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SUBJECT: LESSONS LEARNED IN THE INTRAVAL PROJECT

As you requested, I am transmitting preliminary lessons learned from the INTRAVAL[3] Project. These conclusions are taken from consensus observations and recommendations of the ISI committee of INTRAVAL of which I am the Chairman. This material is taken directly from the ISI final report entitled "Draft INTRAVAL ISI Committee Report".

" RESULTS AND CONCLUSIONS OF INTRAVAL

Through its six-year life, INTRAVAL explored a wealth of geological data from sites in four continents. The great strength of the project was that modeling was tested against real data at a relatively dense observational scale, using all the information available, rather than the very sparse and simplified use of field data seen in all predictive performance assessment modeling to date. The most instructive exercises were those that involved field rather than laboratory tests, as these approached more closely 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 will have considerable impact on the incorporation of repository site data into safety assessment."

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[3] INTRAVAL, the International Project for studying validation of geosphere flow and transport models, was initiated by the Swedish Nuclear Power Inspectorate (SKI). The project began in October 1987 and the final workshop was held in September 1993. The project consists of 24 scientific organizations from 14 countries. The U.S. participants were the U.S. Nuclear Regulatory Commission and contractors (CNWRA, PNL, University of Arizona, MIT, and SNL), U.S. Department of Energy, U.S. Environmental Protection Agency and the State of Nevada as an observer. INTRAVAL Progress Report 10 is enclosed which provides further details.

* The overall lessons of INTRAVAL can be summarized as follows:

- It has become clear to the modelling community that the geological environment is complex and heterogeneous at all scales of observation. Although it contains both discrete features, and regions which can be treated as a continuum, the scales of both are highly variable. Very few discrete features can be characterized with enough determinism to allow for their easy input into a model. Consequently, for the bulk of the rock, analysis must depend on stochastic techniques using statistical data inputs. It is also crucial to ensure that models incorporate real parameters which are intrinsic and measurable properties of the rock. At present, a number of models rely heavily on derived parameters (such as flowpath length and wetted surface area) which are abstract and unlikely ever to be measurable in the field.

- The geological systems studied are dynamic and, over the time periods required by performance assessment, they will respond to an evolving environment such that transport pathways will vary and fluxes will change. In this respect also, it is important to understand that transport cannot be described with any real degree of determinism, and that predictions made by models are highly sensitive to changes in the underlying assumptions about the stability of boundary conditions.

- In the course of the project, no fundamentally new processes were identified which needed to be incorporated in new conceptual models. Most of the model variation centered on differences in the way in which known processes were treated or coupled, or the degree of significance given to them. INTRAVAL developed an understanding of the dominant flow and transport properties of various geological formations and an ability to model these in different ways, thus providing a range of possible outcomes which can be compared and discussed.

- Although up-scaling from the laboratory scale to regions of a few meters appears feasible in most circumstances, it was not possible to demonstrate that up-scaling of predictions from the 10-m to the 1000-m scale is valid in any of the geological environments studied. Even given a reasonable understanding of local field conditions at a test site, it was not possible readily to predict accurately at a larger scale. However, we were able substantially to improve the scientific basis for attempting such predictions. The limitation of scale of some of the field tests also preclude adequate tests of the validity of the conceptual models being evaluated.

- INTRAVAL was not able get to grips with the problem of up-scaling the time factor, other than by looking at long-term migration processes in natural analogue systems. A potentially powerful technique at the site scale is the interpretation of paleohydrogeological data to reconstruct the past history of the site, using the same conceptual models as those used for predictive purposes. This technique, applied to reservoir analysis, is similar in concept to "history matching" in the hydrocarbons sector, and predictions are usually only made as far into the future as history has been matched in the past. For the timescales we are interested in for repository behavior, we have not really begun to test the paleohydrogeological approach to history matching.

- There was only limited evaluation of reactive transport mechanisms, as most test cases involved either simple flow, or the use of conservative tracers. With the exception of the clay test cases, transport under most test conditions was dominated by advection, which emphasizes the need to concentrate effort on heterogeneity and anisotropy of the system. Dispersion, arising from spatial variability of transport properties, is also important. The effects of matrix diffusion remain ambiguous. Attempts demonstrate its impact have been largely curve-fitting exercises which use a matrix diffusion model term to provide a better fit for the tail of tracer breakthrough curves. Although models which did not incorporate it performed less well than ones that did, direct evidence remains elusive.

- It did not, in the event, prove possible to have a significant number of the test cases purpose-designed for model testing, and the project had to live with the data which were available. Consequently, experimental observations frequently did not fulfil the requirements of the modelers, and some important parameters were not recorded. As a result, the "post audit" testing of predictions did not feature as largely as we would have wished. A large part of the project involved the calibration and fitting of models to test cases, rather than rigorously constructed tests of predictive capacity. Where it was attempted, it was usually found that we were lucky to bound the actual values with the predictions. Also, models which performed well in predicting one parameter, would perform badly at predicting others. In some cases a bounding value would prove adequate for performance assessment purposes, provided it could be shown to be conservative (i.e., no alternative conceptual model could produce a less conservative value, and real values were always on the non-conservative side of the predictions). A significant realization is that we can have little belief in the absolute value of any predictions. Confidence must lie in the broad trends that emerge, and in the ranges of parameter values generated.

- At the outset of the project, the full significance of uncertainty was not adequately recognized. There are uncertainties in;

    - choice of conceptual models
    - boundary and starting conditions of a modelled system
    - scaling of predictions
    - the nature of gross inhomogeneities and discontinuities.

  INTRAVAL did not have the opportunity to devise rigorous quantitative methods to evaluate the effects of uncertainty convolution on the outcome of predictions. This is something that remains to be done in future projects.

- Owing to the problem of conceptual model uncertainty, it is not possible to arrive at an unambiguous definition of a flow and transport system, as it could comprise features of several overlapping conceptual models. It is thus important to appreciate that concepts such as "flowpath" and, by extension, "transit time" along a flowpath, are largely abstract, and great care must be taken when translating predictions made in these terms into performance assessment terminology.

- The desire to develop a methodology for discriminating between alternative conceptual models went unfulfilled within INTRAVAL, largely because the Project was unable to sponsor direct tests of one model against another under well-controlled conditions. In some cases it was found that the data which would be necessary to discriminate between models had not been obtained in the field tests. A formal and comprehensive approach to conceptual model discrimination, it was found, would also involve making very many measurements of a system at a variety of scales.

- It was found that most tests could be interpreted by models that were relatively simple. A point of diminishing returns of accuracy is reached quite rapidly as a model becomes more complex. This tends to justify the use of simplifications in performance assessment models. One area where this did not seem to apply was in the interpretation of natural analogue systems involving long-term geochemical transport and deposition. In these cases, the more sophisticated geochemical models were better able to simulate the evolution of the system.

RECOMMENDATIONS FOR SITE CHARACTERIZATION AND PERFORMANCE ASSESSMENT

INTRAVAL brought together many of the leading groups studying radionuclide transport and safety assessment. It formed a valuable focus for the development of ideas both from within the project and from the wider radioactive waste community. Many specific recommendations could be made related to work in particular geological environments or at specific field research or repository site. However, we restrict ourselves here to making some more general recommendations which we hope will help the progressive development of a broadly applicable validation and site characterization methodology which takes account of the intrinsic uncertainties and variability of the natural environment.

- It is essential to have some formal mechanism for defining comprehensively all relevant conceptual models which might be used to describe mass transport at a specific site.

- It must be possible to define clearly what the input parameters are for each conceptual model, and to be sure that these can be measured in the field, or derived transparently from other measurable quantities.

- Site characterization needs to focus on both defining the boundary conditions for all the conceptual models to be used, and on obtaining the input parameters at as wide a variety of spatial scales as possible.

- A robust methodology for scaling-up from one or many small-scale field tests to make larger scale predictions, and to test these with larger scale experiments, does not exist at present, and requires further effort. It is important to consider systems in 3-D as well as 2-D, otherwise potentially important influences may be overlooked.

- Those planning site investigation programs should consider the length of time required to design and run an iterative series of tests of the type used in INTRAVAL, and such as will inevitably be needed at any potential repository site. Three to five years seems a minimum requirement.

- Much more effort should be made to develop rigorous testing procedures for conceptual models, allowing them to undergo a limited amount of conditioning on site data before being required to make verifiable predictions. The "post-audit" approach to making and checking prediction is robust, but sadly very little used. In parallel, a quantitative mechanism needs to be found to discriminate between alternative models once such predictions have been made.

- As part of the validation procedure, conceptual models must be expected to account for properties of a site which are not treated directly in their calculations. The ability to absorb peripheral "soft" geological data (for example, explaining the origin and stability of hydrochemical zonation in deep ground waters) is an essential aspect of model credibility. If a model cannot interpret the past evolution of a site, from which we have copious evidence, then we must have very little faith in its ability to predict the future based only on present conditions.

- Although only a minor part of INTRAVAL, the need to use natural analogues of geochemical systems to carry out rigorous testing of model predictions over long timescales was apparent. The geochemical post-audit approach has been used generically several times, and is highly recommended as a component of repository site characterization studies, where feasible.

- The performance measures used in safety assessment exercises need to be related transparently to parameters which can be predicted by widely accepted conceptual models. A scientific mismatch between a quantity being predicted and a quantity used as a performance target at this stage of a site evaluation would be absurd. At the same time it must be made clear that predictions are not absolute, merely indicative. If it is not understood by now that we do not seek certainty, only adequate confidence, and that we only seek to demonstrate acceptable safety of a repository rather than actual safety, then we should make more effort to drive the points home.

- Site investigators must be urged to make their techniques and their data as transparent and as widely available as possible at the earliest stages of work. This will allow maximum time for the inevitably slow process of peer appraisal which is a vital component of building credibility and ensuring the validity of the final assessment. We note an unfortunate tendency to seclude information in some countries, which will certainly lead to problems in the future.

By following these ideas we may move closer to that vital understanding of the evolution and behavior of a repository site, which underpins making predictions that are broadly accepted as being pertinent, meaningful, and consequently valid, for making decisions on environmental safety."

Please note that these lessons learned from INTRAVAL, and recommendations for site characterization and performance assessment are preliminary. The ISI is presently reviewing these technical points, along with the rest of the draft report, and plans to finalize the report at its last meeting to be held during the week of October 10-14, 1994 in Paris, France in conjunction with GEOVAL-'94.

BIBLIOGRAPHY

A significant number of papers dealing with the INTRAVAL test case descriptions and modeling have been published in the peer-reviewed journals (e.g., Water Resources Research, and Advances in Water Resources[4]). Those focusing on the validation question significantly related to NRC issues are:

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Additional material on the INTRAVAL Project are provided in:

[4] Volume 15 (Parts 1 and 2) of Advances in Water Resources in 1992 was a special issue dedicated to validation of geohydrological models. Many of the authors wrote of their INTRAVAL studies while others were influenced by the work reported on INTRAVAL.

SKI, 1988-1994, INTRAVAL Progress Reports, Test Case Description Reports, and Final Phase I Reports. (INTRAVAL Progress Report 10 is enclosed).

/s/

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Enclosure: As stated

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