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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Attendance at GEOVAL-94
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DATE/PLACE: October 11-14, 1994, Paris (France)

AUTHOR(S): Budhi Sagar and Gordon Wittmeyer

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ATTACHMENTS: Three attachments are included. Please contact the author for copies of full papers.

PERSONS PRESENT: See attendance list (attachment 2). Mr. Tom Nicholson (NRC), Dr. Shlomo Neuman (University of Arizona) and the authors represented the NRC.

BACKGROUND AND PURPOSE:

This was the third in a series of GEOVAL Symposia (the first two were held in 1986 and 1990). GEOVAL-94 was sponsored by the Nuclear Energy Agency (NEA) of the OECD and the Swedish Nuclear Power Inspectorate (SKI). The theme of the symposium was 'validation through model testing with experiments'. The symposium was organized into six sessions (See attachment 1: Final Programme): (i) recent advances in the field of validation, (ii) review of INTRAVAL, (iii) to (v) integrated experimental studies including underground research laboratories, and (vi) strategic approaches for including validation in the planning for siting, design, and licensing of deep geologic repositories. In addition, on the last day of the symposium, half a day was devoted to a discussion panel. Dr. Neuman and Ms. Federline were members of the discussion panel. Because Ms. Federline could not attend the meeting, Dr. Sagar replaced her on the panel. Other members of the panel were C. McCombie, J. Andersson, J. Bruno, A.J. Hooper, G. de Marsily, O. Olsson, C. Pescatore, and H. Rothemayer.

All presentations at the symposium were by invitation only. Symposium proceedings will be published by the NEA. To encourage fruitful discussion, the organizers had requested the presenters to address the following five questions.

- How do they assess success (of model validation)? Whether it is practical or worthwhile to improve success? To what extent a judgement of success takes into account information other than model testing?
- How was the design planned and the experiment analyzed?
- What models were tested? How were they tested with experiments? Were alternative conceptual models tested and assessed?
- How were different disciplines integrated?
- Where did the greatest difficulties lie: interpretation, design, performance etc.?

Before summarizing symposium discussions, a brief introduction to the NEA is provided next. In the field of nuclear waste management, the objective of the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) is to promote a forum for the exchange of information on waste management policies and practices, to develop a common understanding of basic issues and to promote the adoption of appropriate waste management strategies in member countries. The NEA manages this overall objective through its Radioactive Waste Management Committee (RWMC) of which the NRC is a member. The RWMC has created several working and advisory groups to focus on specific areas.

MEETING SUMMARY:

The agenda of GEOVAL-94 is provided as attachment 1. Attachment 3 contains the abstracts of the papers. Following is a brief summary of the meeting. Details are provided in the next section of this report.

There was considerable confusion regarding the meaning of the term 'model validation'. At the beginning of the workshop, C. Pescatore argued that the term not be used in the nuclear waste management program in the future. However, there was great difficulty in coining an alternate acceptable term, as they all bogged down with the same definitional problems. Terms like model testing, model evaluation, model corroboration etc. are now being used by some programs. Several speakers preferred the term 'confidence building in models'. When the chairman called for a show of hands, only a minority of those present said that they will not use the 'V' word anymore. There was also confusion regarding validity of a model versus validity of an entire safety case. Many participants indicated that it is the latter that would eventually be important and therefore we should not lay too much stress on model validation.

The INTRAVAL program that started in 1987 and ended in 1993 was reviewed in terms of lessons learned with respect to model validation. Summarizing the lessons from the INTRAVAL program, Neil Chapman said that validation is a process and not a product! Validation is achieved when there is a substantial body of peer opinion. An important result of INTRAVAL was that no new processes were identified, thus leading one to believe that all important processes were already embedded in the models.

Several ongoing 'integrated' (integrated is used in the context that experiments and model validation activities proceeded hand in hand) experiments were discussed. These included experiments in Boom clay in the underground laboratory at Mol (Belgium), tests on backfill in the underground research laboratory at Pinawa in Canada, radionuclide migration experiments at Grimsel in Switzerland, gas flow experiments at the Äspö hard rock laboratory in Sweden, TVO research tunnel in Finland, experiments in the Asse salt mine in Germany, and experimental investigations at WIPP. It appears that both well planned experiments as well as opportunities presented during the construction process can be used for gaining confidence in models. It was suggested that natural analogs were better used for qualitative conclusions and generating public confidence in long-term safety rather than for quantitative model validation. The audience was briefed on work going on in the DECOVALEX project (aimed at validating coupled thermal-hydrological-mechanical models) which may be extended by another three years.

DETAILED DESCRIPTION:

The symposium was opened with greetings from the Director-General of the OECD and Mr. Norby of the SKI. In explaining the objectives of GEOVAL-94, Johan Andersson (SKI) explained that programs for construction of repositories are close to realization in a number of countries, especially Sweden. Given

that we shall not find final answers to all questions pertaining to the geosphere, he asked, "what shall we do with the unresolved issues?" He reiterated the five questions stated in the Background section of this report and then summarized the program for GEOVAL-94. Details of the symposium proceedings are provided in the following.

C. Pescatore: An Overview of Definitions. The term model validation was not used until the 1950's. A 1957 definition is: validation is a procedure that provides by reference to independent sources, evidence that an inquiry is free from bias or otherwise conforms to its declared purpose. The terms verification and validation came into being in computer science. Validation is conspicuously absent from LLW licensing. The term appeared only recently in the HLW standards. The IAEA standard requires that compliance will be demonstrated by means of models which are validated to the extent possible. Validation is about model testing, it is about predictive accuracy, it is a judgement call. In 1993, the IAEA changed the standard from "... as far as possible" to ... "as far as practicable". The Swiss standard (1993) requires codes to be verified and to show that models are applicable to the repository system and explain the role of model in the chain of overall safety assessment. The definitions can be classified into three main categories: (i) desire to predict the physical world as truthfully as possible (USDOE) - misleading and unsuitable; (ii) operational definition - validation accomplished only when the results of "blind" tests have been predicted - not helpful again; (iii) modernist view - validation is confidence building - open ended as one will not know when a model is validated. Proposed actions: develop an operational definition; consider the 1957 definition as we are interested in validation of the inquiry rather than that of a model.

Several participants rejected the proposed 1957 definition as inadequate and the question of proper definition of validation remained open.

C.F. Tsang: Validation and Technical Issues at GEOVAL-90. We face the problem of predicting for 10,000 to 100,000 years. These large scale predictions are based on small scale experiments. Some kind of validation is needed to establish accuracy or trustworthiness. Main points made in GEOVAL-90 were: (i) validation is a process; there is no absolute validation, (ii) theories are not really proven but these are accepted by consensus of experts, (iii) validation is the only way to connect the model world with the real world, (iv) it is needed for public acceptance, (v) it reduces uncertainties in conceptual models, (vi) a repository with high confidence is better than one with maximum safety, (vii) validation process should not stop with license application, (viii) validation will provide uncertainty bounds, (ix) use natural analogs to look for unexpected phenomena, (x) modeling predictions differ from field observations because of errors in conceptual model, simplifications made, wrong parameter values, etc., and (xi) there is a need to study the residuals to locate systematic error. The technical issues discussed in GEOVAL-90 related to dispersion, fractures, channeling, stochastic models, matrix diffusion, colloidal transport, complexation, anion exclusion, coupled processes, effects of large ionic strength (salts), and vapor-gas transport in unsaturated environment.

In closing, Dr. Tsang expressed his view that we need not worry about scaling as observations at large scale will be available during site characterization.

P. Zuidema: Validation - Practicable Approach. The aim of performance assessment is to provide input for well-balanced and well-formed decisions. To meet this aim, performance assessment has to be bounding, it is not a precise prediction of the future. Adequate validation is achieved once we get confidence in the reliability of (i) our understanding (qualitative and quantitative) of phenomena, and (ii) our ability to bound total system behavior. Validation will be site specific and would be based upon

qualitative arguments with some quantitative evaluations. The ideal disposal system will be robust and modelable. The Swiss validation strategy will consist of demonstrating that all detrimental phenomena have been identified and that bounding calculations have been made.

He disagreed with C. Pescatore that the use of the term validation be banished from further use. However, the term should be explained carefully. He asked the scientists to accept that bounding estimates may be sufficient, the implementer to be ready to investigate the system sufficiently, and the regulator to accept that absolute proof will not be available. There was no satisfactory answer to the question from the audience as to how one will know that estimates were bounding.

N. Chapman: INTRAVAL Integration Committee Report. The objective of INTRAVAL was to advance the state of knowledge on the practical use of quantitative models and to develop an approach to validation. The project ran for six years (1987-93); 46 organizations from 14 countries participated in the two phases of the project with 18 test cases. Models are useful for developing an understanding of the system and helping make informative decisions yet may have only limited predictive capability. There is no such thing as a 'validated model' that can be applied indiscriminately; the ultimate validity is job specific. Validation is achieved when a substantial body of peer opinion has been accumulated. INTRAVAL Phase 1 was devoted to model evaluation and the second phase to studying approaches to model validation. The validation strategy that emerged was: ask relevant questions about models, check its structure, identify parameters, construct sampling strategies, and compare with experiments. No fundamentally new processes were identified; model validation centered on the relative significance of processes, and better understanding of processes was developed. INTRAVAL recommended that formal mechanisms for defining all relevant classes of conceptual models which can consider soft data should be developed. Site characterization should be structured to measure parameters at various scales.

Tom Nicholson: Conclusions from Working Group-1 of INTRAVAL. Data from the Las Cruces Trench and Apache Leap Tuff experiments was used by INTRAVAL Working Group-1 to evaluate models for flow and transport. These experiments were specifically designed for model evaluation purposes and were focused on characterization and modeling of heterogeneity. The Las Cruces Trench test case did not lead to a discrimination between simple and complex models. Later simulations by Mark Rockhold of PNL using conditioning on measured water content and using scaled hydraulic properties led to a better comparison with the observed data. The Apache Leap work was focused on characterization of fractures through inclined boreholes through which air injection tests were conducted. The data was used to test several models including the scaling model of Guzman and Neuman.

Peter Andersson: Conclusions from Working Group-2, Finnsjön Test Case. Tracer tests (interference, radially converging, and dipole) were conducted at Finnsjön in Sweden to increase understanding of transport phenomena. The tests were modeled to study model discrimination and consistency in evaluated parameters. The tests were done before the INTRAVAL project started so these could not be changed to suit its objectives. Different conceptual models—porous medium, network of non-interacting channels, REV (crack tensor theory), geostatistical approach—were investigated. Processes included were advection, hydrodynamic dispersion, matrix diffusion, and sorption. Scales of from one to 1,000 meters were involved. Models were calibrated at a small scale and then extrapolated to large scale. It was concluded that the experimental data was not sufficient to discriminate between different conceptual models. This is not considered to be a problem if the predictions do not differ much.

C.P. Jackson: Conclusions from Working Group-2, WIPP Test Case. Flow in the Culebra aquifer was the focus of this test case. Data from more than 60 boreholes was available. Accidental borehole intrusion

was the main scenario under consideration. Culebra aquifer is only 8m thick but is laterally extensive. Transmissivity data from about 40 pumping tests was available. Five project teams participated in the test case. Stochastic modeling, deterministic modeling and bounding cases were tried. In the stochastic modeling, the results improved as the amount of conditioning on transmissivity and hydraulic head was increased. Alternate conceptual models for two-dimensional vertical flow were explored by two of the teams. The team studying the use of bounding calculations concluded that transmissivity had the most important influence on the ground water flow in the Culebra and that the uncertainties in the salinity were less important.

Peter Bogorinski: Conclusions from Working Group-3, Salt and Clay Related Case. Experiments were designed to test the applicability of Darcy's law for flow in salt formations and clay media. Application of Darcy's law to pure halites could not be validated. However, in anhydrite and clay, it was adequate to describe the flow. Brine movement alone in bedded salt may not cause significant release from the repository unless it is coupled with other phenomena such as gas generation. Seven teams participated in the Mol-clay test case. Data was taken from Mol underground laboratory. Diffusion was concluded to be the dominant transport phenomena. Transport in an erosion channel for the Gorleben test case was modeled. For this case, numerical modeling did not reveal effects of density variation on the flow field. It was concluded that specially designed field tests would be useful for future efforts in validating variable density flow and salt transport models.

Kristina Skagius: Conclusions from Working Group-4, Alligator Rivers Analog. Study was conducted at the Koongarra uranium deposit (about 1000 million yrs old) in the Alligator Rivers region about 200 km east of Darwin, Australia. The objective was to develop a consistent picture of the transport processes in the weathered zone. Uranium mineralization occurs at Koongarra in two distinct ore bodies. Primary mineralization in the main ore body is largely confined to quartz-chlorite schists and 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 to about 80 m. Use of stationary and moving transition zones in modeling transport by the RIVM group gave similar results. Kemakta included recoil and phase transfer in their model and found the results to be less precise than when a simple advection-diffusion with linear sorption model was used. However, the simpler model could not explain the observed activity ratios in bedrock and water. It was concluded that simple models were robust enough to simulate the present extension of the dispersion fan with independent data from the far field. More complex models can simulate several aspects of the system but input data for these models is not available. Uncertain time-varying boundary conditions, which arise because the history of the analog is not fully known, add to the modeling problem. Iterative procedure with data collection, data interpretation, and modeling is important for model validation.

Panel Discussion for Day 1.

Charles McCombie raised the issue of why model validation was such a big issue only in nuclear waste disposal (for example, it was not an issue in the nuclear reactor business!). Was it because of the importance of the topic or simply because funding and time was available to continue the studies? The audience agreed that the importance of the issue stemmed from the fact that safety has to be shown for 10,000 yrs rather than the 30 yrs in the case of reactors. It was also indicated that not only the regulator but the scientific community and the public must accept the disposal concept. Another issue was whether validation was really a continuous process because decisions must be made at discrete times. Discussions continued on whether the "V" word should continue to be used or a new term be defined. Shlomo Neuman indicated that the INTRAVAL project did not really tackle the problem of model validation. He

also suggested that unless models used input and produced output that was measurable, these cannot be validated. He also opposed the use of the word 'performance assessment' in conjunction with natural systems. According to him, PA models could not be validated.

J. Ortiz: MEGAS E5 Experiment. The MEGAS E5 experiment consists of four multi-piezometers installed in 1992 in the Boom clay formation from the HADES underground research facility. It is a three-dimensional experiment to understand the consequences of gas generation in a clay host rock. A central piezometer is used for gas injection, while the other piezometers are used to measure the pressure increase caused by the gas injection. Permeability of a 100 feet thick layer of Boom clay at Mol were measured by measuring pressure drop. Gas was injected till breakthrough at a pressure of 2.36 MPa. The experiment was modeled with TOPAZ-1D (INTERA) two phase model. Clay was initially saturated at 1.5 MPa. The breakthrough times and the distance were not proportional. The reduction in effective stress due to the drilling of the borehole effected the experiment. It is apparent that hydromechanical coupling should be considered in modeling gas flow in clay.

Gale Volcksert: BACCHUS 2—Backfill Hydration Experiment. This is an in situ backfill hydration test performed in the HADES underground research facility situated in the plastic Boom clay layer at 220 m depth. The objective is to demonstrate the installation of a clay based backfill. The instrumentation was designed so that the observations can be used to validate the hydro-mechanical model coded in NOSAT developed by E. Alonso and A. Gens of the University of Catalunya, Spain. The backfill material consists of a mixture of high density (2.1 gm/cm^3), high swelling capacity (swelling pressure of 1 MPa) clay pellets and clay powder. It was deposited around a central filter. The swelling pressure crushed the pellets to give a small conductivity material. NOSTAT (still under development) is a finite element code for unsaturated media that allows simulation of excavation and construction sequences. It was found that hydration takes more time than predicted by the model, and stresses in the backfill are much lower than predicted. So, validation is difficult! It was found that boundary conditions and some of the input parameters were difficult to measure.

Constantine Onofrei: Hygro-thermal-mechanical Behavior of Clay. General definitions of terms accepted by scientists from various disciplines are as follows: System: "Sets of elements standing in interaction"; Model: "A set of rules and relationships that describe something is a model of that thing"; Simulation: "...the art of building mathematical models and the study of their properties in reference to those of the system." A system can generate a large number of models. A project called VALUCLAY to validate models that describe the unsaturated behavior of engineered clay barriers has been undertaken by the AECL. Coupled hygro-thermal-mechanical processes will be investigated. Four codes are currently being evaluated for this project which include porous, fractured media with various type of assumptions. Validation of such models is concerned with appropriateness and plausibility to solve practical problems. Model validity is a matter of degree, affected by the purpose for which the model was designed. Different aspects of validation (internal validity, event validity, hypothesis validity, and intersimulation validity) will be investigated. Only preliminary results from the COMPASS code are currently available.

P. Van Iseghern: Interaction between Glass and Clay. Experiments were conducted at Mol to study the performance of HLW glass in its interaction with clay. Inactive, doped, and active glasses were used. These experiments are part of a ten year program that will end in 1995. The experiments study the effect of medium (clay and corrosion products), temperature (40 to 190 C), surface area/volume ratios (10 to 10,000), Eh (negative to positive) and radiation field (0 to 100Gy/yr). Mass loss, solution pH, Eh, etc. are measured. The Grambow model for glass performance was tested. It was found that clay enhances the leaching rate (pumping effect of clay), long-term leaching rates were not found to be constant, and

dissolution rate was found to be not zero in SiO2 saturated solution. Dissolution was found to be discontinuous due to secondary phases. Long-term experiments have revealed information that will require changes in the modeling approach.

Ivar Neretnieks: Data from a Uranium Ore Body. There is a striking similarity between the uranium ore body at the Cigar lake and a repository. The ore is uranium oxide and it is surrounded on the top by a dense clay which has a much lower hydraulic conductivity than the surrounding rock. The near-field release models for the repository were used to calculate the dissolution rate of uranium and other species at Cigar lake. A large number of measurements on the water composition in and around the ore body have been made. The first water samples from the ore body contained high concentrations of helium, hydrogen, and sulphate. In modeling, the assumption was made that the first samples represented the steady-state concentration of helium in the undisturbed ore. Production of helium by alpha decay of uranium and thorium chains was then calculated. The results from a simple model compared very favorably with measurements.

H. Yoshida: Influence of Microscopic Heterogeneity on Diffusion. Data from a natural analog site (Tono) where a uranium deposit in granite basement is overlain by sedimentary rock was analyzed to study the effect of micro-heterogeneity on the dispersion phenomena. Uranium transport and retardation in and around the deposit was studied to conclude that the simple (Fickian) diffusion model was adequate. Field data however was not presented. Instead data from a laboratory experiment were discussed. The laboratory experiment consisted of dipping one end of a saturated sedimentary rock sample in a Uranium solution for 14 days. The rock sample was then sectioned to measure uranium diffusion. Due to grain-scale heterogeneities, the concentration profile did not fully match the Fickian model. The range of apparent diffusion coefficient was from 8×10^{-13} to 6×10^{-11} m^2/s. The effort will be to model transport by embedding random heterogeneities in the medium.

W.R. Alexander: Grimsel Migration Experiment. The Grimsel transport experiment is designed to demonstrate the applicability of a model and data bases to safety assessment. The fissures in the granitic rock are expected to communicate with the storage space in the matrix. Large velocities are expected to persist in the fractures. The Swiss, therefore, depends upon retardation—matrix and chemical—for demonstrating the safety of their concept. The model used for demonstration need not be "correct" but it has to be conservative. In the experiment, 8 boreholes were drilled in a 70 m long fracture zone. Strong flow channeling was found—70 percent of total flow was found to be in one narrow (2–10 cm wide) channel. A dipole experiment (inject in one hole and pump from the other) was also conducted in which all of the tracers were recovered. Transport was modelled by assuming advection in the narrow channel and diffusion in the neighboring matrix. A simple model assuming flow tubes was able to explain the experiment leading to the conclusion that transport in a fracture is well approximated by a homogeneous dual porosity advective-diffusive model, i.e., "matrix diffusion" is real. Extrapolation of laboratory sorption values to field conditions showed a coherent picture but special care should be exercised for such extrapolation.

S. Banwart: Redox Processes. Details of this presentation are available in a paper published in the Water Resources Research in June, 1994. The object of this experiment at Äspö was to study the effect of preclosure oxygen on corrosion of copper containers before resaturation occurs. This experiment was planned to be conducted during the construction of an access tunnel which crosses a fracture zone at a depth of 70 m (the Äspö laboratory is 450 m deep). The hypothesis was that enough atmospheric oxygen would flow through the fracture zone to change the redox conditions significantly prior to resaturation. However, in the experiment, no breakthrough of oxygen was observed. Instead of oxygen, organic carbon

from surface and increased microbiological activity was observed. This proved that the initial hypothesis was too pessimistic.

G. Backblom: Äspö Characterization Approach. SKB has constructed the Äspö hard rock laboratory to test various aspects of the Swedish approach to the disposal of HLW deep in saturated, fractured granitic rock. Prior to excavation of the Äspö laboratory extensive surface and borehole geologic investigations were conducted, and several detailed geologic models were constructed in order to predict the geologic conditions likely to be encountered as the tunnel progressed. The site characterization plan was based on four basic decisions: (i) division of the characterization and interpretation into distinct stages, (ii) devise models on several scales (regional scale greater than 1000 m, site scale 100–1000 m, block scale 10–100 m, and detailed scale 1–10 m), (iii) select key issues related to the geologic-structural model, groundwater flow, groundwater chemistry, transport of solutes, and mechanical stability, and (iv) integrate data collection and data interpretation. The basic goal of the "validation" exercise was to assess the ability to accurately predict the quality of the rock they would encounter during excavation so that they would know in advance what engineering measures, if any, would be required to strengthen the walls of the adit. They concluded that their ability to predict rock quality, particularly zones of densely fractured, fine-grained granite rock, in the Äspö lab was quite good. In addition their predictions of existence of saline water at depth were, in the presenter's opinion, quite good.

E. Fein: Flow around Asse Salt Anticline. The Asse salt anticline is the site of a former potash and rock salt mine located near Braunschweig in north central Germany. After mining was stopped, the mine was acquired by the Research Center for Environment and Health to conduct research on the safe disposal of radioactive waste and more than 125,000 canisters of low and medium level radioactive waste were emplaced between 1967 and 1978. An extensive array of 48 boreholes have been drilled to conduct pumping tests, and obtain water level and water chemistry data to characterize the hydrogeologic regime of the Asse anticline. Two flow models of the Asse site have been developed using the SWIFT code. These are a three dimensional model referred to as HYGAM1, and a two dimensional model referred to as HYGAM2. The presenter noted that because both models suffered from their inability to account for the effect of density variation due to salinity, and because as of yet they do not have enough data, validation exercises have not yet been attempted.

Panel Discussion for Second Day

On behalf of GEOVAL-94, Mr. Tom Nicholson (USNRC) presented Mr. Alf Larson (Kamakta Konsult AB, Sweden) a certificate of appreciation acknowledging his stewardship of the HYDROCOIN, INTRACOIN, and INTRAVAL projects.

Claudio Pescatore saw an insistence on modeling from first principles. He asked why the methods of empirical correlations commonly used in old days were not adequate any more. This was somewhat of a rhetorical question and nobody in the audience believed that purely empirical models will be acceptable in the repository licensing process. Question was also raised regarding the absence of error bars on experimental (and model generated) data.

J.P. Salo: Characterization and Tracer Tests at the TVO Tunnel. The TVO research tunnel at the VLJ repository in Finland is being used by both Finnish and Swedish researchers to test various construction and characterization methods that may be employed in the development of a HLW repository located in fractured granitic rock. The first portion of the presentation dealt with tests conducted to assess the utility of a new full-face boring method to excavate vertical emplacement holes. The second portion of the

presentation addressed the near-field geological and geophysical characterization conducted within the laboratory, with particular emphasis on the delineation of water bearing fractures.

A.J. Hooper: Zone of Excavation Disturbance Experiment at Äspö (ZEDEX). The excavation of the shafts and adits at a HLW disposal site will induce changes in the stress in the surrounding rock and may therefore affect the rock mass stability and hydraulic properties in the near-field in such a way as to provide preferential pathways for radionuclide transport. To address this issue ANDRA, Nirex and SKB have undertaken an experimental study at the Äspö hard rock laboratory to assess the accuracy of models used to predict these changes. The basic hypothesis is that the excavation disturbed zone (EDZ) in the near-field (< 2m) can be reduced by application of the proper excavation method (TBM or smooth blasting), but that far-field disturbances (> 2 m) are independent of the excavation method employed. The ZEDEX team has developed a detailed plan to measure the effects of excavation on: (i) acceleration, (ii) displacement, (iii) P-wave velocity, (iv) hydraulic conductivity, (v) natural and induced fracturing, (vi) temperature, (vii) acoustic energy release, and (viii) stress state. Testing is scheduled for completion by May 1995, with analysis of results complete by mid 1996.

R.L. Beauheim: Modeling and Experimental Work Related to Brine and Gas Flow at WIPP. Understanding the two-way coupling of brine inflow and gas generation at the WIPP site is essential for accurate assessment of the long-term performance of the repository. The presenter noted that increased brine inflow will accelerate the canister corrosion process, which will in turn increase the rate of hydrogen gas generation and gas pressure which will decrease brine inflow rates. However, the gas pressure may eventually exceed the brine pressure and gas will exit the repository. Beauheim noted that the type of relative gas-permeability function used in modeling had a very strong effect on the predicted performance of the repository. In particular, the Brooks-Corey and van Genuchten-Parker models predict vastly different gas migration rates in the dipping anhydrite beds.

O. Stephansson: The DECOVALEX Project. Stephansson gave a broad overview of the DECOVALEX project on the validation of coupled thermal, mechanical and hydrological models including brief descriptions of all Bench-Mark Tests (BMT) and Test Cases (TC) included in the project. The presenter gave a detailed overview of BMT-3 which is a synthetic experiment designed to test the abilities of models to predict the TMH behavior of a 2D vertical cross-section of a hypothetical heated repository that is located in a densely fractured rock. While most of the models gave similar results for the predicted vertical temperature profile, the predicted vertical distribution of horizontal stress and the estimated water flux history along a particular segment differed greatly among the various models. The next phase of the project will focus on one or two large-scale, underground in-situ experiments of coupled TMH processes in fractured rocks and buffer materials.

J.A.T. Smellie: Use of Natural Analogues in Radioactive Waste Disposal. Smellie discussed in very broad terms the potential use of natural analogs, particularly those in which a uranium ore body is located in a chemically reducing environment, in demonstrating the long-term ability of a HLW repository to safely contain spent fuel. Smellie described some of the uranium ore bodies around the world that are currently being studied by research teams as natural analogs. He stated that uranium deposits are not the only ore bodies that warrant study as natural analogs for spent fuel, noting that carbonatite deposits contain rare earth minerals that provide excellent analogs for the geochemical behavior of the actinides. Smellie gave an extensive list of processes important to PA that may be evaluated through the use of natural and anthropogenic analogs and identified the specific analog sites that could be used to evaluate specific environmental conditions.

P. Jackson: Model Testing and Site Characterization by Nirex. Peter Jackson substituting for A.J. Hooper gave a very broad overview of Nirex's HLW site characterization program in the UK at Sellafield in West Cumbria. Since site characterization began in 1989, various models for the geosphere have been proposed and then rejected as additional site data became available. By mid 1994, 18 deep boreholes had been completed at the Sellafield site to determine whether or not the properties of the basement rocks and the overlying sedimentary units were suitable for a repository. The greatest remaining uncertainties about the site are the hydrogeologic characteristics of the faults and the determination of the effective hydraulic conductivity of the fractured units. Early results have suggested that fracture network models produce the most accurate predictions of head at the Sellafield, however additional hydrogeologic investigations are planned, including a large scale pump test, to better determine the regional scale flow regime.

T. Papp: Coordinated Site Characterization and PA in Sweden. Tonis Papp presented a very broad overview of SKB's strategy for conducting performance assessments concurrent with site characterization. Papp noted that siting and design of a repository is an interactive process in which the gradual accumulation of information affects both the models used in PA and the continued direction of the characterization program.

B. Dverstorp: The SKI SITE-94 Approach to Analyzing Confidence in Site Specific Data. Bjorn Dverstorp gave an excellent presentation on SKI's most recent PA exercise which is based on the Äspö hard rock laboratory. One of the primary objectives of this PA exercise was to evaluate how site specific data should be used in PA, with particular emphasis on methods for incorporating uncertainty. A wide range of models of the site's geology, hydrogeology, geochemistry and geomechanical properties have been evaluated using simple scoping calculations, with particular emphasis paid to the effect of varying spatial scales. Considerable effort was devoted to developing detailed, 3D CAD-type models of the repository system with 3D descriptions of the geologic structure, and hydraulic and geochemical properties at the Äspö laboratory. The 3D model of the fracture system used data obtained from both borehole radar data and from traditional surface-based lineament analysis. Dverstorp noted that measured hydraulic conductivities turned out to be very poor indicators of the fracture networks which actually conducted the most flow. Both discrete fracture models and stochastic continuum models of flow through fractures were used in the PA with greatly different results. With the discrete models 80 percent of the canisters remain dry, while with the stochastic continuum model all canisters are located near high flow zones!

B. Sagar: NRC/SKI Position Paper on a PA Model Validation Strategy. The NRC/SKI validation strategy is based upon gradual building of confidence in models by using evidence from various sources. This strategy differentiates between the purely scientific and regulatory approaches for model validation. In the regulatory approach, the degree of validation has to be sufficient so that a regulatory decision can be made. Thus, a model does not have to explain all aspects of a natural phenomenon, only those that are important to safety, and that to the extent that performance has been allocated to that phenomenon. A total system model that can be shown to predict conservatively will be acceptable from a regulatory perspective. A model hierarchy with mechanistic process models at the bottom and abstracted total system models at the top, with subsystem models in the middle was described. The total system model has to be based on the more detailed process model but the total system model may not reproduce experimental results. Various steps in a validation strategy were described including recommendations on "good practices"

P. Davies: Evolution of Flow and Transport Models at WIPP. Peter Davies presented an excellent retrospective on 16 years of model development for conducting PAs for the WIPP site. The first regional

flow models of the WIPP site assumed that the highly conductive Culebra Dolomite overlying the Salado Formation was hydraulically isotropic and homogeneous at the scale of the controlled area. This simplified model was used primarily because few pump tests had been conducted in the Culebra, and thus the hydrogeologic framework had to be based almost exclusively on the site geology. During the second phase of site characterization the hydraulic conductivity within the Culebra Dolomite was found to vary over 8 orders of magnitude, with high conductivities confined to a distinct zone in the Culebra. The most recent 3D regional model uses lateral boundaries that coincide with structural or basin boundaries and incorporates the entire hydrostratigraphic column consisting of 10 units. For transport modeling it has been determined that the Culebra behaves as a double porosity system. A new series of convergent tracer tests will be conducted to better determine the transport characteristics of the Culebra.

Panel Discussion for Third Day.

Because the presentations took longer than planned, panel discussion for this day was cancelled.

C. McCombie: Moderator of General Panel Discussion on Fourth Day. McCombie began the general panel discussion by posing four questions to the audience and the panel members: (1) how confident are we in our conceptual models, (2) how defensible are our models, (3) what can we do to improve our level of validation, and (4) when will we have models good enough to support our decision making? Following McCombie, panel member S.P. Neuman gave a presentation which stressed the importance of accounting for the effect of scale dependence and the information content of site data in the construction of PA models. Neuman addressed the issue of abstracting simplified PA models from more detailed process models and as an example described the process of smoothing the stochastic advective transport equation to obtain the advection-dispersion equation in which the dispersive term reflects the lack of information about the velocity field. Jordi Bruno discussed what he believed to be the major model validation issues facing the geochemists. It appeared that Bruno was quite optimistic about the efforts being made by geochemists to test their codes against natural analog data, and he seemed particularly pleased by the blind predictive modeling efforts that had been made. Ghislain de Marsily presented a somewhat rambling review of progress made in the development and validation of transport models. De Marsily stated that many researchers believe that the process of matrix diffusion does indeed exist, but, as a counterpoint, he described chloride concentration profiles from a granite core extracted from a port in England that refute the theory of matrix diffusion. He suggested that issues still needing research include: fracture channeling, kakirites, surface/volume ratios and anion exclusion. Claudio Pescatore presented a somewhat cynical view of the efforts being made toward the validation of models for PA of repositories. It appeared that he believes that too much emphasis has been placed on the validation of geosphere transport models and far too little attention has been paid to developing and validating source term models. Pescatore does not think that we have any good analogs for spent fuel, and added that other radionuclides, such as iodine, need to be studied. Pescatore noted that no new fundamental processes have been observed in these studies, an outcome which he appears to feel bodes well for validation efforts. Pescatore concluded that we can never expect to achieve full validation. Validation efforts may cease when the regulator says "enough."

Following the panel discussion an open discussion was conducted which was again moderated by Charles McCombie. Jorge Haderman opened the discussion by warning that we must distinguish between having confidence in the existence and understanding of specific processes, and having confidence in the parameters required to describe the process. S.P. Neuman concurred with Haderman noting that no one argues that certain processes do not take place. Neuman added that the issue of greatest concern is the accurate description of the area over which these processes take place. Tonis Papp emphasized that PA

must be used for decision making during repository construction and not solely for making the licensing decision. Papp noted that confidence in the repository will be gained in small "chunks." Peter Jackson suggested that confidence may not always increase monotonically. Confidence in a site or a model may be lost when certain data are obtained. Johan Andersson addressed various issues of PA modeling and validation noting that we must continue to go forward in our efforts all the while being careful to avoid making promises that we cannot keep. Andersson stressed that we must be aware of the political system. We must maintain trust with the public; we need to be humble and be forthright in admitting that there are technical areas where we do not have confidence. Budhi Sagar expressed his views on the degree of validity that would be required at various discrete stages of the repository licensing process. He identified three stages: authorization to begin construction, permission to receive waste, and authorization for closure. Conceptually, the final validation has to occur at the time a decision is made to close the repository. A lower degree of validity could be acceptable in the earlier two periods. Tom Nicholson stressed the need to carefully design future experiments so the processes of interest are actually observed. Nicholson concluded by asking the audience to try to determine what fundamental processes need to be studied over the next ten years. Chin Fu Tsang stated that while we have made progress in quantifying and incorporating uncertainty in parameters, we have made little progress in addressing event and model uncertainty. Tsang noted that the public is used to dealing with uncertainty and therefore we should not avoid telling the public about the uncertainties associated with HLW disposal. C. McCombie noted that he does see progress in these efforts, particularly with regard to the additional testing and data gathering that has been completed. Claudio Pescatore ended the meeting and concluded that the meeting went quite well.

IMPRESSIONS/CONCLUSIONS:

Most presenters needed more time for their presentations than the allotted time. Therefore, there was not enough time for questions after presentations. In the panel discussions, most of the time was taken by panel members in presenting their views rather than encouraging debate among the participants. Consequently, most of the discussion occurred during coffee breaks and at lunch.

Several of the participants expressed the opinion that the time for a repository-related decisions (site selection, construction) was getting close in many countries. Therefore, practical and pragmatic solutions to thorny problems like model validation were needed.

A side meeting on the new NEA/SKI initiative GEOTRAP was also attended. The DOE delegates (Yucca Mountain and WIPP) participated along with the NRC. It was tentatively agreed that participation in the next GEOTRAP workshop in Cologne in April would be useful. Mr. Eric Smistad (DOE-Yucca Mountain) was asked to check if DOE would release data which could be analyzed under the aegis of GEOTRAP. If that was possible then the DOE will present this data at the workshop while the NRC will discuss the type of problems that should form a part of the GEOTRAP. Mr. Smistad would let us know after checking back with his organization.

PROBLEMS ENCOUNTERED:

No problems were encountered.

RECOMMENDATIONS:

The joint NRC/SKI paper should be finalized and thought should be given to developing a Staff Technical Position.

PENDING ACTION:

Revision of the NRC/SKI joint paper.

SIGNATURES:

Budhi Sagar — 11/7/94 Date

Gordon Wittmeyer — 11/7/94 Date

CONCURRENCE:

R.G. Baca — 11/7/94 Date

W. Patrick — 11/7/94 Date

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ATTACHMENT 1

AGENDA

GEOVAL '94

An international symposium on
validation through model testing with experiments

Paris, France
11-14 October 1994

FINAL PROGRAMME

Organised jointly

by

the OECD Nuclear Energy Agency (NEA)

and

the Swedish Nuclear Power Inspectorate (SKI)

Objectives and Structure of the Symposium

Following the successful GEOVAL symposia of 1986 and 1990, the Nuclear Energy Agency (NEA) of the OECD and the Swedish Nuclear Power Inspectorate (SKI) have organised GEOVAL '94.

GEOVAL '94 is articulated into six sessions and a common theme: *validation through model testing with experiments.* Session 1 will set the scene by reviewing the advancement of the state-of-the-art in the field of validation during the past few years. The new information will come from Session 2, devoted to INTRAVAL, and from sessions 3 to 6. Sessions 3, 4, and 5 will focus on the lesson learned or being learned within integrated experimental studies, including results from underground research laboratories. Session 6 will focus on strategic approaches for including validation in the planning for siting, design, and licensing of deep geologic repositories for long-lived radioactive wastes. The detailed programme of each session is presented in the attached symposium schedule.

At the end of each day a panel of experts will assess, with the help of the audience, the new information which are provided in the papers presented at the symposium. The same panel of experts will convene in plenary session the final day of the meeting to debate with the audience the main issues which have been identified.

In order to favour a fruitful discussion of the main issues at hand, the Programme Committee has asked all speakers to address the following questions:

1. how do they assess success? whether it is practical or worthwhile to improve success? to what extent a judgement of success takes into account information other than model testing?

2. how was the design planned and the experiment analyzed?

3. what models were tested? how were they tested with experiments? and whether alternative conceptual models were tested and assessed?

4. how were different disciplines integrated?

5. where did the greatest difficulties lie: interpretation, design, performance?...

Composition of the Discussion Panel

The discussion panel will be chaired by Mr. C. McCombie. The other members of the panel are: J. Andersson, J. Bruno, M. Federline, A.J. Hooper, G. de Marsily, S. Neuman, O. Olsson, C. Pescatore, and H. Röthemeyer.

Programme Committee

The symposium has been organised by a Programme Committee composed of J. Andersson, T. Äikäs, C. Pescatore, and C.F. Tsang.

Location of the Symposium

The symposium will take place 11-14 October 1994, in Room 1 of the OECD Headquarters, 2 Rue André-Pascal, 75016 Paris.

Participation to the Symposium

Participation to the symposium is open to all representatives to the NEA committees and working groups, the former INTRAVAL community, as well as other representatives from NEA's Member countries provided the latter are designated officially by their own authorities. A small number of participants from non-OECD countries will be accepted on an ad-hoc basis. However, for logistical reasons, the attendance will be limited to 180 persons, say, and prior acknowledgement by the NEA will be required in order to be admitted to the OECD Château. Thus all potential participants are advised to contact the NEA Secretariat well in advance of the symposium. All requests for participation should be sent to:

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France

Fax: +33 (1) 45 24 11 10

Accommodation in Paris

Accommodations in Paris are the direct responsibility of each symposium participant. To that effect, a list of hotels in the general area of the OECD headquarters is also attached.

Symposium Proceedings

The proceedings of the symposium will be published jointly by SKI and the NEA. They will include the contributed papers by the speakers and a transcript of the special session held with the discussion panel on the fourth day of the meeting.

TUESDAY, 11 OCTOBER 1994 (Morning)

Time	Activity	Speaker/Author(s)	Title
9:30	**Welcome Address from Sponsoring Organisations**	K. Uematsu, OECD/NEA S. Norrby, SKI J.-P. Olivier, OECD/NEA	
	SESSION 1		
	Chair: *T. Äikäs*		
9:50		J. Andersson	Objectives and Scope of GEOVAL '94
10:10		C. Pescatore	Validation: An Overview of Definitions
10:30		C.-F. Tsang	Validation and Technical Issues at GEOVAL '94
10:50		P. Zuidema, C. McCombie, I.G. McKinley, P. Smith	Validation: Demonstration of Disposal Safety Requires a Practicable Approach
11:10	**Coffee Break**		
	SESSION 2		
	Chair: *A. Larsson, L. Dewiere*		
11:30		N. Chapman et al.	Developing Groundwater Flow and Transport Models for Radioactive Waste Disposal - Six Years of Experience from the INTRAVAL Project
12:00		T.J. Nicholson, R. Hills, M. Rockhold, G. Wittmeyer, T.C. Rasmussen	Conclusions from WG-1: Partially-Saturated Porous & Fractured Media Test Cases - Las Cruces Trench & Apache Leap Tuff Studies
12:20	**Lunch**		

TUESDAY, 11 OCTOBER 1994 (Afternoon)

Time	Activity	Speaker/Author(s)	Title
	SESSION 2 (Continued)		
	Chair: *A. Larsson, L. Dewiere*		
14:30		P. Andersson, A. Winberg	Conclusions from WG-2: The Analyses of the Finnsjön Experiments
14:50		C.P. Jackson	Conclusions from WG-2: The Analyses of the WIPP-2 Experiments
15:10		P. Bogorinski	Conclusions from INTRAVAL WG-3: Salt- and Clay-Related Cases
15:40		K. Skagius, L. Birgersson	Conclusions from WG-4: The Analyses of the Alligator Rivers Natural Analogue
16:10	**Coffee Break**		
16:30	**DISCUSSION PANEL**		
	Chair: *C. McCombie*	Panel Members	
17:45	**Adjourn**		
18:00	**RECEPTION**		

WEDNESDAY, 12 OCTOBER 1994 (Morning)

Time	Activity	Speaker/Author(s)	Title
	SESSION 3 ***Chair:*** *H. Umeki, J.-C. Petit*		
9:30		J. Ortiz, G. Volckaert, M. Put, M. Impey	The MEGAS E5 Experiment: A Large Scale 3-D In-Situ Gas Injection Experiment for Model Validation
10:00		G. Volckaert, F. Bernier, E. Alonso, A. Gens, M. Dardaine	BACCHUS 2: An In Situ Backfill Hydration Experiment for Model Validation
10:30		C. Onofrei	Modelling Hygro-Thermo-Mechanical Behaviour of Engineered Clay Barriers - Validation Phase
11:00	**Coffee Break**		
11:30		P. Van Iseghem, K. Lemmens, M. Aertsens, M. Put	Interaction Between HLW Glass and Clay: Experiments Versus Model
12:00		J. Liu, I. Neretnieks	Data from a Uranium Ore Body on Release of Dissolved Species: Comparison With a Near Field Release Model
12:30	**Lunch**		

WEDNESDAY, 12 OCTOBER 1994 (Afternoon)

Time	Activity	Speaker/Author(s)	Title
	SESSION 4		
	Chair: *T. Papp, C. del Olmo*		
14:10		H. Yoshida	Confidence Building on the Conceptual Model for Nuclide Migration in Sedimentary Rocks
14:40		W.R. Alexander, U. Frick, I.G. McKinley, C. McCombie, B. Frieg, W. Heer, J. Hadermann, E. Hoehn, T. Fierz	The Grimsel Radionuclide Migration Experiment: A Contribution to Raising Confidence in the Performance of Safety Assessment Models
15:10		S. Banwart, P. Wikberg	Redox Processes in Disturbed Groundwater Systems: Conclusions from an Äspö-HRL Study
15:40	**Coffee Break**		
16:00		G. Bäckblom, G. Gustafson, I. Rhén, R. Stanfors, P. Wikberg	Results and Experiences from the Äspö HRL Characterization Approach
16:30		E. Fein, K. Klarr, C. v. Stempel	Flow and Transport Around the Asse Salt Anticline
17:00	**DISCUSSION PANEL**		
	Chair: *C. McCombie*	Panel Members	
18:00	**Adjourn**		

THURSDAY, 13 OCTOBER 1994 (Morning)

Time	Activity	Speaker/Author(s)	Title
	SESSION 5		
	Chair: *B. Vignal, A. Van Luik*		
9:00		J.-P. Salo, J. Autio, E. Johansson, A. Öhberg, A. Hautojärvi, T. Vieno	Characterization and Tracer Tests in the Full-Scale Deposition Holes in the TVO Research Tunnel
9:30		A.J. Hooper, O. Olsson	Joint ANDRA/Nirex/SKB Zone of Excavation Disturbance Experiment (ZEDEX) at the Äspö Hard Rock Laboratory
10:00		R.L. Beauheim, S.M. Howarth, P. Vaughn, S.W. Webb, K.W. Larson	Integrated Modeling and Experimental Programs to Predict Brine and Gas Flow at the Waste Isolation Pilot Plant
10:30		O. Stephansson, L. Jing, C.-F. Tsang, F. Kautsky	Development of Coupled Models and Their Validation Against Experiments - DECOVALEX Project
11:00	**Coffee Break**		
11:20		J.A.T. Smellie, F. Karlsson, B. Grundfelt	The Potential Use of Natural Analogues Studies in Radioactive Waste Disposal: A Review
11:50	**Lunch**		

THURSDAY, 13 OCTOBER 1994 (Afternoon)

Time	Activity	Speaker/Author(s)	Title
	SESSION 6 ***Chair:*** *A.G. Duncan* *J. Vigfusson*		
14:00		A.J. Hooper	The Approach to Model Testing and Site Characterisation Studies Undertaken by United Kingdom Nirex, Ltd.
14:20		T. Papp, L.O. Ericsson	Coordinated Site Characterization and Performance Assessment - An Iterative Approach for the Site Evaluation
14:40		B. Dverstorp, J. Andersson	The SKI SITE-94 Project Approach to Analysing Confidence in Site-Specific Data
15:00		M. Federline, J. Andersson	The NRC/SKI Position Paper on Validation Strategy
15:20		P. Davies, T. Corbet	Evolution of Flow and Transport Conceptual Models at the Waste Isolation Pilot Plant, 1978 to 1994
15:40	**Coffee Break**		

THURSDAY, 13 OCTOBER 1994 (Afternoon) [Continued]

Time	Activity	Speaker/Author(s)	Title
16:00		P. Bogorinski, K. Schelkes, R. Storck, J. Wollrath	Validation Strategies for Licensing Nuclear Waste Repositories in Salt Formations in Germany
16:20		K.W. Dormuth, A.G. Wikjord	Evaluation of Canadian Performance Assessment Models for Deep Geological Disposal of Nuclear Fuel Wastes
16:40		E. Smistad, A. Van Luik	Providing a Technical Basis for Flow and Transport Modeling in the Yucca Mountain Site Characterization Project
17:00	**DISCUSSION PANEL** ***Chairman:*** *C. McCombie*	Panel Members	
18:00	**Adjourn**		

FRIDAY, 14 OCTOBER 1994 (Morning)		
Time	Activity	Panel Members
9:30	**DISCUSSION PANEL** ***Chair:*** *C. McCombie*	C. McCombie, J. Andersson, J. Bruno, M. Federline, A.J. Hooper, G. de Marsily, S. Neuman, O. Olsson, C. Pescatore, H. Röthemeyer
12:00	**Closure of the Symposium**	

ATTACHMENT 2

ATTENDANCE LIST

13-Oct-1994

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(11-14 October 1994)

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ATTACHMENT 3

ABSTRACTS

GEOVAL '94

Abstracts received

Paris, France

11-14 October 1994

SESSION 1

Objectives and scope of GEOVAL-94

Johan Anderson
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In many countries the ongoing programmes to site and construct deep geological repositories for high and intermediate level nuclear waste are closer to realization compared to the situation four years ago. A number of studies, including the international INTRAVAL-project demonstrate the potential barrier function of the geosphere, but also that there are many unresolved issues, some of which may never be resolved. It is now high time to identify which issues that indeed are resolved and to develop schemes for handling of the unresolved ones. A key to these problems are the possibilities to gain knowledge by Model Testing with Experiments and this is also the theme of GEOVAL-94. GEOVAL-94 will review the state-of-the-art where model testing with experiments have been specifically aimed at increasing confidence in models used for prediction the performance of the geosphere in a deep repository. The sessions cover conclusions from the INTRAVAL-project, experiences from integrated experimental programs and underground research laboratories as well as the integration between performance assessment and site characterisation. Technical issues ranging from waste and buffer interactions with the rock to radionuclide migration in different geological media will be addressed. The different contributions will all be evaluated with the following questions in mind: How to assess results? How to plan experimental designand analysis of results? Are all sensible alternative conceptual models tested? Is it enough integration of different disciplines? Where are the difficulties? A discussion panel will conclude the symposium.

VALIDATION: ON OVERVIEW OF DEFINITIONS

C. Pescatore

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The term "validation" features prominently in the HLW disposal literature and it is generally associated with model testing with observational data. There exists however no unique definition of "validation". Some definitions are strictly operational and associate validation to split-sampling or to blind-tests predictions. In that view the decision to retain a predictive model for use in safety assessments does not belong to the remit of "validation". Other definitions focus instead on the quality of the decision-making process, but unfornately they cannot indicate when a model is actually "validated". The stress on the decision-making process for retaining a model shifts the debate from validation in the observational sense to that on reasonable assurance and confidence building, which tends to blurr the meaning of "validation". The paper reviews the several definitions of "validation" as they have been introducdd and used in the allied fields. Most prominent from this review is the lack of usage of this term in the field of LLW disposal and, more in general, during the first half of this century, i.e., at a time when great adances in science were taking place and deep debates were raging on the meaning of the new discoveries and the reach of the scientific method.

Overview Talk for
GEOVAL-94, Paris
October 1994

VALIDATION AND TECHNICAL ISSUES AT GEOVAL-90

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Abstract

The outstanding issues on model validation and on various scientific and technical problems at the time of GEOVAL-90 are identified and reviewed. Comments are made of the importance of these issues on the safety assessment of nuclear waste geologic disposal. Significant progress has been made on a number of these issues, while much work is still needed on the others. Directions for further work since GEOVAL-90 will also be discussed.

DRAFT

Preliminary and incomplete draft

GEOVAL '94 (Paris, 11-14 October 1994)

Validation: Demonstration of Disposal Safety Requires a Practicable Approach

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Abstract

In the first part of this paper the term 'validation' is briefly discussed and a very pragmatic definiton is provided, taking into account the nature of performance assessment. In the second part of the paper the questions 'what to validate?', 'how to validate?' and 'when to validate?' are briefly discussed and some preliminary ideas are presented. Finally, the third part of the paper contains a summary and some provoking conclusions which hopefully will provide some material for discussion during the meeting.

SESSION 2

Developing Groundwater Flow and Transport Models for Radioactive Waste Disposal
- Six years of experience from the INTRAVAL Project -

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Abstract

Central to the issue of credibility in performance assessment is that of the validity of the information and the models used to make predictions. Owing to the large time and space scales involved in natural systems, both the users of models, and the regulatory agencies who must respond to model predictions, have felt the need for some means of demonstrating belief in their 'fitness for purpose', and that their quantitative output is meaningful. The INTRAVAL project was set up to bring together those working on this issue in many countries; to share experience, to carry out comparison exercises and to help build an internationally accepted approach to developing and applying both the models and the approach to prediction. During the six-year life of the project the philosophical appreciation of 'validation' in radioactive waste disposal has developed considerably.

This paper first comments briefly on the recent debate on the validation of groundwater flow and transport models and then outlines the methodology adopted to evaluating the 18 different test cases of Phase 1 and 2 of INTRAVAL, with summaries of the specific objectives of each. The test cases include hard fractured rock, plastic clay, mixed sedimentary and unsaturated geological environments at many scales, with observations and interpretations on a very wide range of timescales. The overall, rather than the detailed, findings of INTRAVAL are summarised. Lessons have been learned in analysing experimental data and in building confidence and quantifying uncertainties in models used for making predictions in performance assessment. It is hoped that these can find applications in many waste disposal programmes.

INTRAVAL explored a wealth of geological data from sites in four continents. The great strength of the project was that modelling was tested by multiple groups against real data, at a relatively dense observational scale, using all the information available. In addition, the project integrated exercises in both field and laboratory, at a variety of spatial scales. Particularly instructive information came from field tests which illustrated the real problems of using data from natural systems. Although there were ambitious objectives for some test cases, throughout the project we were constantly learning what was possible and what was simply unachievable. These lessons should have considerable impact on the incorporation of repository site data into safety assessment.

Conclusions from Working Group 1: Partially-Saturated Porous & Fractured Media Test Cases Las Cruces Trench & Apache Leap Tuff Studies

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Abstract

Two INTRAVAL test case studies that focused on evaluation of flow and contaminant transport models for unsaturated, heterogeneous (1) porous soils, and (2) fractured rock were the Las Cruces Trench, and Apache Leap Tuff experiments, respectively. The Las Cruces Trench (LCT) experiments were specifically designed to test various uniform, and heterogeneous soil flow and transport models. Experimental data from the first two LCT experiments, and detailed field characterization studies provided information for developing and calibrating the models. Experimental results from the third experiment were held confidential from the modelers, and were used for model comparison. Comparative analyses included: point comparisons of water content; predicted mean behavior for water flow; point comparisons of solute concentrations; and predicted mean behavior for tritium transport. These analyses indicated that no model, whether uniform or heterogeneous, proved superior. Since the INTRAVAL study, however, a new model which conditioned the hydraulic properties using initial field-measured water contents, and depth-averaged initial tension profiles produced reasonably accurate matches to the flow and transport field observations. The Apache Leap Tuff (ALT) experiments were designed to evaluate characterization methods and their associated conceptual models for coupled matrix-fracture continua over a range of scales (i.e., 2.5 centimeter rock samples; 10 centimeter cores; 1 meter block; and 30 meter boreholes). Within these spatial scales, laboratory and field tests were conducted for estimating pneumatic, thermal, hydraulic, and transport property values for different conceptual models. The analyses included testing of current conceptual, mathematical and physical models using the ALT characterization data. Conclusions drawn were: (1) wetting history has a significant influence on formulating the characteristic curve; (2) thermal conductivity is only poorly related in a linear fashion to water content; (3) the accumulation of saturated salt solutions will control the ambient matric potential observed under nonisothermal conditions; and (3) the fracture saturation behind the wetting front initially is very low, perhaps ten percent, but increases to complete saturation during the course of the block wetting experiment contrary to the modeling results which overestimated the fracture imbibition volume by a factor of twenty, and the fracture wetting front advance by a factor of eight. Both the LCT and ALT studies demonstrated the value of field experiments and field experimentalists in helping to define and test unsaturated flow and transport models.

Conclusions from WG-2 : The Analyses of the Finnsjön Experiments

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(Sweden)

Abstract

A comprehensive series of tracer tests on a relatively large scale have been performed by SKB at Finnsjön, Sweden, to increase understanding of transport phenomena which govern migration of radionuclides in major fracture zones. The experimental sequence of tracer tests consisted of; a preliminary tracer test during hydraulic interference tests, a radially converging test and a dipole test. Both sorbing and slightly sorbing tracers were used. The conducted experiments were subsequently selected as a test case for the international INTRAVAL Project, partly because the tests performed at Finnsjön invite to direct address of validation of geosphere models. Work on the Finnsjön test case during Phase 1 of INTRAVAL involved 10 models ranging from advection-dispersion approaches to more complex fracture network approaches. A main conclusion from this phase was that tracer test data from one or two tests at a given site are not sufficient to discriminate between models and active processes. The Phase 2 studies, which involved nine project teams from seven countries, are dominated by porous media approaches in two dimensions, although some project teams utilized one-dimensional and even three-dimensional approaches on a larger scale. The dimensionality employed did not appear to be decisive for the ability to reproduce field responses. It was also demonstrated that stochastic approaches can be used in a validation process. The general conclusion is that flow and transport in the studied fracture zone is governed by advection and that hydrodynamic dispersion is needed to explain the breakthrough curves. Matrix diffusion is assumed to have a small or negligible effect. A variety of validation aspects have been considered. Five teams utilized a model calibrated on one test, to predict another, whereas two teams using the stochastic continuum approach addressed; 1) validity of extrapolating a model calibrated on one transport scale to a larger scale, 2) performance assessment implications of choice of underlying distribution model for hydraulic conductivity, respectively. As a final exercise to assess and illustrate differences in predictive capability between models, a synthetic natural gradient tracer test case was conceived and addressed by some of the modelling teams. The purpose not being to select the best model but rather to quantify the uncertainty associated with alternative calibrated models used to describe the Finnsjön tracer tests when extrapolated to larger transport scales.

Conclusions from Working Group 2 - The Analyses of the WIPP-2 Experiments

C P Jackson
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Abstract

The INTRAVAL WIPP-2 test case is based on data from site investigations carried out at the Waste Isolation Pilot Plant (WIPP) in New Mexico, USA. The site has been chosen as a potential location for a radioactive waste repository. Extensive investigations have been carried out, focused mainly on groundwater flow and transport in the Culebra Dolomite. This is a thin formation extending for many kilometres, which is considered to form the main pathway for transport of radionuclides off the site by groundwater, following an accidental borehole intrusion into the repository itself.

Five INTRAVAL project teams studied the test case. Two teams addressed issues involved in the treatment of heterogeneity. Stochastic models and a Monte Carlo approach were used. Many realizations of the transmissivity of the Culebra were generated with distributions inferred from the data. The groundwater flow and pathlines were calculated for each realization. The uncertainties in predicted quantities of interest were quantified from the range of behaviours of the realizations.

One team quantified the increased uncertainty resulting from fewer data, and explored the issues involved in validation of stochastic models. They recommended a statistical-hypothesis-testing approach, and showed that the differences between some models and the data were statistically significant. The second team developed a new method for conditioning stochastic models on head data, that is generating realizations in which the calculated head matches observations. This team also stressed the need to consider non-Gaussian stochastic models of the heterogeneity.

Two other teams examined issues relating to the choice of conceptual models. Two-dimensional vertical cross-section models were used to explore the importance of vertical flow between the Culebra and overlying formations. A three-dimensional model was also developed. The fifth team advocate the use of a variety of models, including simple scoping and bounding calculations to highlight the most important processes and parameters. On the basis of bounding calculations the team concluded that the distribution of transmissivity was the most important influence on the groundwater flow in the Culebra, and the uncertainties in the salinity were less important.

Overall, the test case provided a valuable opportunity for the INTRAVAL participants to explore the issues involved in validation of field-scale models of groundwater flow and transport using the sort of data that would result from a typical site investigation, and the test case was a strong stimulus to the study and development within INTRAVAL of methods for dealing with heterogeneity.

Conclusions from INTRAVAL Working Group 3: Salt- and Clay-Related Cases

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Abstract

In a number of countries sedimentary rocks, either evaporites, namely bedded salt or salt domes, or clays, are considered to host a nuclear waste repository. The isolation potential of those formations relies mainly on the very low velocities of moving groundwater. In safety assessments the relevant question to be answered is: Which transport mechanisms determine migration of radionuclides and which laws govern those processes? The three test cases defined for INTRAVAL working group 3 to answer this question dealt with the relevant phenomena in the host formation as well as in the overburden.

The WIPP 1 test case studied the flow of brine from a bedded salt formation into open excavations under pressure gradients. Experiments carried out at different scales at the Waste Isolation Pilot Plant in New Mexico, USA were carefully analysed and compared to numerical simulations. It could be concluded from the results that brine movement through the formation can be described with Darcy's law. However, only anhydrite and impure halite containing clay inclusions constitute the main flow paths. The very low permeability of pure halite limits the supply of brine.

The transport of salt leached from a salt dome through an aquifer system and its influence on the flow field by density were studied in the **Gorleben** test case. Measurements from a pumping test and measurements of salt content with depth collected at boreholes throughout the investigation area of the potential repository site at Gorleben, Germany, were compared with the results of analytical and numerical studies. The pumping test could be easily analysed but it failed to show density effects on the flow field. However, it revealed the heterogeneity and anisotropy of the system. Simulations of the regional scale groundwater system in the Gorleben erosion channel concentrated on a two-dimensional cross-section along the channel axis due to the tremendous computer resources needed to carry out a full three-dimensional analysis. This made the comparison to the measured data difficult. Nevertheless, the results demonstrated, that flow is slowed down in regions with high salt contentrations due to density effects.

The Mol test case studied the main transport mechanisms of solutes through clay. Experiments with radioactive tracers were carried out for several years at the Mol underground laboratory, Belgium. The measurements were compared to numerical simulations. The results revealed that advective transport can be neglected and molecular diffusion is the relevant process to describe the migration of radionuclides within this formation.

Neither of the test cases involved validation in its true scientific sense. However, despite all limitations the analyses served the purpose to build confidence in the models applied.

Conclusions from WG-4: The Analyses of the Alligator Rivers Natural Analogue

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Abstract

The Alligator Rivers study is based on work conducted at the Koongarra uranium deposit in the Alligator Rivers Region about 200 km east of Darwin, Australia. The Alligator Rivers Analogue Project (ARAP) was set up in 1987 and was later included as a test case in both Phase 1 and 2 of INTRAVAL. The objective was to develop a consistent picture of the processes that have controlled the transport in the weathered zone of the Koongarra ore deposit and the time scale over which they have operated.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies. The main ore body has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists and 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 primary orebody at Koongarra is estimated to be 10^9 years old and geomorphological information indicates that weathering started a few million years ago.

The work included in INTRAVAL Phase 1 was mainly concentrated to hydrogeological and geochemical modelling which produced results which in INTRAVAL Phase 2 were used in modelling simulations of the uranium migration. The model concepts applied in the migration modelling were based on rather simple performance assessment models accounting for advection, dispersion and linear sorption in one or two dimensions. One 1-D was model extended to include α-recoil and transfer between solid phases. The vertical movement of the weathering front was included in the 2-D model.

The Alligator Rivers Natural Analogue has proven to be a complex system. The interplay of many geochemical and geohydrological processes occurring over large time scales makes it a difficult task to construct a quantitative model of the history of groundwater flow and nuclide transport. The study has shown that in order to get a consistent picture of the evolution of the site, joint interpretation of different types of data and an iterative procedure for data collection, data interpretation and modelling are important. Furthermore it was shown that sorption is an important retardation mechanism, that uranium fixation in crystalline phases is a potentially important retardation mechanism in geologic media where significant alteration of the rock is expected and that α-recoil may have an impact on the distribution of uranium isotopes in the water. The modelling simulations indicated migration times which were in fair agreement with independent geomorphological information. A general conclusion from the study is that rather simple and robust concepts and models seem able to describe the long range migration processes adequately. On the other hand, for more detailed modelling and attainment of comprehensive understanding geochemical processes will have to be addressed more carefully.

SESSION 3

The MEGAS E5 Experiment: A Large Scale 3-D In Situ Gas Injection Experiment for Model Validation

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Abstract

For the option of a deep geological disposal facility, several potential sources of gases were identified: i.e. the anaerobic corrosion of iron, degradation of organic materials, the gas present as such in the waste packages. Of those gases, hydrogen is certainly the gas which can be released in the potentially largest amounts. For the safety evaluation of a repository, it is necessary to know the effects of gases on the host rocks.

The primary objective of the MEGAS project is to understand the consequences of gas generation in a clay host rock. The final objective of this project will be to validate a gas migration model and to confirm our understanding using the MEGAS E5 in situ gas injection experiment.

The MEGAS E5 experiment consists of four multi-piezometers in 1992 installed in the Boom clay formation from the HADES underground research facility. The multi piezometers were installed in a 3-D configuration. A central piezometer is used for the gas injection, while the other piezometers are used to measure the pressure variation caused by the gas injection.

Before the start of the gas injection, hydraulic testing was performed to determine the mean hydraulic parameters in the Boom clay surrounding the piezometers. The results and modelling of this hydraulic testing will be presented.

For the modelling of the two phase flow, INTERA has developed the TOPAZ code. The physical and numerical basis of the TOPAZ code will be explained.

The results of the gas injection test will be presented and compared to the blind predictions made by INTERA using the TOPAZ code.

BACCHUS 2: An In Situ Backfill Hydration Experiment for Model Validation

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M. Dardaine
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Abstract

The BACCHUS 2 experiment is an in situ backfill hydration test performed in the HADES underground research facility. The experiment aims at the optimization and demonstration of an installation procedure for a clay based backfill material. The instrumentation has been optimized in such a way that the results of the experiments can be used for the validation of the hydro-mechanical code NOSAT developed by E. Alonso and A. Gens of the University of Catalunya Spain (UPC).

The experimental set-up consists in a bottom flange and a central filter around which the backfill material was applied. The backfill material consist of a mixture of high density clay pellets and clay powder. The experimental set-up and its instrumentation are described in detail. The results of the hydro-mechanical characterization of the backfill material is summarized.

The physical and numerical basis of the NOSAT is described together with the main model assumptions and the data used for the blind predictions.

The evolution of the stresses, the strain and the degree of saturation in the backfill as obtained from the NOSAT code are compared with the first results of the in situ test. The importance of the model parameters and assumptions will be discussed.

Modelling Hygro-Thermo-Mechanical Behaviour of Engineered Clay Barriers - Validation Phase.

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ABSTRACT

The Canadian Nuclear Fuel Waste Management Program (CNFWMP) is evaluating the concept of disposal of nuclear fuel waste in an engineered vault at a depth of 500 to 1000 m in plutonic rocks of the Canadian Shield. In common with engineered barrier system designs being developed in other countries, the waste would be contained within durable containers which, in turn, would be isolated from the host rock by clay-based materials.

The CNFWMP objective is to develop a disposal concept that will meet the risk criterion of the Atomic Energy Control Board. Assessments of the conceptual vault designs are based on system theory in which an attempt is made to correlate experiences with theoretical concepts of perceived systems in such a way that the resulting coordination is sound and convincing. By necessity, since experiments with a total disposal system can never be performed, both the design and the performance assessment rely on experiments performed on physical models of vault elements and on information inferred from calculation (mathematical models) that simulate the probable behaviour of the system in the space-time domain of interest. For a simulation model to be successful, that is used within a real world situation, it must provide information regarding the behaviour of the system of interest that is clearly better, in some way, than the mental image or other abstracted model which would be used instead. The results of a series of tests performed within the activity known as validation serve as tangible evidence regarding the success of a model in representing the system of interest.

This paper focusses on the validation of the models that describe the hygro-thermo-mechanical behaviour of the engineered clay-barriers proposed for application in the Canadian disposal system concept. The strategy being used to address the key issues in modelling to minimize the model error and to maximize the usefulness of the simulation model, based on testing procedures, is reviewed. Finally, a project initiated within the CNFWMP, dedicated to the VALidation of codes/models that describe the Unsaturated behaviour of engineered CLAY barriers (the *VALUCLAY* Project) is described.

INTERACTION BETWEEN HLW GLASS AND CLAY: EXPERIMENTS VERSUS MODEL

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Abstract

The evaluation of the long-term interaction and performance of waste glass with/in Boom clay disposal surroundings is done both by experiments and modelling. An experimental programme has been started early 80's, to investigate the interaction between glass and clay media. Special attention was given to the role of various parameters, such as temperature, time, redox condition, radiation, clay concentration, the presence of additional solids (canister corrosion products and backfill), test geometry. The tests showed a.o. that different mechanisms (diffusion controlled leaching, matrix dissolution, phase formation in solution and on the glass surface, sorption on the clay) occurred, both simultaneously and sequentially. In-situ tests in the underground laboratory of the SCK•CEN were carried out to validate the laboratory tests.

Recently a programme has been started, to model the interaction between waste glass and the geological disposal media, including the following steps:

- mechanistic modelling of the tests carried out so far;
- application of geomechanical codes, to identify phases possibly formed in the leachate;
- mathematical modelling of the interaction glass - clay media.

The modelling will first consider the system glass + pure water, followed by the system glass + claywater and glass + claywater + clay. Supplementary tests may be carried out to determine particular parameters required for modelling. For instance, the transport parameters of silicon through Boom clay are being determined experimentally.

The paper will review the experiments carried out so far in terms of the mechanisms identified, and the status of the mechanistic and mathematical modelling.

Data from a Uranium Ore Body on Release of Dissolved Species: Comparison with a Near Field Release Model

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ABSTRACT

In the Swedish repository for spent fuel the canisters containing the uranium oxide fuel are surrounded by compacted bentonite clay which has a low hydraulic conductivity. The transport through the clay will be dominated by diffusion. The water flow in the fractured rock is very small and it is likely that the dissolution rate of the fuel will be solubility limited. Release and transport models based on this assumption have long been used in performance assessments (PA) including that used for the Swedish KBS-3 type repository design. The models basically state that the uranium oxide dissolves to its solubility limit at the surface of the spent fuel and that the dissolved species diffuse out through the clay and into the passing water outside the clay. The rate of transfer is determined by the diffusion resistances in the clay and in the water slowly seeping past. The rate of release and thus dissolution is proportional to the driving force i.e. the concentration difference at the fuels surface and the concentration in the approaching ground water. The proportionality constant is determined by the clay and flow geometry and the material properties.

In the uranium ore body at Cigar Lake there is a striking similarity between the ore body and a repository. The ore is uranium oxide and it is surrounded on the top side by a dense clay which has a much lower hydraulic conductivity than the surrounding rock. We have used the same principles as for the near field release models for the repository to calculate the dissolution rate of uranium and other species at Cigar lake. At this location a large number of measurements on the water composition in and around the ore body have been made. At one location in the ore body itself the first water samples contained a very high concentration of helium, hydrogen and sulphate. This decreased with continued sampling. A departure point in our analysis is the assumption that the first samples represent the steady state concentration of helium in the undisturbed ore. The production of helium by alpha decay of the uranium and thorium chains can readily be calculated and assuming that this is also the steady state release we can calculate the "proportionality factor" i.e. the sum of resistances to release in the model from the decay calculated release and the measured concentrations. This agrees very well with what is obtained from the forward modelling using the geometry, water flowrates and material properties of clay and rock.

SESSION 4

Confidence Building on the Conceptual Model for Nuclide Migration in Sedimentary Rocks

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Abstract

Direct field observations of the behaviour of natural uranium within saturated sedimentary sequence, together with supporting laboratory experiments, have been carried out to build a confidence on the conceptual model for nuclide migration in sedimentary rocks. Previous geochemical studies of the uranium bearing sequence revealed that natural uranium has been transported by the groundwater and deposited in the rock matrix. This evidence can be regarded as an analogue of nuclide migration in the case of saturated porous media. The data of geochemical observation, uranium disequilibrium study and supporting laboratory experiments, such as permeability test and diffusion experiment, have been itelatively compared in order to achieve a higher degree of confidence with the conceptual nuclide migration model.

Uranium disequilibrium study of the uranium bearing sequence shows that natural uranium has migrated in microscopically within pore spaces of the rock matrix. The hydraulic conductivities and apparent diffusion coefficient measured by laboratory experiments of the rock sample from uranium bearing sequence are less than $1.0X10^{-10}$ m/s and $4.0X10^{-12}$ m^2/s, respectively. With the experimental data and hydraulic gradient value (<0.05) measured in situ, calculated maximum peclet number suggests that natural nuclide has migrated apparently by diffusion. The comparison between the data from laboratory experiments and the field data show that diffusional process can be appropriately performed as a part of nuclide migration model used in performance assessment.

The Grimsel Radionuclide Migration Experiment: A Contribution To Raising Confidence In The Performance Of Safety Assessment Models

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Abstract

The importance of adequately testing models which will be (or have been) used in a radioactive waste repository safety assessment cannot be over-stated. Indeed, in Nagra`s recent Kristallin-1 safety assessment it was noted that various measures have been adopted to build confidence in the adequacy of such safety assessment models, including the

"use of laboratory and field tests, as well as natural analogues, to test models".

This desire to rigorously test (and thus raise confidence in) the various models which constitute a safety assessment explains why Nagra and PNC (Power Reactor and Nuclear Fuel Development Corp.), in association with PSI, have expended so much effort conducting radionuclide migration experiments in Nagra`s underground laboratory at Grimsel, in the Swiss Alps.

The major aims of this long-term (site investigations began in 1985) programme remain the development and testing ("validating") of radionuclide transport models. The experiments are carried out in a water bearing shear zone in crystalline rock using a suite of tracers of differing geochemical behaviour. Due to the relative complexity of the tracers, a large laboratory support programme has been necessary to fully understand (and predict) the behaviour of the tracers under *in situ* conditions, as has the development of various downhole tools and novel analytical techniques.

The paper discusses not only the Nagra/PNC/PSI approach to code testing, but also emphasises the significant investment of resources required to produce defensible (adequately tested) models for incorporation in a safety assessment.

Redox Processes in Disturbed Groundwater Systems: Conclusions from an Äspö-HRL Study

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Abstract

The Swedish concept for disposal of high level waste includes isolation of spent fuel in copper canisters, buried deep within granite bedrock. Deep repository construction will lead to a highly disturbed hydraulic system in the surrounding aquifer. In addition to opening the deep environment to atmospheric conditions, there is concern that dissolved oxygen may enter vertical fracture zones with the increased surface water recharge. Oxygen can lead to canister corrosion, and enhanced mobility of redox-sensitive radionuclides; Technetium, Plutonium, Neptunium, Uranium. This study addresses the possible inflow of oxygenated surface water into vertical fracture zones during construction of the Äspö Hard Rock Laboratory (HRL).

Entrance tunnel construction at the ÄHRL opened a conductive vertical fracture zone at a depth of 70 meters on March 13, 1991. Three weeks later a sharp dilution front, corresponding to 80% shallow water inflow to the previously saline fracture zone, arrived at the entrance tunnel depth. The predicted outcome of the experiment was that reaction with Fe(II)-bearing fracture minerals would retard oxygen breakthrough. This oxidizing alteration would change the geochemical character of the migration barrier provided by fracture-filling material. The observed outcome is that almost no oxygen breakthrough ever occurred.

In spite of the large inflow of shallow water, the fracture zone remains persistently anoxic. There is increased input of organic carbon, rather than molecular oxygen, with the surface water inflow. Microbial activity is important in the upper bedrock environment studied here. Because of the inflow and microbially-mediated oxidation of organic carbon, this fracture performs as a conduit for additional reducing capacity into the deep environment, rather than as a path for penetration of dissolved oxygen.

Results and Experiences from the Äspö Hard Rock Laboratory Characterization Approach

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Abstract

SKB plans to start deposition of spent fuel within about 15 years from now. The design work for a canister encapsulation plant is under way. Feasibility studies for repository siting are in progress in cooperation with two (September 1994) municipalities.

An extensive research, development and demonstration programme will support the detailed designand licensing of the encapsulation plant and the deep repository.

Construction of the Äspö Hard Rock Laboratory down to 450 m below the surface will be complete in early 1995. Prior to excavation, the results of the pre-investigations of the bedrock were analyzed and modelled on several geometric scales. For each scale, key issues were selected. Several hundred parameter values were then predicted. During construction these predicted values are being compared to the situation in the tunnel and in the boreholes. Between 100 - 200 borehole sections have been monitored on-line.

The prediction-outcome matches are now under evaluation and the final report will be published 1995. Many important results have been obtained and valuable experience has been gained.

The paper summarizes important findings which will influence the detailed planning of the site characterization programme for the Swedish deep repository.

Flow and Transport around the Asse Salt Anticline

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Abstract

The Asse anticline near Braunschweig is part of the Subhercynian Basin which is bounded in the south by the Harz Mountains, in the east and the north by the river Aller, and in the west by the river Oker which flows into the river Aller. The Asse structure ranges lengthwise and breadthwise approximately eight and three km, respectively. It is oriented in NW-SE direction.

In 1965 the GSF Research Center for Environment and Health acquired the former Asse salt mine on behalf of the FRG in order to carry out research and development work with a view to safe disposal of radioactive waste.

To assess long term safety it is important to predict groundwater flow and radionuclide transport in the vicinity of the salt anticline. In order to show the reliability of these predictions they have to be proved by means of validation. For this purpose an experimental program was carried out with the twofold intention to set-up and validate hydrogeological models of the overburden of the Asse salt mine and to provide these with data.

In the course of about 25 years five deep boreholes from 700 m to approximately 2,250 m below surface, and four geological exploration shallow boreholes were drilled in order to improve the knowledge about the geological formation of the Asse area. Moreover, 19 hydrological piezometers and 27 hydrological exploration boreholes were sunk to perform pumping and tracer tests and yearly borehole loggings. In the end about 50 boreholes and wells, 25 measuring weirs and about 70 creeks, drainages and springs were available to collect hydrological data and water samples. It turns out that the water movement within the mesozoic rocks of the overburden of the Asse anticline as deep as 200 m below surface is influenced by exogenic (e.g. morphological and meteorological) factors, whereas below 700 m the movement is almost stagnating.

The different experiments and their evaluations as well as different hydrogeological models are presented and discussed. Since there is no suitable numerical model available which is able to take into account the effects of variable density due to salinity for large and complex geological structures like the Asse up to now all models neglect salinity.

SESSION 5

Characterization and Tracer Tests in the Full-Scale Deposition Holes in the TVO Research Tunnel

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Abstract (June 3, 1994)

Three wells of the size (diameter 1.5 m, depth 7.5 m) of the deposition holes in a spent fuel repository have been bored with a new full-face boring method in the TVO Research Tunnel which lays at the level of -60 metres in the VLJ Repository at Olkiluoto. The wells are 6 metres apart. Comprehensive pre- and post-characterization of the rock and the wells has and will be performed. The test programme include among other things hydrological measurements and tracer tests. The aim is to evaluate the feasibility of the deposition hole boring method and to study properties of fractures and groundwater flow in the rock and in the disturbed rock zone around the deposition holes and below the tunnel floor.

Characterization and tests in the bored wells and evaluation of the results is in progress. So far, the investigations have revealed the following: Full-face boring is a practicable method to construct deposition holes. Fracturing and other small-scale properties of the rock can be characterized a priori by means of small-diameter (56 mm) boreholes, high frequency seismic survey and radar. The inflow rate of groundwater in two of the three wells is 6 and 18 litres/hour. The well in the middle is almost dry (inflow 0.05 litres/hour) as expected on the basis of the pre-characterization. Visual inspection of the inflow and tracer tests give indications of flow in sparse and narrow channels. The observed non-Fickian dispersion is thought to be caused by velocity differences over the channel width or by diffusion into stagnant pools in the fracture filling. The inflow rate of groundwater into the wells is almost as high as the total inflow rate into the Research Tunnel which is 50 metres in length and 7 metres in height. The inflow into the tunnel takes place at few spots, too. Visual inspection and hydraulic tests do not reveal such a highly disturbed rock zone below the tunnel floor as assumed in the TVO-92 safety analysis.

These and forthcoming results of the investigations will be discussed from the point of view of determining the locations of deposition holes in a repository as well as from the point of view of performance analysis.

Joint ANDRA/Nirex/SKB Zone of Excavation Disturbance Experiment (ZEDEX) at the Äspö Hard Rock Laboratory

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The excavation of access shafts and tunnels and of the disposal areas of a waste repository will cause a disturbance in the surrounding rock mass with possible alterations to rock mass stability and hydraulic properties. For a number of disposal concepts this disturbance may be important for the operational and/or post-closure safety of the repository. Furthermore the disturbance may extend over time as a consequence of processes such as stress relaxation.

The sponsors of ZEDEX, namely ANDRA, Nirex and SKB, are interested in developing the ability to produce reliable models of the disturbed zone that will develop around large cross-section excavations in fractured hard rock masses that are initially water saturated. Various models have been developed to calculate the important characteristics of the disturbed zone in such rock masses as a function of parameters related to the rock mass quality and the geometric description of the excavation.

ZEDEX was initiated in the Äspö Hard Rock Laboratory in April 1994 with the drilling and instrumentation of boreholes running alongside the planned extension of the spiral access ramp and a planned parallel experimental tunnel. The experiment seeks to exploit the extensive database that has been established for the bedrock through the site characterisation programme at Äspö. A range of geophysical measurements are to be carried out in the instrumented boreholes with the objective of determining the characteristics of the disturbed zone resulting from subsequent excavation. The characteristics will be expressed in terms of parameters that are output from various models applied to the rock mass and which are also applicable in performance assessment.

ZEDEX has been designed to generate information for alternative methods of excavation. The extension to the spiral ramp is to be made by tunnel boring whereas the parallel experimental tunnel will be excavated in part by "normal" blasting and in part by smooth blasting. The objective is to build confidence in the modelling of the disturbed zone to support the selection of excavation methods for repository construction.

Integrated Modeling and Experimental Programs to Predict Brine and Gas Flow at the Waste Isolation Pilot Plant

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Abstract

Evaluation of the performance of the WIPP repository involves modeling of brine and gas flow in the host rocks of the Salado Formation. Numerous physical, chemical, and structural processes, some of them coupled, must be understood to perform this modeling. Gas generation within the repository, for instance, is strongly coupled to the amount of brine inflow to the repository because brine aids in the corrosion of metals and associated generation of hydrogen gas. Increasing gas pressure in the repository, in turn, decreases the rate of brine flow. Ultimately, the gas pressure may exceed the brine pressure and gas may flow out of the repository. The initial models used by WIPP Performance Assessment (PA) were simplified because of a lack of WIPP data on important processes and parameters. Relative permeability curves and a correlation between threshold pressure and permeability taken from studies reported in the literature were used in PA models prior to being experimentally verified as appropriate for WIPP. In addition, fracture apertures and permeabilities were treated as constant and independent of effective stress in early models, after which an assumed (and unverified) relationship between aperture, permeability, and pore pressure was used. Parameter-sensitivity studies performed using the simplified models identified important parameters for which site-specific data were needed. Unrealistic modeling results, such as room pressures substantially above lithostatic, showed the need to include additional processes in the models. Field and laboratory experimental programs have been initiated in conjunction with the modeling to provide information on important processes and parameters. Current field experiments are aimed at determining the permeability of anhydrite and halite beds under undisturbed conditions, the pressure-dependence of anhydrite fracture permeability, the threshold pressure of anhydrite fractures, and the hydraulic fracturing pressure of anhydrites. Laboratory experiments are being performed on anhydrite core samples to determine permeability and porosity as a function of applied stress, capillary pressure curves, and relative permeability curves. The current PA models built upon these experimental data are considerably more realistic and credible than the initial models used and, in some cases, predict significantly different consequences.

Development of Coupled Models and Their Validation against Experiments - DECOVALEX Project

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Abstract

An international co-operative research project has been established under the name DECOVALEX for theoretical and experimental studies of coupled thermal, hydrological and mechanical processes in hard rocks. A capability of modelling coupled phenomena are of particular importance to the safety assessment of geologic disposal of radioactive waste materials. Different mathematical models and computer codes have been developed by different national research teams and these are used to study the so-called Bench Mark Test and Test Case problems developed within this project. Bench-Mark Tests are defined as initial-boundary value problems of a generic nature, and Test Cases are experimental investigations of part or full aspects of coupled thermo-hydro-mechanical processes in hard rocks. Presented in this introductory paper are the motivation, organization and approaches of the project, definitions of Bench-Mark Tests and Test Case problems and descriptions of mathematical models used in Phase I of the DECOVALEX project. A brief introduction to the Phase II and Phase III of the project is also presented.

There is currently nine Funding Organizations, one Funding Party, one Participating Party and Two Observers in the project, representing nine countries plus CEC. They support fourteen Research Teams working on Bench-Mart Test and Test Case problems. The three phases of the project are close to completion and the continuation of the project for another three years has been approved.

The Potential Use of Natural Analogue Studies in Radioactive Waste Disposal: A Review.

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Abstract

Radioactive waste must be disposed of in such a way that it remains safe for periods of time which are often well beyond our ability to guarantee control and surveillance. To ensure adequate protection to the biosphere, a series of barriers are erected to prevent the widespread dispersal of potentially dangerous radionuclides. Having designed such a multibarrier system, the next stage is to demonstrate its safety. The performance of the repository cannot, of course, be demonstrated practically nor by experiment because of the long time scales involved. Model predictions should be valid for thousands of years and, in the case of very long-lived radionuclides, even hundreds of thousands of years. Consequently, safety analysts over the past 10 years have recognised that the study of natural systems (or natural analogues) provides opportunities to test, by observation and measurement, many of the geochemical processes that are expected to influence the predicted reliability of radioactive waste containment over realistically long periods of geological time. In addition to the time scale factor, these analogue studies attempt to understand the multiprocess complexity of the natural system by an interdisciplinary approach, which contrasts with the limitations of the laboratory.

This paper reviews the application of natural analogue studies to demonstrate the safety of deep radioactive waste disposal. Examples of such applications are described and finally the main performance assessment objectives are discussed. Future areas of improvement are also addressed.

SESSION 6

The Approach to Model Testing and Site Characterisation Studies Undertaken by United Kingdom Nirex Ltd

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Abstract

U K Nirex Ltd is currently characterising a site at Sellafield in West Cumbria to determine its suitability for the deep disposal of intermediate-level and some low-level radioactive wastes in a repository located within hard fractured basement rock: The Borrowdale Volcanic Group. A programme of drilling has been underway at the site since 1989 and by mid 1994 some eighteen deep boreholes had been drilled and extensive geophysical surveys had been carried out on both regional and site scale. Geological evaluation of the site was carried out, using existing information, prior to 1989 to inform the process leading to the selection of the site for investigation.

The paper records the process by which conceptual models for the site were evaluated and successively rejected or revised as an integral part of the site characterisation programme. The process has become increasingly specific as the programme has developed. Initially the objective of the site characterisation programme was to confirm the availability at Sellafield of the Basement Rock Under Sedimentary Cover (BUSC) concept that performed well in the assessments carried out to inform site selection, and to confirm that rock properties lay within the range that had been employed in these assessments. Thereafter, the site characterisation programme has been directed to address in a systematic manner the most significant uncertainties in the conceptualisation of the site. These uncertainties have included the hydrogeological characteristics of faults that were detectable by geophysical methods and the nature of the controls on the effective hydraulic conductivity of the fractured BVG.

The paper notes that as the issues to be addressed in the site characterisation programme become more specific, the relationship between the various models used to interpret and evaluate field data becomes increasingly important.

Finally the paper notes the requirement for site characterisation to be carried out on an appropriate scale and discusses the role of a large scale pump test planned for late 1994 as a major development of the overall strategy. The strategy for further development from surface-based characterisation to underground experiments in the proposed Rock Characterisation Facility is also discussed briefly.

Coordinated Site Characterization and Performance Assessment - an Iternative Approach for the Site Evaluation

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Abstract

SKB planning for siting a deep repository involves surface based characterization and drilling on two canditate sites and detailed characterization of one site including a shaft to proposed repository depth. The selection of a site or the detailed layout of the repository defines characteristics that might influence safety in a broad sense. There is a strong link between the safety, technical (engineering) and functional aspects.

At an early phase of the investigations only limited information is available for safety evaluation. The site selection will be based on general geoscientific information, ie mechanical stability, ground-water chemistry, slow ground-water movements and complicating factors like high potential for mineralization.

Site characterization provides input to more quantified safety considerations. The general layout of the repository in the actual geological stucture of the site must be done with regard to a number of guidelines, eg to hydraulically separate the parts of the repository containing the spent nuclear fuel from those for other types of longlived waste and to separate the two stages of the spent fuel repository so they can be handled separately in the licensing process.

When the various parts of the repository have been tentatively located the consequence of the multiple barrier principle is that the layout of the various parts should be made with the aim to utilize the available natural barrier system at the site as well as possible.

Siting and design of nuclear waste repository is an iterative process with a gradual knowledge build-up by means of data collection, conceptualization, analysis and renewed proposals for data collection, etc. Safety and design aspects follow the site characterization process in parallell.

The SKI SITE-94 Project Approach to Analysing Confidence in Site-Specific Data

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Abstract

The ongoing SKI SITE-94 project is a fully integrated performance assessment based on a hypothetical repository at 500 m depth in crystalline rock. One main objective of the project is to develop a methodology for incorporating data from a site characterisation into the performance assessment. The hypothetical repository is located at SKB's Hard Rock Laboratory at Äspö in south-eastern Sweden. The site evaluation in SITE-94 uses data from the pre-excavation phase that comprised measurements performed on the ground and in boreholes, including cross-hole hydraulic and tracer experiments.

Interpretation of site specific data involves several steps of model testing, each associated with different sources of uncertainty. These uncertainties affect the final performance assessment results to a varying degree. Uncertainties related to measurement technique, equipment and methods for interpretation were evaluated through a critical review of geohydraulic measurement methods and a complete re-evaluation of the hydraulic packer tests using the generalised radial flow (GRF) theory. Groundwater chemistry samples were analysed for representativity and sampling errors.

A wide range of site models within geology, hydrogeology, geochemistry and rock mechanics has been developed and tested with the site characterisation data. Key features of the model testing include assessment of reasonableness through simple scoping calculations, development of alternative conceptual models on different spatial scales - each consistent with field data. The question of consistency between geologic, hydrogeologic, rock mechanical and geochemical models of the site is also being addressed.

The multiple interpretation approach makes it possible to illustrate conceptual uncertainties regarding the description of processes and structures. Integrated interpretation of geologic, hydraulic and geochemical data using 3D CAD tools together with multivariate analyses are expected to give information on possible correlations in the site data and to aid in the discrimination between the alternative conceptual models. Remaining unresolvable conceptual and other uncertainties will be propagated through the assessment and quantified in the subsequent calculations of radio nuclide release and transport to determine their importance. Attempts are also made to illustrate the effects of errors introduced when estimating effective parameters used in the performance assessment models. Although experiment planning and design are beyond the scope of SITE-94, suggestions for improved measurement strategies is another expected outcome from this site evaluation exercise.

THE NRC/SKI Position Paper on Validation Strategy

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ABSTRACT

Views on model validation of the U.S. Nuclear Regulatory Commission (NRC) and the Swedish Nuclear Power Inspectorate (SKI) in the context of licensing a high-level nuclear waste (HLW) repository are presented in this report.

An important consideration in the regulatory uses of mathematical models in the safety assessments of HLW repositories is the degree of validation needs for regulatory decision making. A substantial body of literature exists indicating the manner in which scientific validation of models is usually pursued. Because models for a nuclear waste repository performance assessment (PA) cannot be tested over the spatial scales of interest and long time periods for which the models must make predictions, the usual avenue for model validation—comparison of model predictions with actual data at the space-time scales of interest—is precluded. Further complicating the model validation process in the HLW program are the uncertainties inherent in describing the complex geology of the site and its interactions with the engineered system with a limited set of generally imprecise data, making it difficult to discriminate among alternative models. A successful strategy for validation, therefore, must attempt to resolve these difficulties and document the resolutions in a careful manner. The end result of validation efforts should be a documented enhancement of confidence in the ability of the model to aid in regulatory decision making. The level of validation needed should be determined by the intended uses of these models, and their importance to the regulatory issues, rather than by the ideal of validation of a scientific theory.

EVOLUTION OF FLOW AND TRANSPORT CONCEPTUAL MODELS AT THE WASTE ISOLATION PILOT PLANT, 1978 TO 1994

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Flow and transport conceptual models have evolved as the result of interactions among specific model concepts, field studies, and numerical simulation studies. This paper examines major steps in that evolution process beginning with the relatively primitive models used in the original Environmental Impact Statement in the late 1970's. Major iterations in field testing and model revision have occurred over the past 15 years. This review illustrates the evolution from relatively little conscious consideration of underlying conceptual models to significant focus on the assessment of alternative conceptual models, both numerically and in the field. Major flow conceptual issues include degree and importance of flow confinement in the Culebra Dolomite and the existence and importance of long-term transients. A major transport conceptual issue is characterization of the degree of fracture-matrix interaction in the transport process.

Validation Strategies for Licensing Nuclear Waste Repositories in Salt Formations in Germany

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Abstract

The Gorleben salt dome in Germany has been selected as a potential site for a radioactive waste repository to be constructed within a salt dome. Licensing of such a nuclear waste repository requires the demonstration of the post-closure safety of the facility. This involves extensive use of models to assess the potential future evolution of the site with respect to thermal-geomechanical effects, behaviour of the waste, release of radionuclides and their migration through the geosphere and uptake by man. Since observations of the relevant processes will not be available over the long time period involved, confidence-building measures are needed to convince the authorities as well as the public, that the repository is safe. Part of this process is model testing, usually referred to as validation, which requires the design of appropriate experiments and data sampling, both to be carried out during site characterization as well as in the underground facilities to be constructed.

Validation has to be done within the framework of German regulations which require compliance with deterministic dose limits.

With rock salt as host formation, a number of specific phenomena and processes have to be considered. Models for the creep of salt and compaction of backfill material and seals due to heat and pressure as the most important processes in the near-field have to be tested against in-situ experiments and supporting laboratory experiments. Appropriate laboratory experiments are also carried out to validate geochemical models used to determine the degradation of the waste form and the solubility of the radionuclides under the conditions of a brine environment. Groundwater movement and hence radionuclide migration in the strata overlying the salt dome is strongly influenced by density changes caused by the dissolution and transport of salt. The observed current salt distribution in the aquifer system can be used as a natural analogue for modelling the corresponding processes in the far-field. Sorption processes in a brine environment require special attention.

Since mechanisms in the near-field are independent of those in the far-field, validation work on these areas can be performed separately. However, the scope of the work in these fields should be consistent and concentrate on the relevant issues. Use of natural analogues helps to build up confidence in analyses carried out over long time periods.

Evaluation of Canadian Performance Assessment Models for Deep Geological Disposal of Nuclear Fuel Wastes

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Abstract

The evaluation of models for long-term performance assessment of geological disposal systems plays a vital role in establishing the reliability of the assessment. A model may be evaluated by testing the underlying hypotheses or by comparing model predictions with observations. Evaluations do not in themselves allow one to conclude that the use of the models in an assessment is valid. Rather, the validity of the assessment must be discussed in the overall context of data, assumptions, model results, interpretation of results, and conclusions. In particular, the discussion of the validity of a model cannot be separated from the discussion of the conclusions drawn.

In assessing the safety of waste disposal systems, it may not be necessary or practicable to model a particular process in detail. Conservative and unrealistic assumptions which lead to an overestimate of impacts are often made. In these cases, evidence, which can be theoretical reasoning or observation, must establish that the assumptions are in fact conservative.

The reliability of models can be continuously improved through a process that allows new information to be continuously incorporated into the assessment as the project proceeds. The safety analyses, and the underlying hypotheses on which the analyses are based, become increasingly robust as additional information and understanding are generated. This process is consistent with the observational approach to siting, constructing and operating a geological disposal system.

Examples from the assessment of the Canadian nuclear fuel waste disposal concept illustrate the evaluation of models of the vault, geosphere, and biosphere. The examples show the role of (i) comparisons of model results with observations on real systems; (ii) natural analogues to test the underlying hypothese and improve the understanding of important processes; and (iii) evidence to support conservative assumptions. These evaluations will be discussed in the context of the conclusions drawn to support the safety case for the Canadian concept.