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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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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 semivariogram 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 a 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.

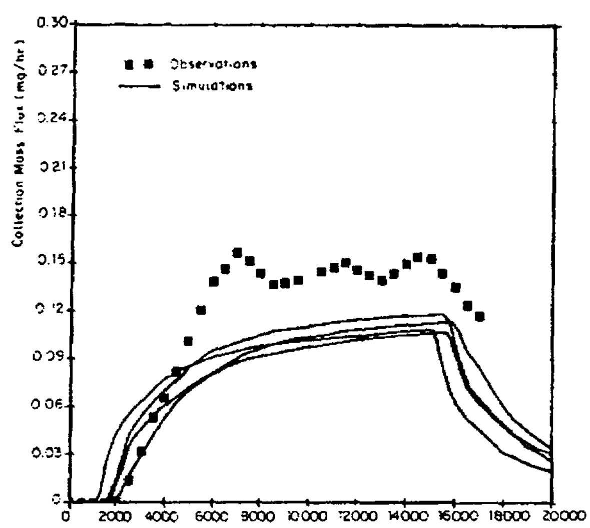

Figure 1. Stripa, BTGM/ANDRA. Observed and simulated mass flux curves for Uranine, Random Channel Model.

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.

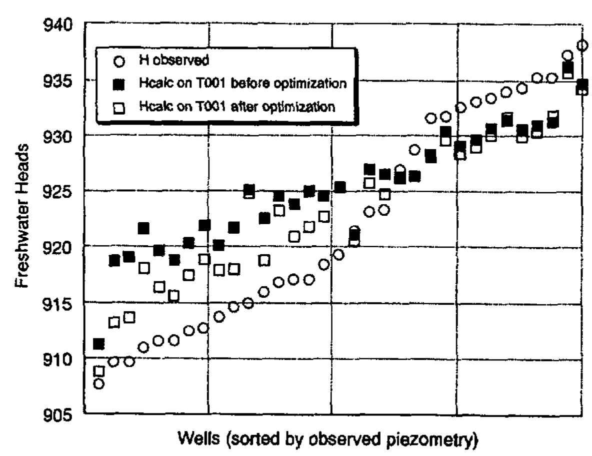

Figure 2. WIPP 2, UPV/ENRESA. Observed and calculated piezometric heads.

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).

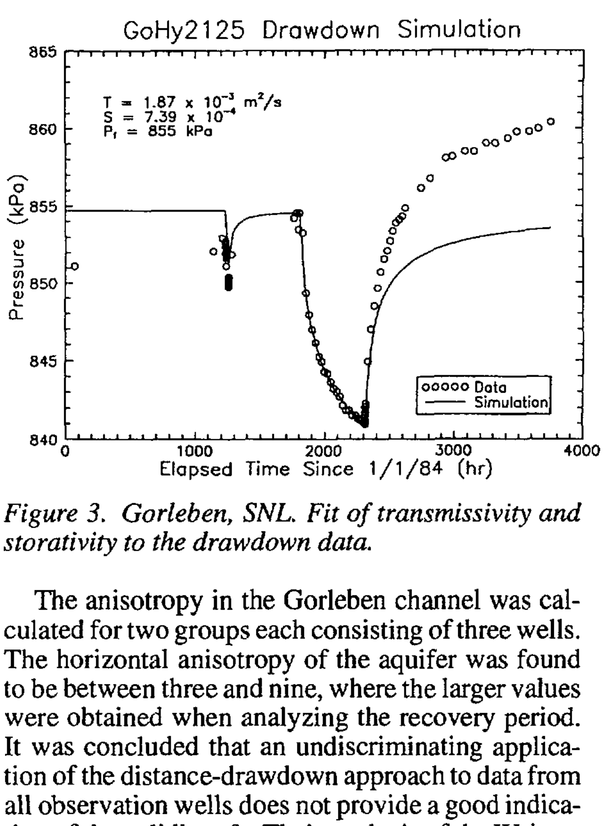

Figure 3. Gorleben, SNL. Fit of transmissivity and storativity to the drawdown data.

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.

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.

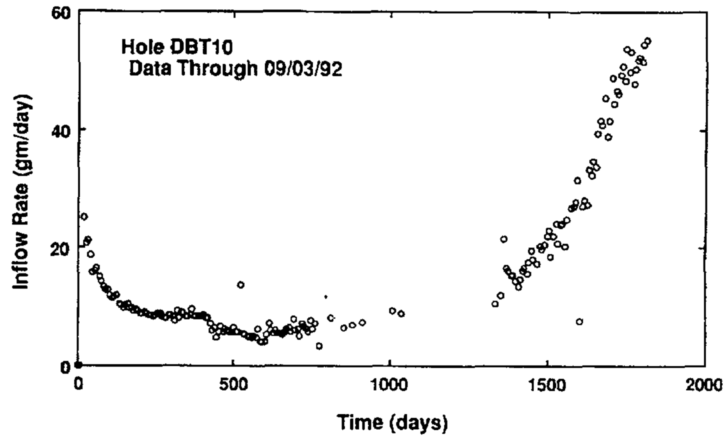

Figure 4. WIPP 1, SNL/WIPP. Brine inflow rate into borehole DBT10.

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.

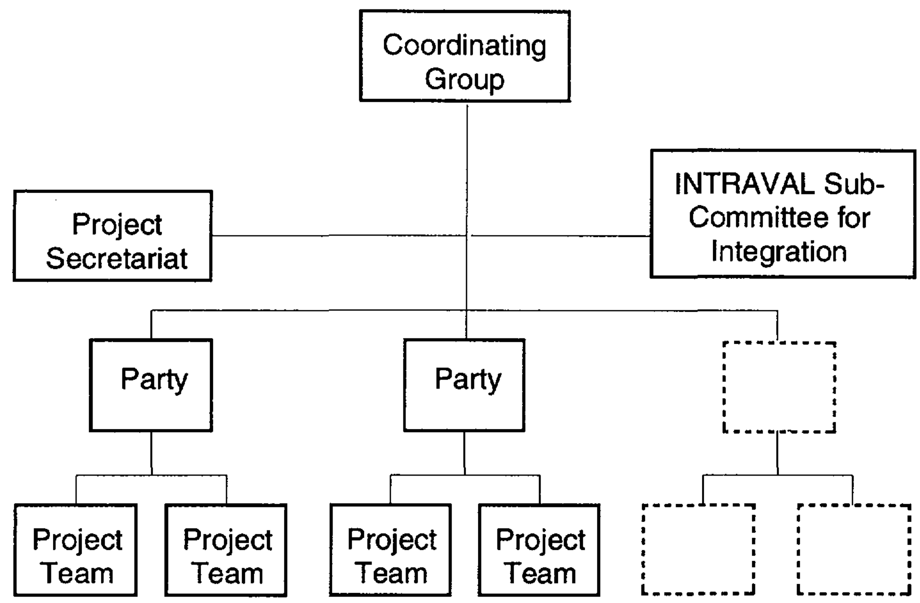

Figure 5. INTRAVAL Organisational Chart.

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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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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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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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

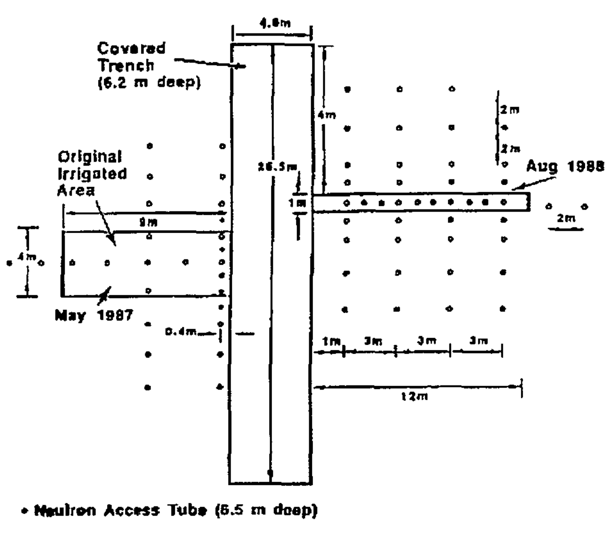

Figure 6. Las Cruces. Top view of the trench with irrigated areas.

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.

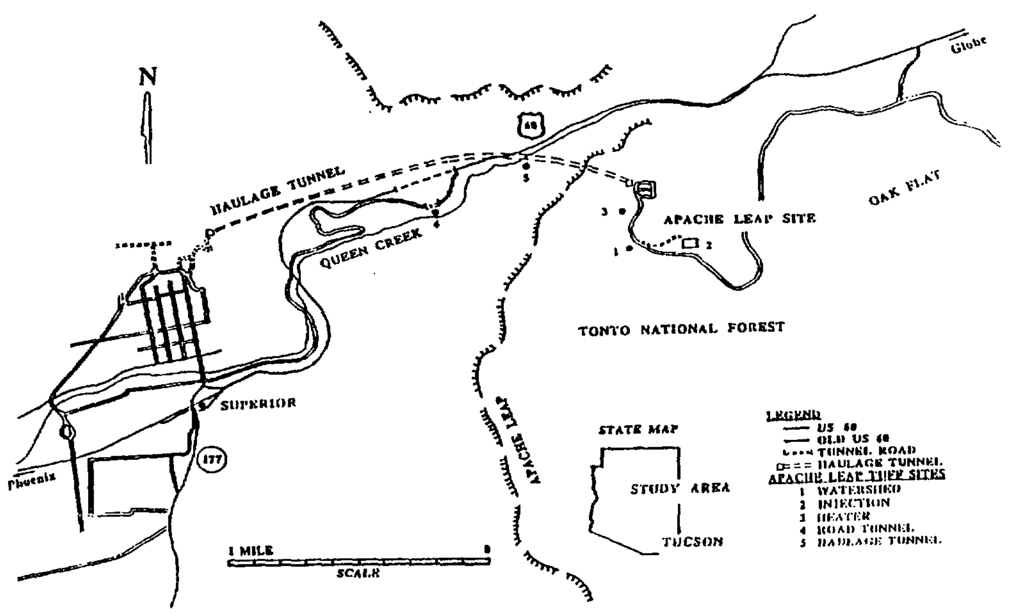

Figure 7. Location of testing facilities at Apache Leap Tuff site.

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.

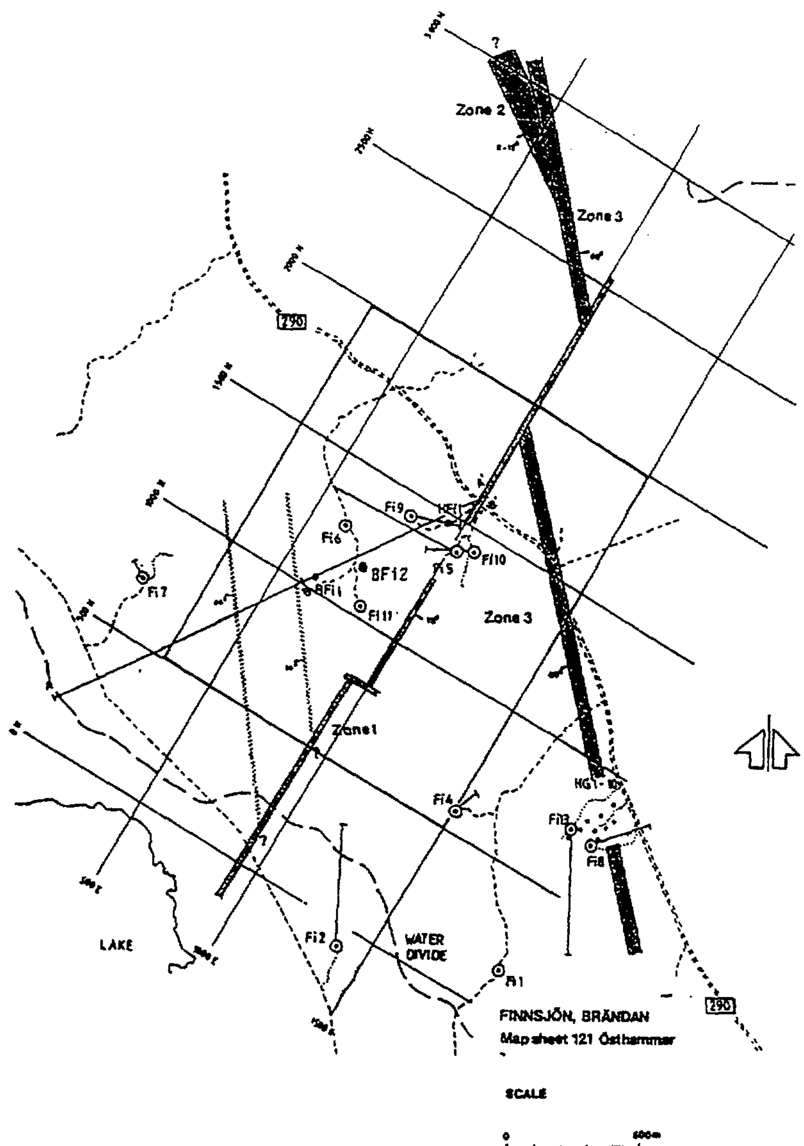

Figure 8. Finnsjön. Borehole location in the Brändan area.

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.

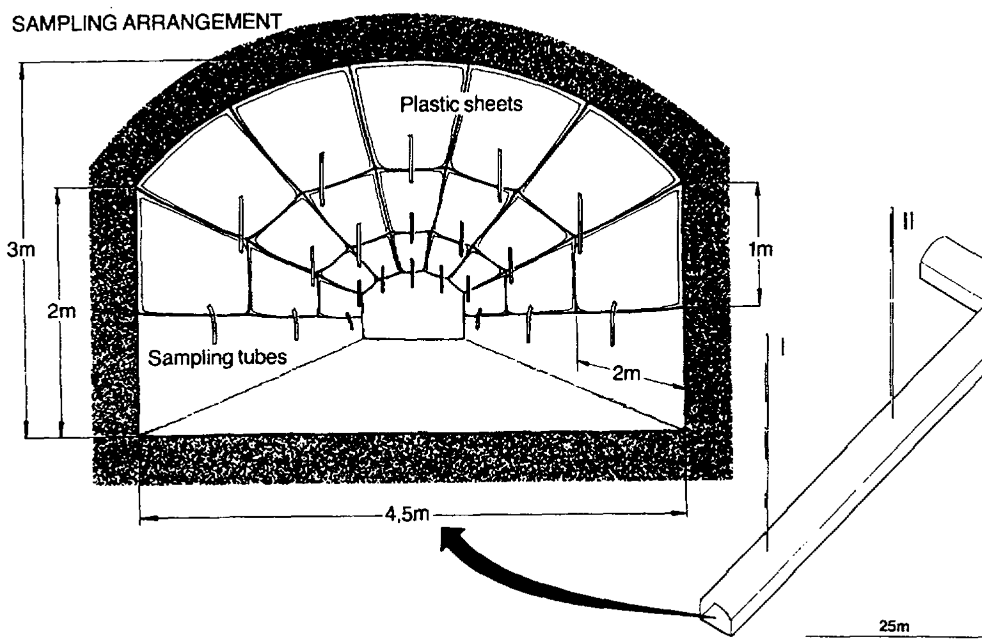

Figure 9. Layout of experimental 3-D drift at Stripa and sampling arrangement.

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.

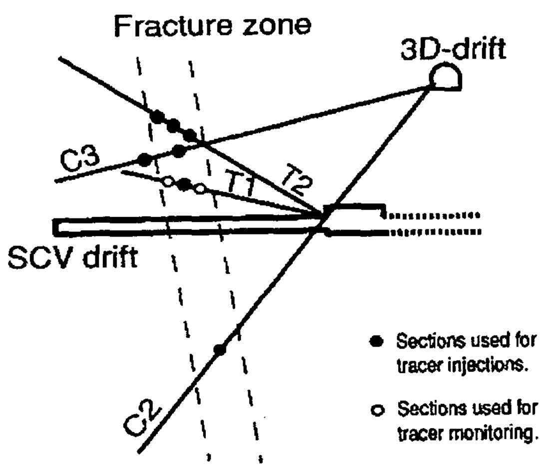

Figure 10. Stripa. Layout of tracer experiment (SCV).

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

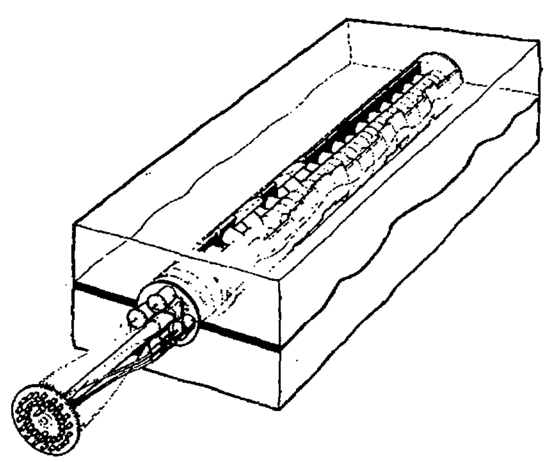

Figure 11. Stripa. Design of the multiped packer (Channelling Experiments).

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	
Quaternary	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.

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

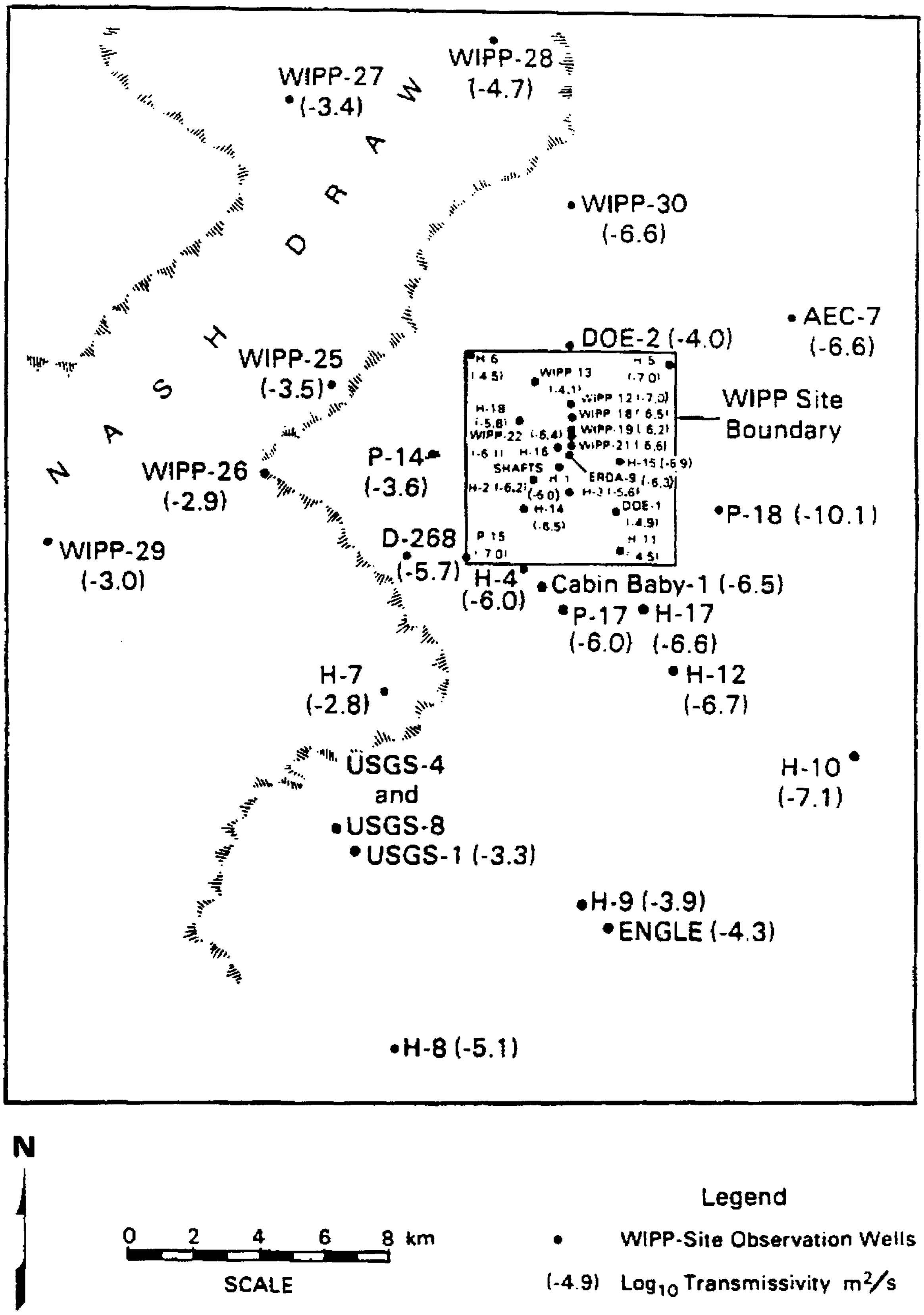

Figure 13. WIPP 2. Culebra Wells and measured transmissivity near the WIPP site.

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 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 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 (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).

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.

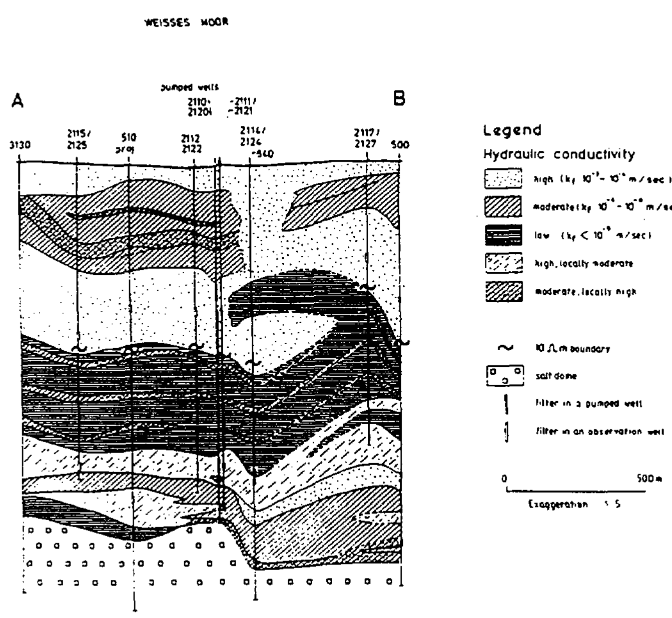

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

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.

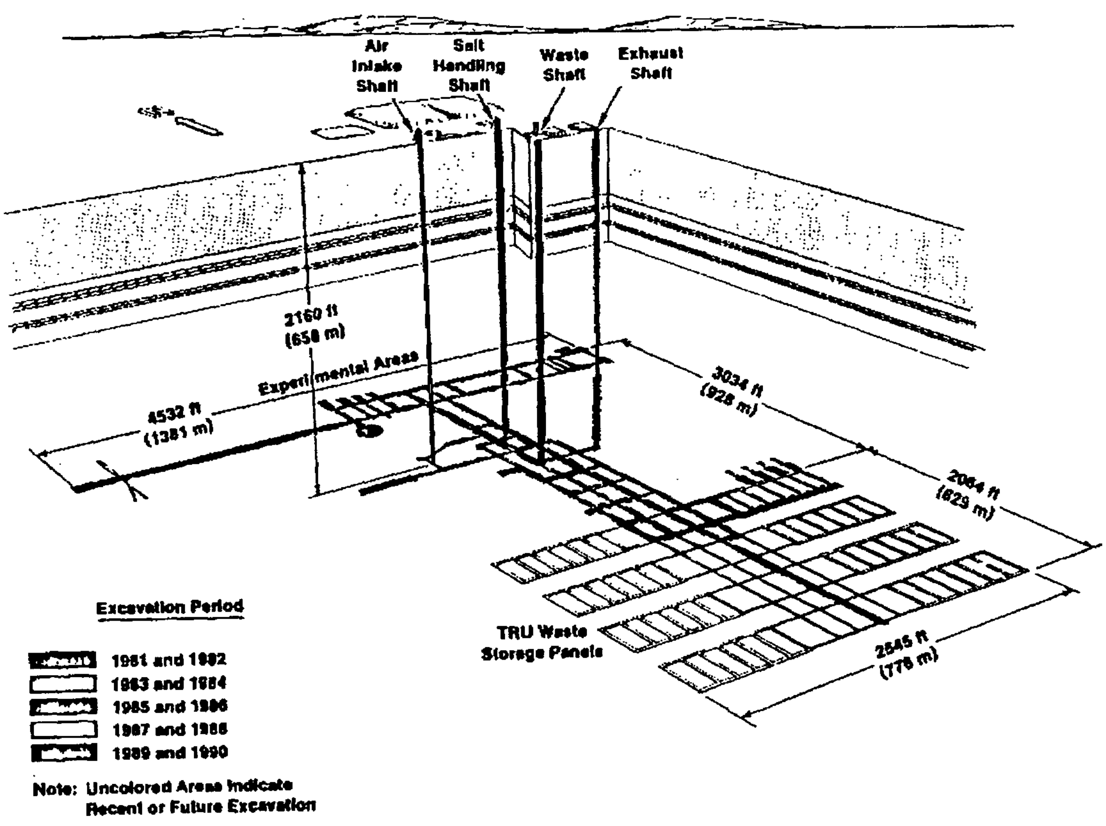

Figure 15. WIPP 1. Schematic view of the WIPP site.

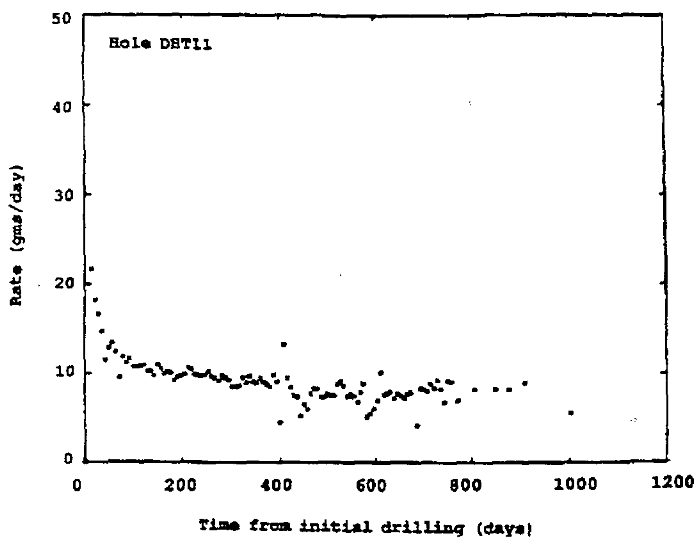

Figure 16. WIPP 1. Brine inflow rate vs time in a borehole (Hole DBT11).

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

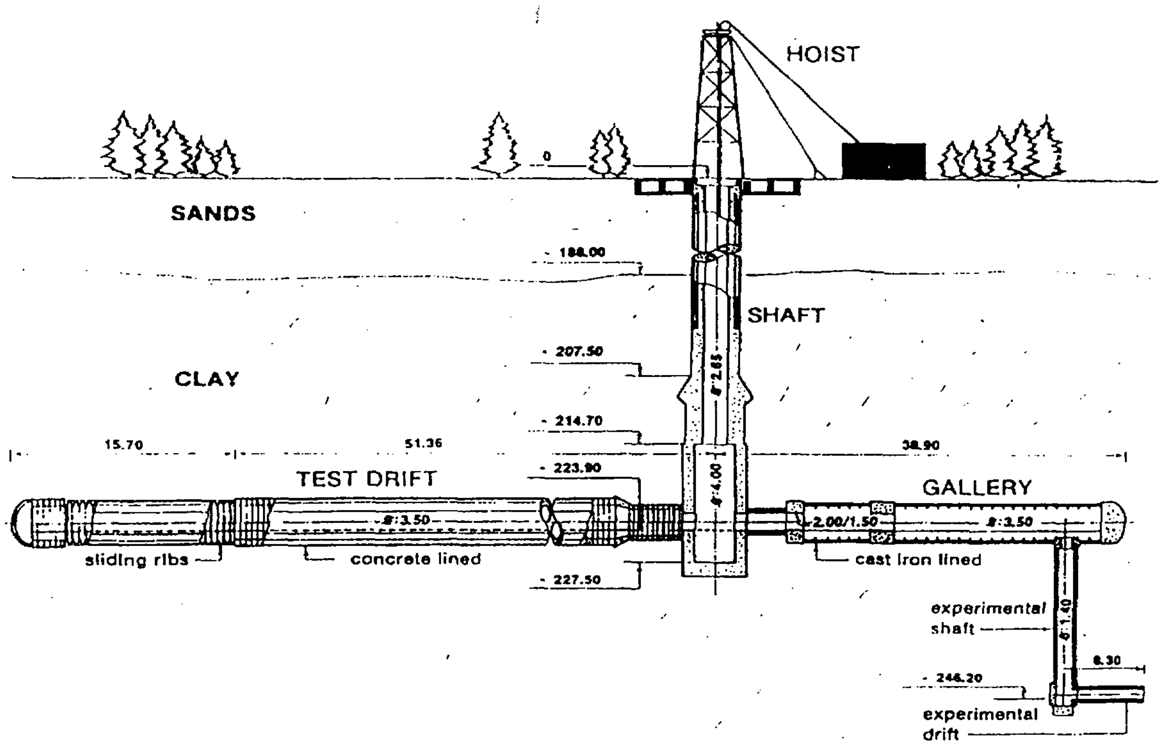

Figure 17. Scheme of the underground facility at Mol.

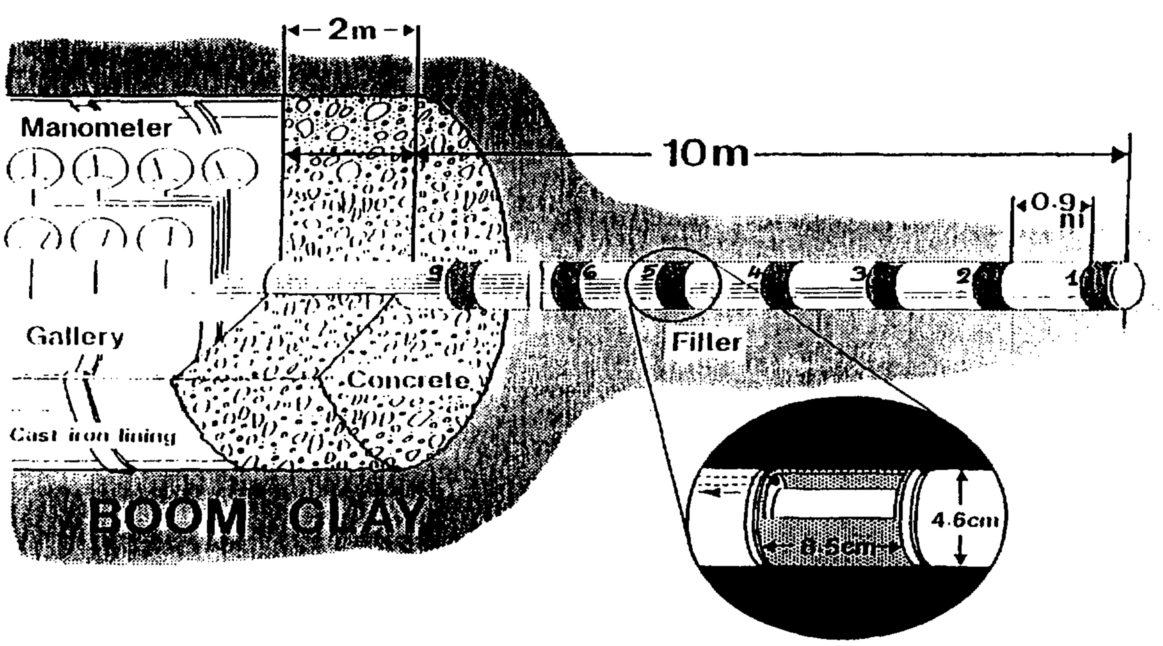

Figure 18. Mol. Conceptual view of the piezometernest.

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

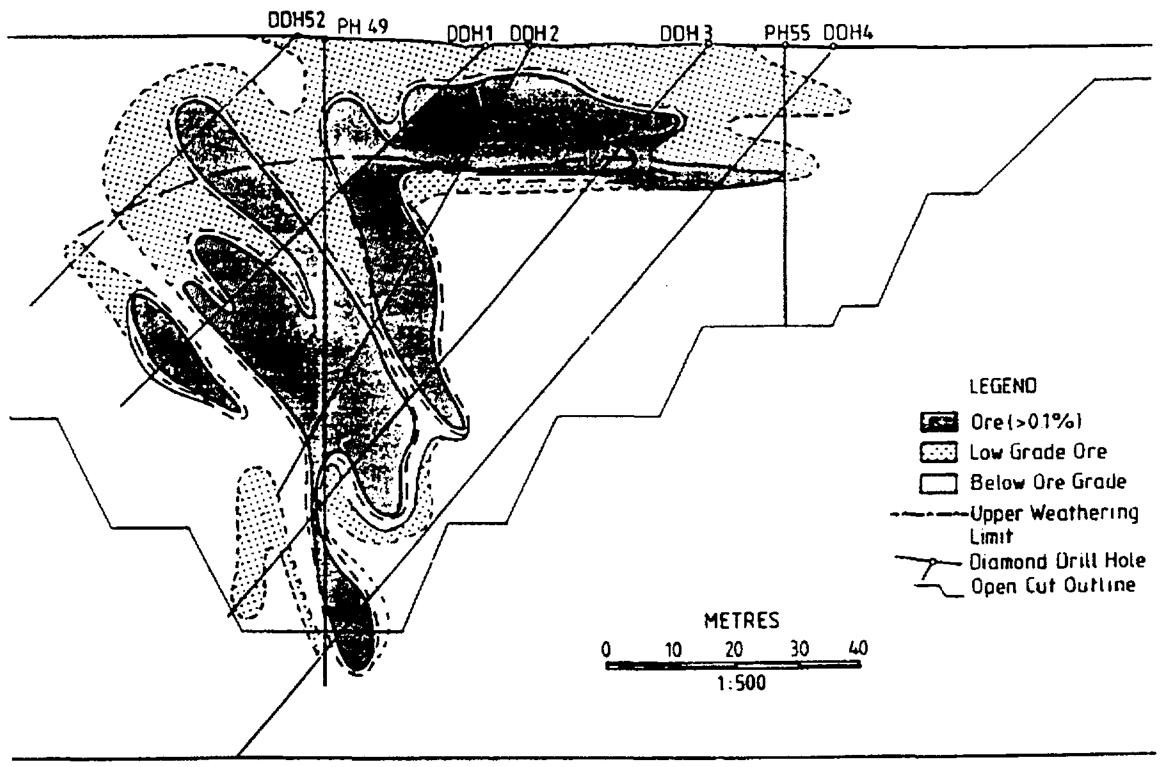

Figure 19. Alligator Rivers. Cross section showing the dispersed zone at the Koongarra deposit.

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)

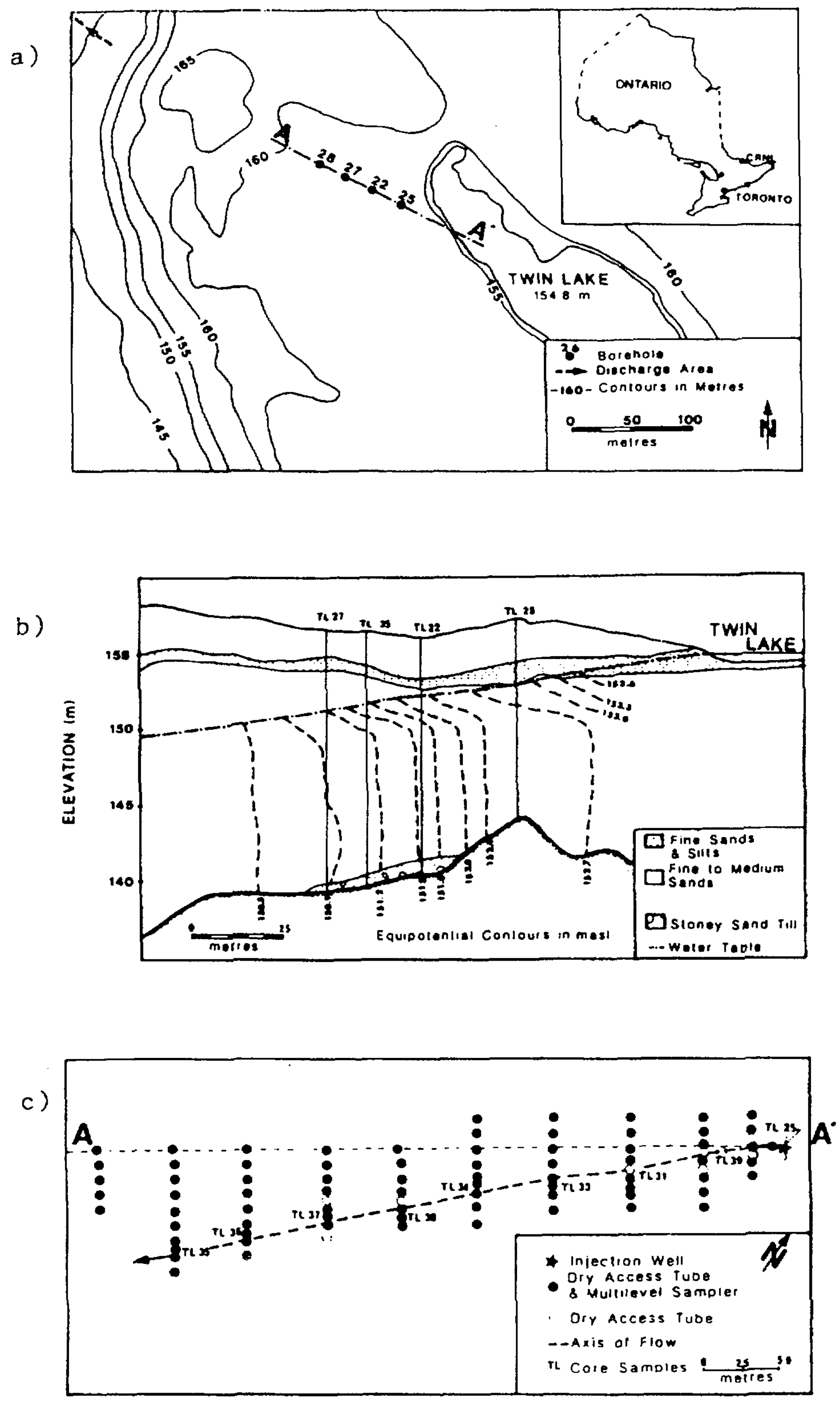

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

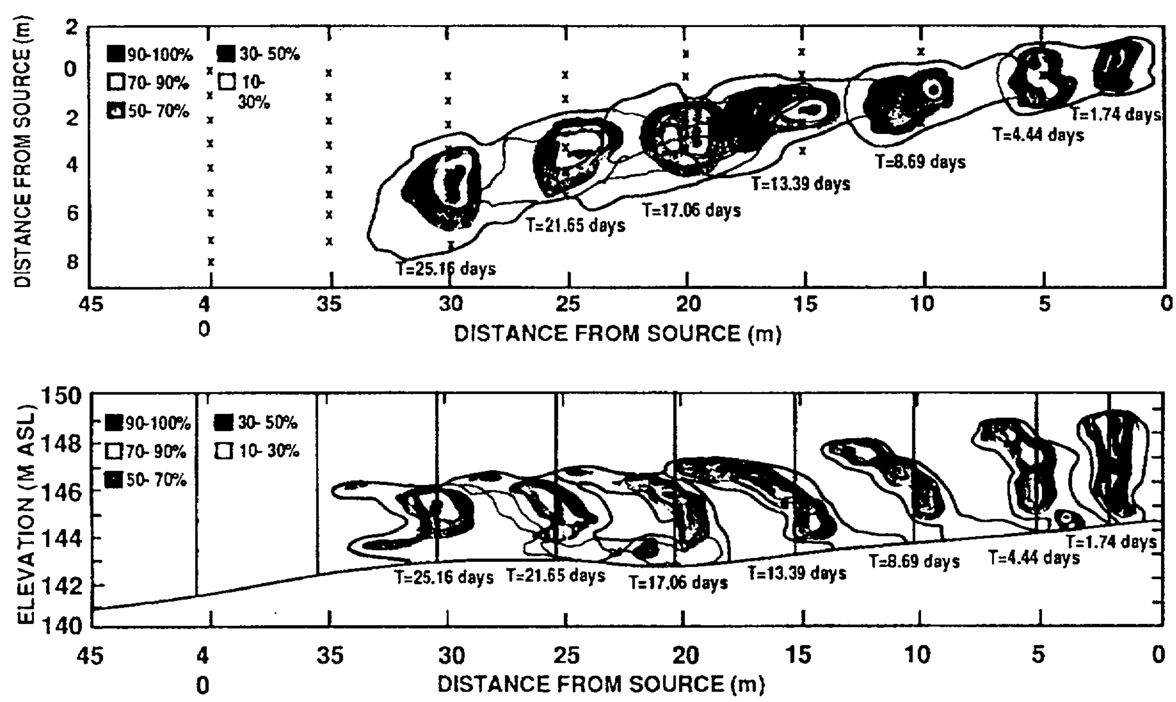

Figure 21. Twin Lake. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration)

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.

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 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.

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 m, 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., Nonisothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Crosshole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Lindgren M., and Rasmuson A., Two-Phase Flow Simulations in a Heated Tuff Drillcore, INTRAVAL Workshop, Cologne, October 1990.

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M., and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

Experiments with changing Near-Field Hydrologic Conditions in Partially Saturated Tuffaceous Rocks, G-Tunnel (TEST CASE 12)

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L., and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

Experimental study of Brine Transport in Porous Media (TEST CASE 13)

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G., and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Bogorinski P., Jackson P., and Porter J.A., New Approach to the RIVM Experiment, INTRAVAL Workshop, Cologne, October 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M., and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K., and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Groundwater Flow in the Vicinity of the Gorleben Salt Dome (TEST CASE 14)

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case, INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for a Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Hills R., and Wierenga P., Las Cruces Trench Experiments Phase 2, and Validation Strategy, INTRAVAL Workshop, Seattle, April 1991.

Hills R., and Wierenga P., A Quantitative Model Validation Methodology with Application to the Las Cruces Trench Experiments, INTRAVAL Workshop, Sydney, February 1992.

Hills R.G., and Wierenga P.J., Validation Results from the Las Cruces Trench Experiment, INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M., and McCord J., Las Cruces, Summary of Post Analysis. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M., Conceptual Approach and Initial Numerical Modelling of the Plot 2b Experiment Using PORFLO-3, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M.L., Gee G.W., and Kincaid C.T., Simulations of Las Cruces Trench Experiment 2b, INTRAVAL Workshop, San Antonio, November 1992.

Sagar B., and Wittmeyer G., Las Cruces Trench Experiment, Plot 2a, Model Validation Methods, INTRAVAL Workshop, Sydney, February 1992.

Wittmeyer G., and Sagar B., Flow and Transport Modelling of Test Case, INTRAVAL Workshop, Seattle, April 1991.

Wittmeyer G., Las Cruces Trench Experiment Plot 2b. Model complexity and Predictive Capability, INTRAVAL Workshop, San Antonio, November 1992.

APACHE LEAP TUFF

Codell R., Performance Assessment Considerations for the Vapor Phase in Unsaturated Fractured Rock - Applications to the Apache Leap Tuff Studies, INTRAVAL Workshop, Sydney, February 1992.

Ford W., Pole J., Codell R., and McCartin T., Simulations of Hypothetical Flow Experiments in Fractured Rock Blocks, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Sully M., and Neuman S.P., Three Dimensional Characterization of Pneumatic Permeabilities in Unsaturated Fractured Tuff at the ALT Site, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Neuman S.P., Lohrstorfer C., and Basset R., Air Permeability Determinations. Scale Effects, INTRAVAL Workshop, San Antonio, November 1992.

Lehman L.L., Apache Leap - Benchmarking of the Beta Mode Code V-TOUGH on the UNLV Cray, INTRAVAL Workshop, Sydney, February 1992.

Rasmussen T.C., and Anderson I., Unsaturated Apache Leap Tuff Experiments: Fracture Imbibition Tests and Non-Isothermal Core Tests, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., and Evans D., The Apache Leap Tuff Site Proposed Field Heater Experimental Plan, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., Isothermal Coupled Fracture-Matrix Flow and Coupled Thermal-Solute-Water Matrix Flow through Apache Leap Tuff, INTRAVAL Workshop, San Antonio, November 1992.

Sully M., Guzman A., and Neuman S.P., In Situ Pneumatic Permeability, INTRAVAL Workshop, Seattle, April 1991.

Sully M.J. , Guzman A.G., Neuman S.P., and Lohrstorfer C., Validation Studies for Assessing Unsaturated Flow and Transport through Fractured Rock at the Apache Leap Site, INTRAVAL Workshop, Sydney, February 1992.

YUCCA MOUNTAIN

Lehman L., The Effects of Variability in Selected Model Inputs on Modeled Unsaturated Water Content Profiles at Yucca Mountain, Nevada, INTRAVAL Workshop, San Antonio, November 1992.

Robey T., Rautman C., and Kaplan P., Unsaturated Flow and Geostatistics Applied to the Yucca Mountain Test Case, INTRAVAL Workshop, San Antonio, November 1992.

Voss C., Yucca Mountain Test Case. Status report, INTRAVAL Workshop, San Antonio, November 1992.

FINNSJÖN

Andersson P., Brief Summary of New Data From Finnsjön, INTRAVAL Workshop, Sydney, April 1992.

Fillion E., and Schwartz J., Interpretation of Interference Tests at Finnsjön Site, INTRAVAL Workshop, San Antonio, November 1992.

Gomit J.M., Finnsjön Test Case, INTRAVAL Workshop, Seattle, April 1991.

Hatanaka K., Umeki H., Sasaki N., Mukai S., and Doi, H., Preliminary Analysis on Tracer Transport Test at Finnsjön Site, INTRAVAL Workshop, Sydney, February 1992.

Hatanaka K., Preliminary Modelling of the Effect of Heterogeneity on Tracer Transport at Finnsjön Site, INTRAVAL Workshop, San Antonio, November 1992.

Hautojärvi A., Do Break-through Curves in Field Tests Reveal Matrix Diffusion?, INTRAVAL Workshop, San Antonio, November 1992.

Kung C.S., Cvetkovic V., and Winberg A., Calibration and Validation of a Stochastic Continuum Model using the Finnsjön Dipole Tracer Test, INTRAVAL Workshop, San Antonio, November 1992.

Vuori S., Evaluation of Migration Processes and Geometries Using Tracer Break-through Curves of INTRAVAL Test Cases (Finnsjön, Stripa, WIPP 2), INTRAVAL Workshop, Seattle, April 1991.

STRIPA

Andersson P., Monitoring of Saline Tracer Transport by Radar Measurements and Model Simulations, INTRAVAL Workshop, Sydney, February 1992.

Guerin F., Billaux D., Chiles J.P., and Sauty J.P., Stripa: First Attempt at Tracer Experiments. Simulations by a Set of Interconnected Channelized Fractures, INTRAVAL Workshop, Seattle, April 1991.

Guerin F., and Billaux D., Analyzing Flow and Transport in the Stripa 3-D Site; Influence of Connectivity, INTRAVAL Workshop, San Antonio, November 1992.

Hautojärvi A., Analysis of Stripa 3D Data Employing EVE (Extreme Value Estimation) deconvolution Method, INTRAVAL Workshop, Sydney, February 1992.

Neretnieks I., The Stripa Site Characterization and Validation (SCV) Experiment and Review of Earlier Work, INTRAVAL Workshop, Sydney, February 1992.

WIPP 2

Beauheim R., Overview of Tests Conducted on the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Capilla J.E., Gómez-Hernández J.J., and Sahuquillo A., Stochastic Analysis of Groundwater Flow at the WIPP Site, INTRAVAL Workshop, San Antonio, November 1992.

Cliffe K.A., Jackson C.P., and Impey M.D., Summary of Results of a Preliminary Geostatistical Analysis of WIPP 2: Uncertainty and Validation, INTRAVAL Workshop, Sydney, February 1992.

Cliffe K.A., Jackson C.P., and Impey M.D., Further Results on WIPP 2, INTRAVAL Workshop, Sydney, February 1992.

Corbet T.F., Overview of Modeling Studies of the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Corbet T.F., Overview of Recent Progress on Geostatistical Estimates of the Culebra Transmissivity Field, Interpretation of Tracer Tests, and Alternative Conceptual Models of Regional Groundwater Flow, INTRAVAL Workshop, Sydney, February 1992.

Gomez-Hernandez J., and Capilla J., Application, INTRAVAL Workshop, Sydney, February 1992.

Grindrod P., Flow Through Fractal Rock: What does the WIPP 2 Field Data Reveal?, INTRAVAL Workshop, Seattle, April 1991.

Jackson P.C., Preliminary Discussion on WIPP 2, INTRAVAL Workshop, Seattle, April 1991.

Kröhn K-P., Modelling of Regional Variable-Density Flow at the WIPP-Site. Initial Results for a Vertical Section, INTRAVAL Workshop, San Antonio, November 1992.

LaVenue M., Application of an Automated Pilot-Point Inverse Technique to Generate Calibrated Conditionally-Simulated Transmissivity Fields, INTRAVAL Workshop, San Antonio, November 1992.

Sahuquillo Herraiz A., Further Conditioning of Transmissivity Fields: Honoring Piezometric Data Theory, INTRAVAL Workshop, Sydney, February 1992.

GORLEBEN

Arens G., and Wollrath J., BfS - Calculations on Pumping Test 'Weisses Moor', INTRAVAL Workshop, Sydney, February 1992.

Beauheim R.L., Evaluation of Hydraulic Anisotropy from Weisses Moor Pumping Test, INTRAVAL Workshop, San Antonio, November 1992.

Bogorinski P., and Pöttl B., Modeling the Gorleben Channel, INTRAVAL Workshop, Sydney, February 1992.

Porter J., Application of Indicator Methods to the Gorleben Data Set, INTRAVAL Workshop, San Antonio, November 1992.

Schelkes K., Gorleben Test Case, INTRAVAL Workshop, Seattle, April 1991.

Schelkes K., Status of Test Case and Validation Issues, INTRAVAL Workshop, Sydney, February 1992.

Schelkes K., and Vogel P., Salt Water Movement in the Gorleben Channel. Studies on Dispersion and Geometry Effects, INTRAVAL Workshop, San Antonio, November 1992.

Vogel P., and Schelkes K., 2D-Studies on Salt Water Movement in the Gorleben Channel - First Results, INTRAVAL Workshop, Sydney, February 1992.

Wollrath J., and Arens G., BfS-Calculations on INTRAVAL Test Case Pumping Test Weisses Moor", INTRAVAL Workshop, San Antonio, November 1992.

WIPP 1

Beauheim R., Interpretation of Permeability Tests (WIPP 1) SOP01 and L4P51, INTRAVAL Workshop, Seattle, April 1991.

Beauheim R.L., and Roberts R.A., Integrated Numerical/Analytical Interpretation of S1P73-B Hydraulic Tests, INTRAVAL Workshop, Sydney, February 1992.

Finley S.J., Small Scale Brine Inflow Experiments (WIPP 1): Data and Interpretation, INTRAVAL Workshop, Seattle, April 1991.

Foesch J.A., Small-scale Brine Inflow, INTRAVAL Workshop, San Antonio, November 1992.

Gorham E., et. al., Status of WIPP 1 Test Case and Current Validation Strategy, INTRAVAL Workshop, Sydney, February 1992.

MOL

Kozak M., Initial Analyses of Anion Exclusion as Applied to the Mol Site, INTRAVAL Workshop, Sydney, February 1992.

Mouche E., and Rouzier P., Tracer Experiment at the Mol Site: Modeling and Sensitivity Analysis, INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M., and McCord J., Mol: Preliminary Analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Put M., Mol: Case Description and Modelling Methodology with Results, INTRAVAL Workshop, Seattle, April 1991.

Put M., Theoretical Validation Considerations for the Mol Test Case (with Results), INTRAVAL Workshop, Sydney, February 1992.

Put M., Mol Test Case. Validation of used model, INTRAVAL Workshop, San Antonio, November 1992.

ALLIGATOR RIVERS

Birchard G., and Murphy W., Koongarra Analogue of the Near Field of an HLW Repository, INTRAVAL Workshop, Seattle, April 1991.

Birchard G., Groundwater Geochemical Speciation Modelling, INTRAVAL Workshop, Sydney, February 1992.

Emerson D., Site Characterization, INTRAVAL Workshop, Sydney, February 1992.

Golian C., Uranium Series Radionuclide Mobility in the Koongarra Weathered Zone, INTRAVAL Workshop, Seattle, April 1991.

Golian C., Transport Modelling of Natural Analogue - Approach and Findings, INTRAVAL Workshop, Sydney, February 1992.

Kimura H., and Murakami T., Uranium Migration Considering Alternation of Chlorite at Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Skagius K., Modelling of Uranium and Thorium Migration in the Weathered Zone at Koongarra, INTRAVAL Workshop, Sydney, February 1992.

Skagius K., Modelling of Uranium and Thorium Migration in the Weathered zone at Koongarra, INTRAVAL Workshop, San Antonio, November 1992.

Tanaka Y., Miyakawa K., and Kawanishi M., Three-Dimensional Groundwater Flow Analysis on the Basis of Schistosity at the Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Townley L., Hydrology of the Koongarra Site, Including Predictions of 3D Groundwater Flow Patterns, INTRAVAL Workshop, Seattle, April 1991.

Townley L., Summary of Hydrology Workshop, INTRAVAL Workshop, Sydney, February 1992.

Waite D., Implications of Sorption in Retardation, INTRAVAL Workshop, Sydney, February 1992.

van de Weerd R., Geochemical Modeling of the Koongarra Uranium Deposit, INTRAVAL Workshop, Sydney, February 1992.

van de Weerd R., Richardson-van der Poel M., and Hassanizadeh S.M., Preliminary Results of Modelling of Nuclide Transport at Koongarra, INTRAVAL Workshop, San Antonio, November 1992.

TWIN LAKE

Durin M. and Mouche E., Comments to Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Goblet P., Modelling of Mass Transport with a High Peclet Number. Application to the Twin-Lake Tracer Experiments, INTRAVAL Workshop, San Antonio, November 1992.

Gomit J-M., Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Moltyaner G., A Novel Methodology for Characterizing Geologic Heterogeneities, INTRAVAL Workshop, Sydney, February 1992.

Moltyaner G., Indirect Testing of a Constitutive Law, INTRAVAL Workshop, San Antonio, November 1992.

Mouche E., Twin Lake Tracer Experiments: Can a Stochastic Modeling be performed?, INTRAVAL Workshop, San Antonio, November 1992.

Munakata M., and Kimura H., Preliminary Results of Twin-Lake Tracer Test (1983), INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M. and McCord J., Twin Lake: Preliminary analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Olague N., and Davis P., Validation Aspects for the Twin Lake Studies and Data Analysis of Twin Lake 1983 Tracer Tests, INTRAVAL Workshop, Sydney, February 1992.

INTRAVAL Parties:

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