mainly located to the transition zone whereas the uranium transport has ceased in the highly weathered rock. Data also support the theory that there has been only minor changes in magnitude and direction of the average groundwater flow with time. Furthermore, the analyses of the data indicate that uranium in crystalline phases of the weathering zone is not in isotopic equilibrium with the groundwater whereas uranium in other phases of the weathering products is in isotopic equilibrium with the groundwater. This suggests that the crystalline phases are inaccessible to the water, but there might be a transfer of uranium from the accessible phase to the inaccessible crystalline phase. The theory of a linear sorption equilibrium is supported by data as the relationship between uranium concentrations in groundwater and in the accessible solid phase is linear. The activity ratios between ^{234}U and ^{238}U in the inaccessible phase is larger than 1 which might support that transfer of ^{234}U from the accessible to the inaccessible phase is by recoil.

The migration of uranium in the transition zone has been modelled as advection-dispersion in a homogeneous porous medium in 1-D and 2-D assuming linear sorption. The calculated migration distance agreed fairly well with observed migration distances for migration times of $0.2 \cdot 10^6$ - $2 \cdot 10^6$ yr. Other mechanisms such as chain-decay, recoil and phase transfer were also included in the modelling with reasonable success. The applied methodology has showed the importance of joint interpretation of different types of data as well as the importance of an iterative procedure for data collection, data interpretation and modelling. The evaluation of this test case has shown that sorption is an important retardation mechanism, that uranium fixation in crystalline phases is a potentially important retardation mechanism in geologic media where significant alteration of the rock is expected, that recoil may have an impact on the distribution of uranium isotopes in the water, and that geochemistry is an important part of radionuclide transport.

The Project Team from RIVM presented their recent modelling of the uranium transport considering the downward movement ($1.4 \cdot 10^{-5}$ m/yr or 25 m/$1.8 \cdot 10^6$ yr) of the transition zone. The thickness of the transition zone is assumed to be 5 m. The uranium transport mechanism considered is advection-dispersion with linear sorption, and the water flux was assumed to be 1.3 m to the south. Compared to similar calculations without downward movement of the transition zone the migration distance is shorter. The team concluded that geological processes like weathering may be important for transport of radionuclides over long time periods.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20, 40 and 260 m natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contains hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations, etc.

Analyses by the Project Teams

The following teams have worked with the Twin Lake test case:

- AECL-CRL
- AECL-WR
- JAERI
- CEA/IPSN
- SNL/USNRC

The main model validation objectives for the AECL-WR team was to identify the quantitative (physical) measure of aquifer performance. Another aim was to identify the best aquifer and transport simulation model with regard to the measure. The team applied a 2-D steady-state flow model and a 2-D transient transport model to solve this problem. The transport model was based on a moving mesh having a fine resolution around the tracer plume. Some discrepancies were noted between the field data and the model results, but the general pattern of the concentration contours agree with field data. One major lesson that was learned from this exercise was that there seems to be a fine layering of the aquifer on the scale of a few centimeters. This layering could have caused a velocity variation which resulted in an increased dispersivity.

The Pilot Group (AECL-CRL) has critically evaluated the usefulness of hydraulic conductivity data, determined on the basis of head measurements or empirical relationships, for heterogeneity characterisation and contaminant transport predictions. The conventional approach of quantifying aquifer heterogeneities is based on characterisation of the spatial pattern of hydraulic conductivity and it has been found that the inherent variability to a large extent is lost, since measured hydraulic conductivities are based on mean values for the medium. Furthermore, estimation of conductivity heterogeneities by calibrating a flow model against measured head data is deemed to be inappropriate, because heads are not particularly sensitive to conductivity variations. It was therefore suggested that the most reliable approach to account for local heterogeneities is to measure velocities and velocity variations rather than conductivities. Estimates of hydraulic conductivities based on grain size analysis are directionless and thus improve the velocity calculation only when they are used in conjunction with tracer test data. The heterogeneities observed from grain size analysis are smoothed if hydraulic conductivities are used.

An important finding that the Pilot Group pointed out was that grain size analysis and the applicability of an empirical formula to relate an "effective" grain diameter to hydraulic conductivity have allowed for a detailed resolution of aquifer heterogeneity at the Twin Lake site.

The work performed by the SNL team was limited to identification of models which produced conservative results with regard to the observed concentration distributions.

The JAERI team applied a three step procedure for the 2-D concentration calculations. The first step was a generation of hydraulic conductivities followed by flow calculations and finally a random walk concentration calculation. The code MIGINT was used for generation of the hydraulic conductivities in 2-D. The code MIG2DF, which is a 2-D finite element code, was used for the groundwater flow calculations. The transport part of the problem was solved applying a random walk model including advection and dispersion. The team concluded that the applied model seemed to explain the results qualitatively, but that more data of geostatistics and experimental conditions are needed in order to validate the model.

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 Inspectorate (SKI) acts as Managing Participant. 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 expenses, 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.

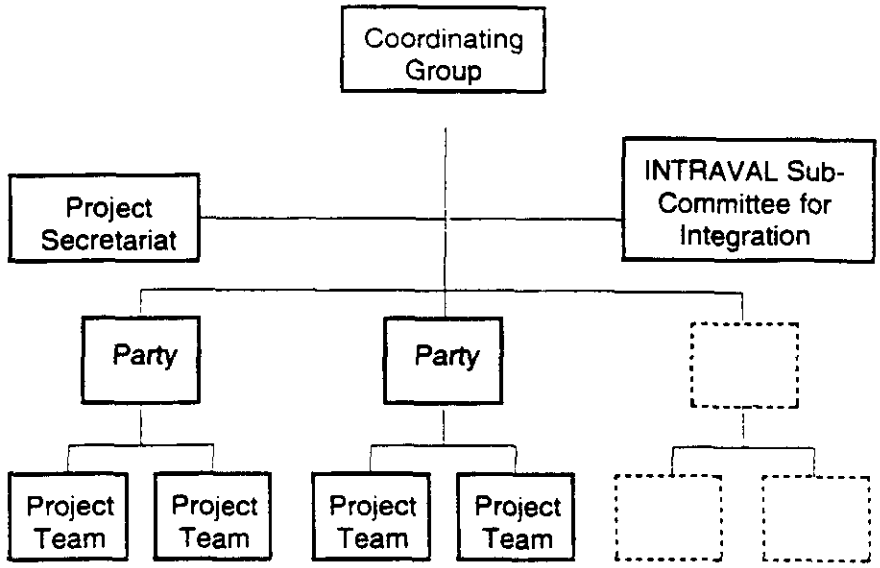

Figure 5. INTRAVAL Organisational Chart.

Managing Participant: SKI

Coordinating Group:

- Chairman: J. Andersson, SKI
- Vice Chairman: T. Nicholson, U.S. NRC
- Secretary: B. Dverstorp, SKI

Principal Investigator: KEMAKTA Consultants Co.

Project Secretariat:

J. Andersson, SKI
L. Birgersson, KEMAKTA
B. Dverstorp, SKI
M. Ericsson, KEMAKTA
P. Jackson, AEA Technology
A. Larsson, KEMAKTA
J.P. Olivier, OECD/NEA
K. Pers, KEMAKTA
K. Skagius, KEMAKTA