ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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RADIOACTIVE WASTE ISOLATION IN SALT:
PEER REVIEW OF THE OFFICE OF NUCLEAR WASTE ISOLATION'S
PLANS FOR REPOSITORY PERFORMANCE ASSESSMENT

by

W. Harrison

with

J. Ditmars, D. Edgar, D. Fenster, A. Lerman, G. Pinder,
M. Robinet, D. Rote, J. Russell, F. Sargent, M. Seitz,
W. Sha, M. Tissue, E. Walbridge, and W. Wendland

Energy and Environmental Systems Division
Geoscience and Engineering Group

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Department of Energy
Chicago Operations Office
Salt Repository Project Office
505 King Avenue
Columbus, Ohio 43201-2693

May 10, 1984

NOTICE TO READER

At the request of DOE's Salt Repository Project Office, Argonne National Laboratory conducted reviews of two draft reports: "Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt" (April 1983) and "Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt" (June 24, 1983).^{*} These reports are important tools in the early planning of the Salt Repository Project, which has as its goal the licensing of a repository in salt.

The peer review comments have proven valuable. We are adopting Argonne's suggestion that the performance assessment plan and verification and validation plan be combined into one plan, and this new plan should be available for public distribution in July 1984. A series of reviews of the combined plan will be conducted with the objective of fully discussing the approach, strategy, and plans with interested parties, and then reflecting the results of these reviews in a revised plan. The revised plan will be a key reference in our site characterization plans for salt sites and will be formally updated in successive revisions.

Leslie A. Casey
for R. C. Wunderlich
Acting Chief
Engineering and Technology
Salt Repository Project Office

^{*}Microfiche copies of the draft reports reviewed can be found inside the back cover of this report.

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FOREWORD

Documents are being submitted to the Salt Repository Project Office (SRPO) of the U.S. Department of Energy (DOE) by Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI) to satisfy milestones of the Salt Repository Project of the Civilian Radioactive Waste Management Program. Some of these documents are being reviewed by multidisciplinary groups of peers to ensure DOE of their adequacy and credibility. Adequacy of documents refers to their ability to meet the U.S. Nuclear Regulatory Commission's standards enunciated in the 10 CFR Part 60 rule, and National Environmental Policy Act and Nuclear Waste Policy Act of 1982 requirements. Credibility of documents refers to the validity of the assumptions, methods, and conclusions, as well as to the completeness of coverage.

Since late 1982, Argonne National Laboratory has been under contract to DOE to conduct multidisciplinary peer reviews of program plans and reports covering research and development activities related to siting and constructing a high-level nuclear waste repository in salt. Part 1 of this report summarizes Argonne's review of ONWI's Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt dated April 1983. Argonne was requested by DOE to review this plan on March 23, 1983 (see App. A). The review procedure involved obtaining written comments on the plan from two members of Argonne's core peer review staff and from three Argonne and two extramural experts in related research areas. The peer review panel met at Argonne on June 7, 1983, and reviewer comments were integrated into Part 1 by the review session chairman, with the assistance of Argonne's core peer review staff. Each of the peer review panelists concurred in the way in which his comments were represented in this report (see App. B), and a draft of Part 1 was sent to SRPO on June 17, 1983.

Part 2 summarizes Argonne's review of ONWI's Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt dated June 10, 1983. Argonne was requested by DOE to review this plan on June 10, 1983 (see App. A). The review procedure involved obtaining written comments on the plan from two members of Argonne's core peer review staff and from seven Argonne and four extramural experts in relevant research areas. Reviewer comments were discussed during the formal Argonne review panel meeting on July 12, 1983. A core group of five Argonne panelists then reviewed all of the comments and drafted Part 2 of the present report. Each of the peer review panelists concurred in the way in which his comments were represented in this report (see App. B), and a draft of Part 2 was sent to SRPO on August 24, 1983.

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT"

- ANL/EES-TM-242 Peer Review of the Office of Nuclear Waste Isolation's
Geochemical Program Plan (Feb. 1984)
- ANL/EES-TM-243 Peer Review of the Office of Nuclear Waste Isolation's
Socioeconomic Program Plan (Feb. 1984)

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Microfiche copies of the following reports are attached to the inside back cover of this report:

1. Czyscinski, K.S., et al., *ONWI Geochemical Program Plan*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio (July 1982).
2. Office of Nuclear Waste Isolation, *Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt*, Battelle Memorial Institute, Columbus, Ohio (April 1983).
3. Office of Nuclear Waste Isolation, *Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt*, Battelle Memorial Institute, Columbus, Ohio (June 24, 1983).

PART 1

PEER REVIEW OF PRELIMINARY PERFORMANCE ASSESSMENT PLAN

by

W. Harrison, G. Pinder,* M. Robinet,[†] D. Fenster,
M. Seitz,[†] W. Sha,** M. Tissue, and F. Sargent^{††}

*Princeton University

[†]Occupational Health and Safety Division, ANL

[†]Chemical Technology Division, ANL

**Components Technology Division, ANL

^{††}Whiteshell Nuclear Research Establishment, AECL

PEER REVIEW PANEL MEMBERS

*Mr. David F. Fenster
Geoscience and Engineering Group
Energy and Environmental Systems Division
Argonne National Laboratory

**Dr. Wyman Harrison
Associate Director for Geoscience and Engineering
Energy and Environmental Systems Division
Argonne National Laboratory

Professor George F. Pinder
Chairman, Department of Civil Engineering
Princeton University
Princeton, New Jersey

Mr. McLouis J. Robinet
Health Physics Section
Occupational Health and Safety Division
Argonne National Laboratory

Dr. F. Peter Sargent
Head, Geochemistry and Applied Chemistry Branch
Whiteshell Nuclear Research Establishment, AECL
Pinawa, Manitoba, Canada

Dr. Martin G. Seitz
Geochemistry Group
Chemical Technology Division
Argonne National Laboratory

Dr. William T. Sha
Director, Analytical Thermal Hydraulic Research Program
Components Technology Division
Argonne National Laboratory

Ms. Mary W. Tisue
Geosciences Editor
Energy and Environmental Systems Division
Argonne National Laboratory

The credentials of the peer review panel members are summarized in App. C.

*Member of core peer review staff.

**Review panel and review session chairman, and member of core peer review staff.

PART 1

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by

W. Harrison, G. Pinder, M. Robinet, D. Fenster,
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SUMMARY OF RECOMMENDATIONS

The following recommendations have been abstracted from Part 1 of this report. The Office of Nuclear Waste Isolation's Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt should:

1. State clearly the precise purpose of the plan, preferably at the beginning and under an appropriate heading.
2. Also under an appropriate heading and immediately after the section on purpose, describe the scope of the plan, including what the plan covers and the major bounds and interfaces of the plan.
3. Under a heading like "Approach to Performance Assessment," discuss the major steps to be taken and the techniques to be used to achieve the objectives outlined in the section on scope.
4. Be edited for syntax, word usage, spelling, and grammar. Unnecessary redundancies should be eliminated.
5. Include a well-written executive summary.
6. Discuss in the text not only the content but the significance of the figures. In particular, for each figure that lists computer codes, the related text should briefly describe what each code is designed to accomplish.
7. Provide complete correspondence among terms used in the appendixes, figures, and text. The glossary (App. C of the plan) should be tailored to fit the report.
8. Be carefully reviewed and evaluated, with an eye to improving the flowchart presentations. Figure 6.1, for example, is difficult for a lay person to understand, and it is not clear whether the figure will be useful for specialists.

9. Provide a flowchart showing how a hypothetical performance assessment computer code is selected, verified, validated, confirmed, and applied. An explanation of this chart should be given in the text, along with a caveat statement that computer codes are no better than the assumed mathematical models on which they are based and that their predictive capability is strongly conditioned by the comprehensiveness and accuracy of the data bases used.
10. Focus attention on the quantitative capabilities that exist and those that require research and development. Describe, wherever possible, "those performance assessment techniques, including simplifying assumptions and boundary conditions, for which development work is substantially complete, with particular emphasis on identification of the types and quality of data needed" (U.S. Nuclear Regulatory Commission's Regulatory Guide 4.17, Sec. 10.2.4.1). Then describe briefly those site-specific and generic models and computer codes that will "still require significant additional development work at the time the SCR [site characterization report] is prepared" (ibid., Sec. 10.2.4.2).
11. Discuss the actual conditions that lead to appropriate definition of boundary and initial conditions.
12. Consider in more detail, perhaps with references, the issues of parameter estimation, simulation under uncertainty, fractured-media flow, and transport simulation with chemical reactions.
13. Combine information and approaches on flow, transport, and geochemistry, as these factors are best treated as subsets of a single phenomenon.
14. Provide documentation of experiments planned to resolve critical issues, such as corrosion rates in radiation fields.
15. In App. A of the plan discuss briefly, if possible, the actual governing equations to be used in the various simulations. Such equations vary dramatically, depending on the formulations used. The extent of verification and validation (and confirmation?) of each code should be summarized briefly in App. A of the plan.
16. Explain whether data bases for brines are available for use with the chemical and geochemical codes.

1 INTRODUCTION TO PART 1

Development and implementation of plans for analyzing the many processes and hypothetical events that could affect the performance of a repository for high-level nuclear waste is of prime importance to the U.S. Department of Energy's (DOE's) Civilian Radioactive Waste Management (CRWM) Program. Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI) is under contract to develop such a plan for DOE's application on behalf of the Salt Repository Project to the U.S. Nuclear Regulatory Commission (NRC) for a license to construct a repository in salt, whether or not such application is made.

Argonne National Laboratory's peer review of ONWI's Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt involved obtaining written critiques of the plan from two of Argonne's core peer review staff, and from three Argonne and two extramural experts in related research areas. The Argonne panelists then reviewed all of the comments, and the review session chairman drafted Part 1 of the present report, with the assistance of Argonne's core peer review staff. Panelists did not contact ONWI personnel, and none of the panelists has been involved in any programs sponsored by DOE or directed by ONWI such that his participation in the review could be construed as a conflict of interest.

Although no specific guidance was provided to Argonne by DOE on the manner in which the review was to be conducted, the following questions were prepared by DOE to assist in the review process (see App. A):

1. Is the scope of the plan clearly bounded/delineated?
2. Are the major milestones to achieve the objectives correctly identified? Are there key activities that have been overlooked?
3. Is the plan achievable?
4. How could the work in this performance assessment plan best be described to the lay public assuming they have no knowledge of math modeling or radioactive materials behavior?
5. Should any descriptive material (e.g., appendices) be added or subtracted to make the document more useful?
6. Are interfaces with other parts of the ONWI project clear?
7. Are the main technical issues identified?
8. Are the technical statements of the problems accurate?

Throughout its review, the Argonne panel referenced its comments on the ONWI Performance Assessment Plan to two documents: (1) 10 CFR Part 60, NRC's proposed rule entitled *Disposal of High-Level Radioactive Wastes in Geologic Repositories*, Fed. Reg., 46(130):35,280-35,296 (July 8, 1981) and (2) NRC's Regulatory Guide 4.17 entitled *Standard Format and Content of Site Characterization Reports for High-Level-Waste Geologic Repositories* (July 1982). These documents are referred to in the text that follows as "10 CFR 60" and "Regulatory Guide," respectively.

2 REGULATORY GUIDE REQUIREMENTS

The only specific reference to performance assessment in the Regulatory Guide occurs in Sec. 10.2.4 (Performance Assessment Issues). Here, the guide calls for description of performance assessment techniques under two subheadings: "Substantially Completed Analytical Techniques" and "Analytical Techniques Requiring Significant Development."

The plan should describe, wherever possible, "those performance assessment techniques, including simplifying assumptions and boundary conditions, for which development work is substantially complete, with particular emphasis on identification of the types and quality of data needed" (Regulatory Guide, Sec. 10.2.4.1). The plan should then describe briefly those site-specific and generic models and computer codes that "still require significant additional development work at the time the SCR [site characterization report] is prepared" (ibid., Sec. 10.2.4.2).

In other words, the ONWI Preliminary Performance Assessment Plan should clearly distinguish between quantitative performance assessment capabilities that exist and those that require research and development. The plan should also describe, or indicate ONWI's intent to describe, the data expected to be important for performance assessment. In addition to the summary of required data found in App. B of the plan, Sec. 10.2.4.2 of the Regulatory Guide requires information on the quality of data required and a summary of current availability.

The foregoing data requirements suggest that the plan should be much more specific about how the performance assessment team will interface with other ONWI teams and subcontractors providing data for modeling activities. The emphasis in the Regulatory Guide on performance assessment, both during and after site characterization, suggests that the plan should provide for a monitoring program to obtain critical data on system performance not only during site characterization, but also during the construction, operation, and postclosure phases of repository life.

3 SUGGESTIONS TO IMPROVE PRESENTATION

As presently written and illustrated, the ONWI Preliminary Performance Assessment Plan is frequently difficult to understand. The following suggestions should assist the authors in their next revision of the plan.

3.1 INTRODUCTORY MATERIAL RELATING TO THE PLAN ITSELF

3.1.1 Purpose, Scope, and Approach

The purpose of the plan should be stated clearly, preferably at the beginning and under an appropriate heading. A few paragraphs are needed that explain just what the plan is attempting to accomplish. Ingredients for a statement of purpose are now spread through Secs. 1 and 2. For example, the first reference to purpose is found in paragraph 3 of Sec. 1 (Introduction): "The ONWI performance assessment plan outlines the activities required to meet the above objectives..."

The scope of the plan should be clearly delineated, again under an appropriate heading and immediately following the section on purpose. At present, the first reference to the plan's scope is found in Sec. 1.2 (ONWI Program -- Brief Review): "Performance assessment activities as related to all these tasks [given in the text above] are described in this plan." Where scope is more specifically discussed in the last paragraph on page 9, the prose is cumbersome and the logic somewhat unclear. The scope is spoken of as having "two major thrusts." It would be better to simply describe all that the plan intends to cover, including the bounds of what will be covered, under each of the activities listed and any important interfaces with other ONWI and contractor activities.

Under a heading like "Approach to Performance Assessment," the major steps to be taken and the techniques to be used to achieve the objectives outlined in the section on scope should be summarized. Such items as the establishment and implementation of a quality assurance program (last paragraph on p. 11) would logically belong in this subsection.

Implementation of the above recommendations should result in a much clearer presentation of the fundamentals of the plan. If the remaining introductory material now found in Sec. 1 is to be retained, it should be condensed by someone familiar with CRWM and ONWI programs and inserted after the subsections on purpose, scope, and approach.

The public information office of ONWI might well be advised to consider using media other than this report for communicating the essence of this highly technical and complex plan to the lay public. To improve professional understanding of the plan, a well-written executive summary should be included in the next iteration.

3.1.2 Technical Approach to Performance Assessment

The title for Sec. 2 (ONWI's General Technical Approach to Performance Assessment) should be recast. A title to consider is "Overview of ONWI's Approach to Performance Assessment." The first sentence under this heading tells what ONWI's approach to performance assessment is based on but doesn't say what it is. As recommended in Sec. 3.1.1 of this report, the approach should be outlined in several paragraphs as part of the introduction. Details can then be given in Sec. 2 and subsequent sections of the plan.

Section 2.8 (Use of Digital Graphic Technology for Data Verification and Interaction) runs the risk of promising more than can be delivered. It tells the readers what will be done without telling them how it will be accomplished. The final sentence in Sec. 2.8 is both gratuitous and weak: "Using recent advances in digital computers, the important spatially and time-dependent input and result parameters will be displayed by simple to detailed 3-D surfaces and color graphics to provide an extremely effective and efficient means for the scientists for verifying inputs and information transfer."

3.2 SYNTAX, GRAMMAR, AND WORD USAGE

The quality of writing in the plan is not only uneven but generally poor. Parts of Secs. 5 and 6 are particularly difficult to understand. Articles are occasionally missing, verb forms are sometimes incorrect (e.g., third sentence in Sec. 6.6 on p. 108), sentence structure is confusing (e.g., first sentence of third paragraph under Sec. 6.6 on p. 108), and exceedingly long sentences attempt to communicate a multiplicity of thoughts (e.g., lines 8-13 on p. 79). Even though the issues addressed in the plan are complex, the content should not be so difficult to understand.

The plan should be very carefully edited for syntax, grammar, spelling, and word usage. Redundancies should be eliminated.

3.3 FLOW DIAGRAMS, FIGURES, AND OTHER GRAPHICS

The use of graphics, either in the form of flowcharts or figures, can be very helpful to the reader. However, to be effective, such graphics must be carefully thought out and executed. In general, the content and significance of the figures should be discussed in the text. Some of the figures in the plan appear to have been added as an afterthought. When there was discussion of the graphics in the text, the explanations sometimes clouded the issues. Certain illustrations were difficult to decipher (e.g., Fig. 5.4). Careful attention should be paid to the correspondence between terms used in the text, figures, and appendixes.

Some of the flowcharts were rather confusing and occasionally illogical. Figure 6-1 seems particularly onerous in this regard. Figure 7-3, on

the other hand, gives a good overall review of the philosophy and rationale of Sec. 7. All flowchart presentations should be carefully evaluated with an eye to their retention, improvement, and better integration with the text.

Lay readers as well as professionals would be well served if the plan provided a flowchart showing how a hypothetical performance assessment computer code is selected, verified, validated, confirmed, and applied. An explanation of this chart should be given in the text, along with a caveat statement that computer codes are no better than the assumed mathematical models on which they are based and that their predictive capability is strongly conditioned by the comprehensiveness and accuracy of the data bases used.

Computer codes, probably the most critical element of the plan, are abstract and difficult to discuss. The use of summary figures (e.g., Fig. 4-13) is a novel approach. However, program names are generally irrelevant, that is, uninformative; input information is of necessity vague, which tends to neutralize a figure's utility; and output information is generally uninformative. However, some form of condensed presentation is needed. A summary chart with all codes and tasks addressed simultaneously might be helpful, as many of the codes seem to have overlapping tasks. At a minimum, the authors should briefly describe in the text what each code is designed to accomplish.

3.4 APPENDIXES

Appendix A should discuss briefly and wherever possible the actual governing equations to be used in the various simulations. Such equations vary dramatically, depending on the formulations used. The extent of verification and validation (and confirmation?) of each code should also be summarized briefly in App. A of the plan.

The glossary (App. C of the plan) should be tailored to fit the report. It now contains items not found in the text, and many words that are in the text are not in the glossary.

4 TECHNICAL ISSUES

4.1 IDENTIFICATION OF TECHNICAL ISSUES AND THE ACCURACY OF THEIR PRESENTATION

The ONWI Preliminary Performance Assessment Plan identifies the main technical issues, except that a monitoring program is not included (see Sec. 2 of this report). A minor technical issue that the authors might want to address is the effect of humid air on wall and roof stability of the repository during construction and operation. A related issue is the effect of water introduced when salt is used as backfill after having been crushed in humid air (see Sec. 5.7.2 of the plan).

As for the accuracy of the technical statements in the plan, the panelists in many cases could not tell whether the statements of the problems were accurate because of the poor quality of the writing. For example, one panelist familiar with geostatistical analysis had the following comments on Sec. 6.4:

The first paragraph on "data compilations" is sketchy and poorly written. For example, how can an objective of data compilation be "critical examination of the data base for consistency from various sources"? A more structured and complete explanation is needed of the need for and the process of compilation.

The remaining three paragraphs do not in fact contain any clear statements of the problems requiring geostatistical analysis. Only the author's various approaches to analysis are covered, and these in a most general way.

The last paragraph in this section is very poorly written, is not related to the section heading, and seems to belong elsewhere in this plan or, perhaps, in some other plan.

Thus, in answer to question 8 [see Sec. 1 of this report], the problems the authors attempt to cover in Sec. 6.4 are so poorly presented that one must say that the technical statements of the problems are not accurate.

4.2 COMMENTS ON SPECIFIC TECHNICAL ISSUES

In general, the actual conditions that lead to appropriate definition of boundary and initial conditions should be discussed, and specific assurance should be provided that existing codes and data will be conservative. In those areas where critical issues remain, documentation of experiments planned to resolve these issues is needed (e.g., experiments to determine corrosion rates in radiation fields).

One panelist questioned whether data bases for brines are available for use with the chemical and geochemical codes. Another panelist felt that the issues of parameter estimation, simulation under uncertainty, fractured-media flow, and transport simulation with chemical reaction should be developed in more detail. The panel members agreed that, in general, it would be advantageous to combine information and approaches on flow, transport, and geochemistry, as these factors are best treated as subsets of a single phenomenon.

4.2.1 Temperature Analyses within the Waste Package Component

The statement in Sec. 4.3 that "...peak fuel temperatures will be calculated by using two-dimensional steady-state models that consider either boxed or bundled fuel elements and include heat transfer effects of package structural members such as box walls and box supports" is somewhat misleading. For steady state calculations, the heat capacity effect of the structural material is immaterial. Also, in many situations, the peak temperature can only be calculated by three-dimensional analysis.

If the gap between barriers is filled with air, free convection with recirculatory flow will take place. In this case, three-dimensional analysis is needed for calculating the temperature distribution in the waste package component.

4.2.2 Assessment of Repository Subsystem Thermal Analysis

Although the main technical issues have been identified in Sec. 5.5, key parameters, as well as uncertainties concerning the models used in these analyses, have been neither identified nor quantified. Areas needing more experimental data and further research and development should be delineated.

4.2.3 Fluid Flow Conditions in the Repository Regime

The main technical issues have been identified in Sec. 5.7. However, the issue concerning resaturation was not clearly delineated. Because the temperature gradient in the vicinity of the waste package is working against water ingress into the waste isolation system, the probability of such ingress is reduced.

The question of uncertainty and sensitivity analysis is mentioned in line 24 on page 90. Uncertainty could prove to be the Achilles' heel of the entire plan. The credibility of the plan will hinge on how well uncertainty is accommodated. The mathematical apparatus may not exist to simulate this system properly. Monte Carlo-type methods require enormous computations, even for simple systems, and perturbation methods cannot accommodate the large

uncertainty observed in the field. Sensitivity analysis, while achievable, does not quantify the uncertainty in the forecasts.

Uncertainty is also discussed in the last paragraph of page 104. While what is stated is not incorrect, a very important dimension of the problem is omitted. While spatial variability of measurable properties is important, the uncertainty in inferred parameters is much greater. Permeability, for example, cannot be measured but must be "backed-out" of data based on observations. The degree of uncertainty in the model that is assumed for the inversion procedure is highly uncertain, as is the inverse process itself.

The tasks presented on page 90 require additional explanation. It is not apparent how these tasks will be accomplished. One panelist's experience suggests that some may require Delphi-type methods, which provide uncertain values that require models that can accommodate uncertainty.

Separation of chemical reactions from the transport phenomenon is unnatural since they are totally intertwined. The overall problem is formulated using transport equations augmented by thermodynamic and other chemical constraints. The complete description is very complicated, even for simple systems. One panelist believes, in fact, that the details of these relationships remain largely unknown. The umbrella approach described in the opening paragraph of Sec. 4.6 may be beyond the state of the art. Prior to introducing this task, the authors should consult the literature and evaluate the problems presented in addressing such a complicated system.

Reference is made to postulated flow events in the first paragraph of Sec. 5.9. Selection of these events is an important task because the veracity of the plan will hinge on the events selected and their credibility. An extended section should be devoted to this critical issue.

Line 16 of page 104 mentions the use of trace tests to obtain flow and transport parameters. This field experiment is very difficult to do because of the long times required for transport over distances large enough to be meaningful. One panelist doubts that such experiments could be carried out successfully.

Although the meaning of the last paragraph on page 106 is elusive, there appears to be some confusion regarding the application of Monte Carlo and perturbation analysis. Perhaps the authors could review this section and then indicate how these methods are to be employed.

There are serious limitations inherent in each of the proposed procedures for solving the stochastic partial differential equations. These constraints should be reviewed, and how these difficulties will be overcome should be explained.

Determining meaningful probabilities for rare events is a challenge (see paragraph 1 on p. 105). It would be helpful if strategy were discussed in more detail in the plan.

4.2.4 Regional Groundwater Flow and Hydrologic Budget

Paragraph 1 on page 107 speaks of parameter adjustment and matching, which conflicts with the concept of simulation under uncertainty. If one uses a probabilistic coefficient distribution, no adjustment or matching is used unless it is part of a Bayesian estimation strategy. This paragraph should be reviewed and clarified.

The need for a perturbation method benchmark is easily documented. However, the perturbation approach has serious limitations, as have all the methods applied to uncertainty analysis. Because the Latin Hypercube method is a rather novel approach to this problem, it should be explained more extensively.

4.2.5 Geochemical Reactions Affecting Radionuclide Transport in the Site Regime

In the first sentence of Sec. 6.6, the word "factor" should be deleted. The basic set of equations referred to will lead to a distribution of radioactivity that cannot be captured by a single factor. The plan should also specifically include "confirmation" of computer codes as discussed in Sec. IX of the ONWI Geochemical Program Plan.* Perhaps the term "validation," as used in the Performance Assessment Plan, subsumes "confirmation" as used in the Geochemical Program Plan. If so, this discrepancy of terminology should be resolved.

In general, combining the discussions of flow, transport, and geochemistry has merit.

4.3 IS THE PLAN ACHIEVABLE?

Success of the plan will depend greatly on the credibility of the models and on timely completion of the various modeling efforts. The modeling activity is crucial to completion of the plan, although one doesn't necessarily discern this from the plan itself. In fact, there may not be adequate data available to validate (or "confirm") many of the codes in the available time. This should be addressed either here or in ONWI's Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt.

While all of the deductions and calculations described in Sec. 6.6 may be theoretically achievable, one panelist's experience with chemical modeling suggests that they are perhaps not practically achievable. If the authors

*K.S. Czyscinski et al., *ONWI Geochemical Program Plan*, Office of Nuclear Waste Isolation, draft manuscript (July 1982). (A microfiche copy is attached to the inside back cover of this report.)

know of situations where such calculations have been made, particularly with reference to paragraph 2 in Sec. 6.6, such examples should be cited to give the paragraph more credibility.

Finally, a key activity that is missing from Fig. 3-2 is a milestone for a subplan that specifies the interactions between modelers and data generators. Such interactions will affect whether the plan can be achieved or not.

5 PAGE-BY-PAGE COMMENTARY

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
4	1	The word "commensurate" is inappropriate. Sentence is not clear.
4	24-26	There are time constraints imposed by the Nuclear Waste Policy Act of 1982. There are also deadlines on data collection.
52	18	Shouldn't "not" be inserted between "function" and "only" so that the sentence reads "That the heat generation rate is a function <u>not</u> only of nuclide inventory but the rate of heat transfer..."?
54	19-21	Can the assumption that there is no horizontal heat transfer by convection so that vertical boundaries can be treated as reflecting planes for thermal calculations be defended as conservative?
54	29	To refer to a publication by its number (AESD-TME-3131) is not standard. Most readers won't remember that this designation refers to the Westinghouse Electric Corporation salt waste package conceptual design report mentioned on page 48.
62		To be consistent with the text on page 61, insert "● Regional Stress State" as an Input Data item.
63	19-24	What is the distinction between "geochemical interactions" and "performance reactions"?
63	30-34	Do minerals produce water by dehydration when heated, or does water exist as brine inclusions, which are moved by a thermal gradient? Both sources of water should be considered.
64		Canister-overpack reactions appear obvious because two dissimilar metals are connected by an electrolyte. Shouldn't brine-overpack interactions be included in the list of processes considered?

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
65	1-7	Because brine composition will change with radiation field and temperature, both of which change with time, how can a final brine composition be determined unless a time is specified? It would be advantageous to be able to refer to the ONWI Geochemical Program Plan for the methods to be used in determining the "final brine composition."
65	8-11	Should the phrase "water contained in the salt; and vertical and horizontal distribution of hydrated minerals may migrate..." read "water contained in salt and other hydrated minerals may migrate"?
65	14-17	It may be exceedingly difficult to make such predictions accurately, especially because the brine compositions, etc., will change locally within the salt. Rather than trying to predict all of the reactions, performance assessment should only be concerned with those minerals that make a difference as far as nuclide migration.
68	22-23	Can a brief explanation of the analysis be inserted?
69		No reference is made in the text to the breakdown of fluid inclusions. What is the point of the figure?
71	10-13	Resaturation is not defined. Is it the complete filling of the void around the waste package? Leaching could proceed, then, without resaturation.
82	20-23	Line 23 refers to "superfluous detail" in stratigraphic investigations. While there are certainly economic and technological constraints on the amount of information obtained in the field, it would appear that more information is better than less. One can always average data if warranted for computational expediency, but the argument that detailed investigations are somehow detrimental is inappropriate. This is particularly true in this situation, where the system will always be known with great uncertainty.
84	8-10	Good statement. This point should be made more often.

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
88	31-33	<p>The performance assessment objectives inferred from this sentence do not seem to be addressed in the material that follows. In addition, it appears that the basic objective is the radionuclide transport forecast, which requires:</p> <ul style="list-style-type: none"> • Governing equations, preferably suited to simulation under uncertainty; • Parametric information, either as deterministic or stochastic functions; • Boundary conditions, probably deterministic; • Initial conditions, either deterministic or stochastic; and • A numerical procedure for solution of the resulting system of equations. <p>Section 5.7 should probably address how current or proposed technology will address, over the period of analysis, each of these requirements. It would be particularly valuable if this presentation could be achieved with a minimum of jargon and mathematics.</p>
90	4-10	<p>This would be a good place to discuss the important interfaces among rock engineering, conceptual design, and performance assessment.</p>
91		<p>Figure 5-6 is of marginal utility. More complete code descriptions, more information on inputs, a more detailed figure, and more comprehensive descriptions of the output would help.</p>
92	31-34	<p>The two sentences in this paragraph appear to be unrelated. These sentences could form the basis of separate paragraphs.</p>
93	1-22	<p>One panelist stated that Sec. 5.7.3 was more in line with his perception of how the plan should be written. Although the section merely addresses the question of mathematical equations, the text states what technology is available, why it is needed, and how it will be used. However, the last sentence in this section seems inappropriate because it implies that uncertainty analysis will help unscramble the physics. The physics must be known beforehand.</p>

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
88-93		Subsections 5.7.1 and 5.7.2 are only peripherally related to the objectives of the performance assessment presented in Sec. 5.7, while Sec. 5.7.3 appears to relate directly to these objectives. It is not clear whether the first two subsections are meant to support the main topic or are basically independent of one another. If they are meant to be integrated, a connecting line of thought should be provided.
93-94	23-31; 1-14	Could the discussion in Sec. 5.8 be expanded to be compatible with the detailed presentation in Fig. 5-7?
94	13	The word "tentative" is used for the first time in this context. The word "general" was used for similar figures?
94	21	Should "the boundary conditions" be changed to "the concentration boundary conditions"?
94	25	The authors could discuss their concept of "dead end sorption by disturbed zone." This term is not defined in the glossary.
94 and 96	15-35; 1-26	It is not clear why Sec. 5.9 has been separated from the very short preceding section, which also deals with the general topic of species transport and chemical reactions. Sections 5.8 and 5.9 naturally fall under Sec. 5.7.
97	28-30	This sentence does not appear to be a precise definition of the far field.
97	33	Perhaps the word "discharge" could be replaced by a more precise statement. The intended meaning is not clear.
98	4	"Performance criteria" have not been addressed in any serious way in the plan.
101	31-32	Do the authors mean that the modeling will provide the human-caused phenomena?

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
101	36-38	This statement implies that modeling will provide rock properties. While this may be true in an abstract sense, "behavior" might be a better choice of words.
103		Figure 6-3 is far better than the earlier ones that listed codes. It is much more informative and understandable.
104	1-4	How will site performance assessment provide input to the location recommendation reports? The data on this scale are insufficient for all analyses, especially groundwater flow and geochemical reactions. Also, aren't the site recommendation reports being supplanted by the environmental assessments?
104	19-20	The Kriging technique does not provide optimal "interpretation." The authors may have meant "interpolation."
109		The text is inaccurate and perhaps misleading. An approach similar to that used in Fig. 6-3 would be better.
111	3-5	Simulation of the far field requires hydrological and transport parameters. Because these will be very hard to determine in the repository environment, it would perhaps be helpful to discuss the proposed methodology more specifically.
111	5-7	Determining the age of the groundwater will not verify the flow modeling. It should be made clear that transport calculations are also required.
111	9	What are benchmark zones? This term is not defined in the glossary. While the panelists were able to extract a meaning for this term from the paragraph, the authors might wish to make this paragraph easier for the lay public to understand.
111	16-21	Additional explanation would help the reader relate benchmark testing to radionuclide transport.

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
111	22-35; 1-16	Section 6.7 could be eliminated because evaluation of the transport simulation at a 10-km radius is a rather straightforward application of the regional transport code. If retained, this section needs extensive editing.
121	7	The word "potential," when applied to hazard analysis, usually means that something is possible but not very likely. In this case, that implication is misleading because some plant personnel will definitely be exposed to radiation. The phrase "potential radiation exposures" might be applied to exposure of the general public, but it would be more precise to simply state that the objective is to minimize the radiation exposure of plant personnel and the general public.
121	23	What are the hazards other than radiation dose? If there are other hazards, where are they discussed and how are they quantified?
125	2-4	"Mitigative feedback loops are provided for work operations found to be initially unacceptable." Such loops are very important, for they make certain that, after each dose prediction, the facility and procedures will be redesigned if the dose to workers and the general public is found to be unacceptable. It is unfortunate that the statement of this iterative process is clouded in technical jargon.
128	5-8	The implication is that there may be large "quantities" of radiation without large quantities of radioactivity or vice versa. It would be possible to have high dose rates and/or high levels of radioactive contamination, both airborne and on surfaces. If this is the intent, it should be stated more clearly.
128	17-20	A reader might imply that the classification of a worker enters into the dose equation. It should be explained that the objective is to predict the collective dose per task for each classification of worker. Also, the subsection title would be more descriptive if it read: "Collective Dose per Worker Classification."

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
128	21-22	<p>"The total exposure is determined by forming the product of these three terms." It would be clearer and more precise to write (for a given type of worker):</p> $\text{Predicted Collective Dose per Task} = \text{Average Rate at Worker \#1} \times \text{Exposure time of Worker \#1} + \text{Average Dose x Exposure Time + Etc. Rate at Worker \#2}$ <p>Average Dose x Exposure Time + Etc. Rate at of Worker #2 Worker #2</p> <p>If the dose rates and the exposure times of all workers are the same, which is highly unlikely, then:</p> $\text{Predicted Collective Dose per Task} = \text{Average Dose Rate to All Workers} \times \text{Exposure Time of Workers} \times \text{Number of Workers}$
128	27	It may not be obvious to every reader that "construction and maintenance estimators" are engineers specializing in estimating how long it will take a certain number of people to do a certain task.
129	10-12	This is the first statement that explains the need to classify workers. This point should be made earlier and more clearly.
129	23-24	"The last parameter involved in dose calculations is the definition of radiological conditions for each UO." How can a parameter be a definition? The term "radiological condition" is vague and confusing. Was the intent to include surface and airborne contamination in addition to dose rate as the radiological condition? If so, this should be explained. However, given the context in which "radiological condition" is used, it would be more descriptive to use the term "dose rate."
130	2-3	What is the "Reference Repository Conditions" document? No reference is given for ORIGEN2.

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
130	8	No reference is given for the ISOSHL code.
130	10-11	"Example output parameters determined by this code are as follows." The sentence should read: "Example 'input'-parameters 'required' by this code are as follows."
130	19-20	"The radiological conditions surrounding each UO discussed earlier are given in terms of expected maximum dose rate." See comment for page 129, lines 23-24, on use of the term "radiological condition." Use of the word "surrounding" is confusing. Why is the "maximum" rather than the "average" dose rate used? Couldn't the dose rate for a given exposure period vary from near background levels to some maximum that is orders of magnitude greater? Unless the exposure periods are very short, dose predictions based on maximum dose rates could be greatly overestimated?
130	29	If there is a mechanism for routine release of radioactive particulates, the facility design should prevent it.
130	31-33	What does "proportion of the source terms" mean? The source term is usually expressed in terms of a quantity of something released per unit of time, such as curies (or bequerels) per second. The quantity of interest in the area of an exposed person is the concentration of whatever was released in units like curies per cubic meter. Also, it is more precise to speak of the "maximum exposure" limit for an individual in the general public rather than the "maximum individual exposure limit."
131	1	What kind of dose consequence will be calculated? Would it be the probability of contracting cancer or life shortening? Why attempt to determine any consequence other than dose?
133	1-12	See the comment immediately above. From the context of this paragraph, the term "radiological dose consequence" should be replaced with the term "radiological dose" or simply "dose."

<u>Page(s)</u>	<u>Line(s)</u>	<u>Comments</u>
133	30	What is a "reference environment"? This term is not in the glossary.
135	6	What is the rationale for choosing an upper limit of 0.03 rem/yr per worker for each unit operation?
137	7	It should be explained that \$1,000/person-rem is often used as a reference point, but that such use is controversial.
137	23-24	No reference is given for the EPA recommendation (Fed. Reg., 46[15]:7836 [January 23, 1981]).
141	14-16	While it is true that summation of the annual doses from all events is meaningless, shouldn't the annual dose from some events be summed?
151	1	Change "313" to "3131."
153	9-10	The Kathren (1980) reference is incomplete. Its report number is DOE/1830/T-5.

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PART 2

PEER REVIEW OF VERIFICATION AND VALIDATION PLAN

by

W. Harrison, J. Ditmars, J. Russell,* M. Seitz,[†] G. Pinder[†]
D. Fenster, W. Sha,[§] M. Robinet,** F. Sargent,^{††} W. Wendland,^{‡‡}
D. Rote, E. Walbridge, A. Lerman,^{§§} and D. Edgar

*Texas A&M University

[†]Chemical Technology Division, ANL

[‡]Princeton University

[§]Components Technology Division, ANL

**Occupational Health and Safety Division, ANL

^{††}Whiteshell Nuclear Research Establishment, AECL

^{‡‡}Illinois State Water Survey

^{§§}Northwestern University

PEER REVIEW PANEL MEMBERS

REVIEWERS OF ENTIRE PLAN AND SELECTED CODE DOCUMENTS

<u>Panelist</u>	<u>Code(s)</u>
Dr. John D. Ditmars Leader, Geophysics and Engineering Section Geoscience and Engineering Group Energy and Environmental Systems Division Argonne National Laboratory	MMT, LAYFLO
*Mr. David F. Fenster Geoscience and Engineering Group Energy and Environmental Systems Division Argonne National Laboratory	FFSM (various submodels)
**Dr. Wyman Harrison Associate Director for Geoscience and Engineering Energy and Environmental Systems Division Argonne National Laboratory	FFSM
Professor George F. Pinder Chairman, Department of Civil Engineering Princeton University Princeton, New Jersey	NETFLO, FE3DGW
Mr. McLouis J. Robinet Health Physics Section Occupational Health and Safety Division Argonne National Laboratory	DACRIN, PABLM
Professor James E. Russell Brockett Professor of Mining Engineering and Geophysics Department of Petroleum Engineering Texas A&M University College Station, Texas	SALT 4
Dr. F. Peter Sargent Head, Geochemistry and Applied Chemistry Branch Whiteshell Nuclear Research Establishment, AECL Pinawa, Manitoba, Canada	EQ3/EQ6

*Member of core peer review staff.

**Review panel and review session chairman, and member of core peer review staff.

PEER REVIEW PANEL MEMBERS (Cont'd)

REVIEWERS OF ENTIRE PLAN AND SELECTED CODE DOCUMENTS (Cont'd)

<u>Panelist</u>	<u>Code(s)</u>
Dr. Martin G. Seitz Geochemistry Group Chemical Technology Division Argonne National Laboratory	PHREEQE, UCB-NE
Dr. William T. Sha Director, Analytical Thermal Hydraulic Research Program Components Technology Division Argonne National Laboratory	DOT

REVIEWERS OF SELECTED CODE DOCUMENTS ONLY

Dr. Dorland E. Edgar Geoscience and Engineering Group Energy and Environmental Systems Division Argonne National Laboratory	FFSM, Geomorphic Processes Submodel
Professor Abraham Lerman Department of Geological Sciences Northwestern University Evanston, Illinois	WAPPA
Dr. Donald M. Rote Geoscience and Engineering Group Energy and Environmental Systems Division Argonne National Laboratory	WAPPA
Dr. Edward W. Walbridge Geoscience and Engineering Group Energy and Environmental Systems Division Argonne National Laboratory	DOT
Dr. Wayne M. Wendland Head, Climatology and Meteorology Section Illinois State Water Survey Champaign, Illinois	FFSM, Climate Submodel

PART 2

PEER REVIEW OF VERIFICATION AND VALIDATION PLAN

by

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D. Rote, E. Walbridge, A. Lerman, and D. Edgar

SUMMARY OF RECOMMENDATIONS

The following recommendations have been abstracted from Part 2 of this report. The ONWI Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt should:

1. State clearly the precise purpose of the plan, preferably at the beginning and under an appropriate heading.
2. Also under an appropriate heading and immediately after the section on purpose, describe the scope of the plan, including what the plan covers and the major bounds and interfaces of the plan.
3. Be edited for syntax, word usage, spelling, and grammar.
4. Include a well-written executive summary.
5. Indicate that codes will be documented according to NRC's *Final Technical Position on Documentation of Computer Codes for High-Level Waste Management* (NUREG-0856).
6. State that ONWI will notify NRC via a software summary whenever a new version of a code is released or when major modifications to codes are made.
7. Reflect the NUREG-0856 guidelines for development of users' manuals for all codes.
8. Define the terms "verification" and "validation" when first used in the text. The following definitions, which correspond more closely to those of NUREG-0856 but still retain the introductory words "test and evaluation" from the Verification and Validation Plan, should be used.

Verification -- test and evaluation to assure that a computer code correctly performs the operations specified in a mathematical model.

Validation -- test and evaluation to assure that a model as embodied in a computer code is a correct representation of the process or system for which it is intended.

9. Mention induced fracturing in Table 1-1. Performance assessment must indicate whether fracturing will be induced.
10. Present an expanded milestone chart that covers the following additional activities: selection of codes to be used in performance assessment, performance specification review, design review, code design verification, peer review, and any other activities that are mentioned in the plan for future completion (e.g., establishment of benchmark problems).
11. For each code, include a specific milestone that provides for a meeting between the individuals responsible for validating the code and those providing input data for validation.
12. Identify wherever possible the parties responsible for activities like quality assurance and establishment of criteria for mathematical and computer code acceptance.
13. For the purpose of estimating whether the plan is achievable, include (1) a discussion of the resources (principally funding and personnel) required to verify and validate the codes chosen for performance assessment and (2) an estimate of the time and cost required to simulate the behavior of the entire repository system at a prime salt site, given the range of possible scenarios, after all of the codes have been verified and validated.
14. Include a master chart that gives the relationships among the codes, the links or overlaps between codes, and the respective assessment realms that the codes cover, that is, very near field (waste package), near field (repository), and far field (site).
15. Present a master milestone chart that gives all of the significant performance assessment and code validation milestones and their relationships to major milestones of related programs.

16. Explain more clearly what constitutes validation of a code for the salt repository program. For example, how are the results of a code validation exercise interpreted to determine whether the code is indeed validated?
17. Expand the discussion of code verification to include techniques available for determining numerical errors; criteria for deciding how much error will be acceptable and under what scenarios such tests should be conducted; use of sensitivity and response studies to gage code behavior; checks on nonstandard outputs (total mass, heat, energy, etc.) to assess conformity with appropriate conservation laws; discussions of the problems of comparing discrete finite-difference or finite-element results with continuous experimental and analytical results or with output from other models; and quantitative measures of agreement.
18. Downplay the use of data bases acquired for engineering design for code validation. Because data bases acquired for engineering design are not likely to be sufficient or entirely appropriate for code validation, acquisition of data bases for validation requires special consideration.
19. Improve the code status reports by using better (generally simpler) headings, by giving more specific information on results under the relevant headings, and by more accurately describing the codes themselves.
20. Give more realistic appraisals of the degree to which code documents support the plan and specify the nature of, and schedule for, each code's required development, verification, and validation.

The Argonne core peer review staff also recommend that ONWI give serious consideration to combining the Verification and Validation Plan with the Performance Assessment Plan. Combining the plans would provide for an overview section, presently lacking in both plans, that would describe the interrelationships between performance assessment and verification and validation activities.

6 INTRODUCTION TO PART 2

Development and implementation of a plan for verification and validation of computer codes for modeling the many processes and hypothetical events that could affect performance of a repository system for high-level nuclear waste is of prime importance to DOE's CRWM Program. The Office of Nuclear Waste Isolation at Battelle Memorial Institute is to develop such a plan for DOE's application to NRC for a license to construct a repository in salt, whether or not such application is made.

Argonne National Laboratory's peer review of ONWI's Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt involved obtaining written critiques of the plan from the panelists listed on pages 29-30. A core group of five Argonne panelists then reviewed all of the comments and drafted Part 2 of the present report. Panelists did not contact ONWI personnel, and none of the panelists has been involved in any programs sponsored by DOE or directed by ONWI such that their participation in the review could be construed as a conflict of interest.

Although no specific guidance was provided to Argonne by DOE on the manner in which the review was to be conducted, the following questions were prepared by DOE to assist in the review process (see App. A):

1. Are the scope and purpose of the document clear?
2. Are the milestones most appropriately identified? Are there key activities that have been overlooked?
3. Is the plan achievable?
4. Are the VVP [Verification and Validation Plan] milestones clearly linked to the ONWI project as a whole?
5. Are the descriptive parts of the plan necessary and appropriate to make the VVP effective in making the plans clear?
6. Is it clear what the plans are code by code and for the ONWI project as a whole?
7. Will the V & V [verification and validation] plans if carried out result in confidence in the results of ONWI's performance assessments?

In addition to responding to the above questions, the Argonne panelists commented on the technical quality of the plan, on the descriptions of the code documents in the plan, and on how well each code document supports the

plan as a whole. Finally, expanded summaries were written for three of the code documents. These summaries analyze the applicability of each code to performance assessment.

Throughout its review, the Argonne panel referenced its comments on the ONWI Verification and Validation Plan to four documents: (1) 10 CFR Part 60, NRC's proposed rule entitled *Disposal of High-Level Radioactive Wastes in Geologic Repositories*, Fed. Reg., 46(130):35,280-35,296 (July 8, 1981); (2) 10 CFR Part 60, NRC's final rule entitled *Disposal of High-Level Radioactive Wastes in Geologic Repositories, Technical Criteria*, Fed. Reg., 48(120):28,194-28,229 (June 21, 1983); (3) NRC's *Final Technical Position on Documentation of Computer Codes for High-Level Waste Management*, NUREG-0856 (June 1983); and (4) NRC's Regulatory Guide 4.17 entitled *Standard Format and Content of Site Characterization Reports for High-Level-Waste Geologic Repositories* (July 1982). These documents are referred to in the text that follows as "10 CFR 60" (proposed and final), "NUREG-0856," and "Regulatory Guide," respectively.

7 U.S. NUCLEAR REGULATORY COMMISSION'S POSITION ON CODE DOCUMENTATION

Of particular significance to ONWI's Verification and Validation Plan is NUREG-0856, which is NRC's final technical position on documentation of computer codes for management of high-level waste. As stated in an introductory notice, this document was

...issued to provide guidance that NRC staff believes should be followed to partially meet the requirements of 10 CFR 60. NUREG-0856 is not a substitute for the regulations, and compliance is not a requirement. However, an approach or method different from the guidance contained herein will be accepted only if the substitute approach or method provides a basis for determining that the above cited [10 CFR 60] regulatory requirements have been met.

Although the final version of NUREG-0856 was published in June 1983, an earlier draft, published in December 1981, is cited on page 79 of the plan. Comparison of the 1981 and 1983 versions of NUREG-0856 indicates only minor differences. However, there are significant differences between NUREG-0856 and App. B of the plan (Procedure for Code Documentation, Revision and Transfer). These differences and several other deficiencies of App. B are discussed below.

Section 1.0 (Purpose) should indicate that code documentation will meet NUREG-0856 requirements. Following this NRC document is important because the codes will help in providing a means of meeting the "reasonable assurance" requirement of 10 CFR 60.

Section 2.0 (Scope) should be rewritten to include all five categories listed on page 1 of NUREG-0856. At present, only three of the categories are listed.

Section 3.0 (References) states that the guidelines in the plan for documentation "...were adopted from NUREG-0856...and ANSI [American National Standards Institute] Standard N-413..." In actuality, the Verification and Validation Plan guidelines are an abbreviated and modified form of NUREG-0856. Although NUREG-0856 is based on ANSI N-413, it represents an expansion of that standard to better suit the licensing requirements for high-level nuclear waste isolation. In particular, it calls for theoretical documentation in much more depth than the ANSI standard requires. Therefore, at a minimum, the plan must meet the NUREG-0856 documentation requirements. On page 1 of NUREG-0856, it states that "more detailed treatment of the basic methods is necessary for high-level waste licensing application because of the anticipated importance that modeling will have in licensing decisions and because certain codes are relatively new."

Section 5.0 (Requirements) should be rewritten to conform to the revisions recommended above for Sec. 2.0 (Scope).

Section 5.1 (Code Abstract) is apparently useful in ONWI's scheme of things, but it should not take the place of NRC's software summary, a revised copy of which should be sent to NRC when a new version of a code is released or when codes are significantly modified. Indeed, the entire matter of notifying NRC via software summaries (NUREG-0856, Sec. III.A.) is ignored in the plan. This oversight should be corrected.

Section 5.2 (Mathematical Models and Numerical Methods) is significantly deficient in coverage compared with NUREG-0856. All of the items specified in Sec. III.B. of NUREG-0856 should be incorporated into the plan unless clear and compelling reasons are given for not doing so.

Section II (Procedure for Code Revision) seems to correspond to Sec. III.E. (Continuing Documentation and Code Listings) of NUREG-0856 but does not refer to NRC's reporting requirements for code revisions by ONWI. All NRC requirements should be incorporated into the plan's procedures for code revision.

Section III (Procedure for Code Transfer) appears to go beyond NRC requirements and seems well designed. The authors are to be commended for developing this procedure.

8 SUGGESTIONS TO IMPROVE PRESENTATION

As presently written and illustrated, the ONWI Verification and Validation Plan is frequently difficult to understand. The following suggestions should assist the authors in their next revision.

8.1 INTRODUCTORY MATERIAL RELATING TO THE PLAN ITSELF

8.1.1 Preface

The preface is of marginal utility because of the repetition between it and Sec. 1 (Scope and Objectives). If retained at all, it should be shortened and carefully edited for spelling and grammar. The terms "verification" and "validation" are introduced at this point but without definition, and the definitions in the glossary do not correspond to the way in which these terms are used in the text. Using the definitions given in the glossary, one would not normally use verification and validation together. As defined, the former term refers to the computer code and the latter to the mathematical and conceptual model. As an example of inappropriate use, consider the following phrase: "The V&V of mathematical models used in the computer codes..." (line 11 on p. 1).

8.1.2 Scope and Objectives

As suggested in Part 1 of this report, it would be better to begin the plan with the following three sections (or subsections): Purpose, Scope, and Approach. The purpose of the plan is not clearly stated but can be discerned as one reads through Sec. 1 (Scope and Objectives). However, only the first sentence in Sec. 1.2 (Objectives) deals with objectives as such. (Again, poor syntax weakens the sentence, which says (in part) that one of the objectives of the plan is "to define...the current status of activities." What does this phrase mean? The remaining material in Sec. 1.2 concerns not only approach but also methodology. Perhaps the material on methodology could be presented in its own subsection.

Section 1.1 (Scope) begins with a sentence that is difficult to understand and only tangentially related to scope but is somewhat related to purpose. The second sentence is better designed to cover scope but does not identify all of the main processes to be considered. This second sentence refers to Table 1-1 entitled "Various Scientific and Engineering Processes Considered in Performance Assessment of Mined Geologic Repository Systems in Salt." The use of the word "scientific" is confusing. Is "natural" meant? And, what is meant by "engineering processes"? The many details in this table are not helpful at this point in the presentation. Also, some of the topics

are repeated; radioactive decay, for example, appears in both item 1 and item 8. A revised section on scope should include the limits of the subjects to be covered, their relationships to the ONWI Performance Assessment Plan discussed in Part 1, and the important interfaces with other aspects of the ONWI program.

A major omission in the discussion of scope is that Table 1-1 does not mention induced fracturing. The potential for fracturing, particularly in any overlying aquitards, is of major concern in performance assessment, primarily because of the increased hydraulic conductivity associated with fractures and the potential for freshwater intrusion into the host salt bed. The available computer codes mentioned in the plan are based on continuum theories and will produce estimates of stresses and deformations (strains or changes in displacements). These estimates may be adequate, along with a knowledge of the temperature, to estimate whether the rock will fracture at a particular point so long as the appropriate fracture criterion is known. However, once fracturing has been initiated, the continuum-type codes are not adequate to estimate the stresses or deformations in the neighborhood of induced fractures. In other words, existing computer codes will not simulate the response of the rock mass very well once fracturing is initiated. Obviously, the design strategy should be to avoid inducing fractures by controlling parameters like areal extraction ratio and thermal loading. Performance assessment must be able to evaluate whether fracturing will be induced.

In rewriting Sec. 1, care should be taken with grammar, syntax, and word usage. This section is loaded with jargon, undefined terms, and contradictory and vague statements. The first paragraph on page 2 is particularly difficult to unscramble. Also, the first complete sentence on page 3 should be revised. One reads "No standard formats are proposed for V&V documents to be developed for specific codes and models," while Sec. I of App. B is devoted to procedures for code documentation and presents in detail the required document structure.

Finally, one would expect to find clear definitions of "verification" and "validation," along with the distinguishing features of verification and validation exercises in the context of salt repositories. No definitions are given in the introductory material, not even those that appear in the glossary. There is also no discussion of potential difficulties in arriving at the elusive states of "verification" and "validation" or of determining what constitutes these states. Discussions in the technical literature of verification and validation of models are usually dominated by such issues and are oriented toward finding quantitative measures of verification and validation. The plan never seems to confront these central issues.

8.2 IDENTIFICATION OF MILESTONES

Milestones are not specifically mentioned in the ONWI Verification and Validation Plan. Although Fig. 4.1 gives a schedule for documentation,

verification, benchmarking, and validation of performance assessment computer codes, it deals only with specific computer codes and not with the plan itself. Milestones for 12 of the 26 codes have question marks associated with them, and the milestones as given have only a general relationship to the key verification and validation activities identified in Sec. 3. Why are performance specification review, design review, code design verification, and peer review activities not included in the legend? More important, however, is the lack of a milestone chart to mark completion of the future activities mentioned in the plan. Annual review of the plan itself is an obvious example, but there are other activities mentioned in Sec. 2.2. Items such as establishment of benchmark problems and other inputs to the whole verification and validation system must be scheduled.

As mentioned in Sec. 8.1, further discussion is needed of what constitutes verification and validation for each specific code. A milestone relative to this question may be needed for each code.

On page 29, it states that the "...current uncertainty with respect to long-range schedules for site characterization, and consequently the time of availability of site-specific data for in situ validation [requires that only fiscal years be] given for the planned validation activities rather than specific completion dates." Years are not given for each of the individual codes discussed in Sec. 4, and no dates are given even for activities like benchmarking that do not depend on the schedule for site characterization.

In general, the plan would be improved by giving dates for milestones and indicating which milestones are the most uncertain because of necessary interactions with other components of the program. Other key items that need to be included on a milestone chart are the activity that will result in selection of the codes to be used in performance assessment and the activity that may result in inclusion of additional codes.

9 KEY ACTIVITIES THAT HAVE BEEN OVERLOOKED

9.1 COORDINATION BETWEEN MODELERS AND DATA GENERATORS

Because the use of various data sets for model validation is mentioned in the ONWI Verification and Validation Plan, it is very important that meetings between salt-site data generators and modelers be planned early in the verification and validation schedule for each model. The data needs of modelers must be communicated as early as possible to the data generators, and data generators must communicate the problems they foresee in satisfying the data needs of the modelers.

Site-specific laboratory or field data may indicate a need to revise a computer code. Alternatively, field or laboratory validation of computer codes with preliminary data may indicate a need for code revision. For example, as more site-specific data are gathered, increased knowledge of natural or repository-induced processes may require revisions to various codes. This type of activity should be given a specific milestone in Fig. 4.1.

A perfect example of lack of coordination between modelers and data generators is found in ONWI-436 (INTERA, 1983a). Although one reads again and again about user-supplied input and its importance, nothing is said of mechanisms for ensuring that the input is timely, valid, and achievable by data generators in the ONWI program. Finally, a major conclusion of PNL-4129 (Doctor et al., 1982) is that

...geostatistical and hydrologic analyses should be integrated with the field work as soon as possible after data collection begins. This would allow additional characterization data to be collected while the study is in progress, creating a more cost-effective data base.

9.2 DEVELOPMENT OF USERS' MANUALS

The development of a user's manual for each computer code is almost overlooked in the plan. Although this important item is mentioned in Sec. 5.3 in App. B, it is not discussed explicitly elsewhere in the plan, and it comes up only at random in the individual code status reports.

9.3 ASSIGNMENT OF RESPONSIBILITIES

Assignment of responsibility for many important activities is vague or missing. For example, documented code review is by "developer and/or other persons" (p. 8), responsible parties for quality assurance are not identified (p. 10), and responsibility for establishing criteria for mathematical model and computer code acceptance is not assigned (p. 13).

9.4 IDENTIFICATION OF PROBLEMS TO BE ADDRESSED BY MODELS

An important stage in the evaluation of models has been omitted, or at least is not explicitly apparent. Checking on the definition of the "real problem" should always be the first step in the verification and validation process. Then prior to, or as part of, the review of performance specification (p. 6), the relationship between the analysis to be conducted and the perceived salt repository problem should be considered. In other words, the appropriateness of the given analysis to a specific problem or group of problems needs review. Although this issue is discussed in the ONWI Performance Assessment Plan, these steps should come first in verification and validation activities. Without them, much effort may be expended on verifying and validating models that may have little utility for the current set of problems. Problems have a way of being redefined as programs progress.

9.5 INTERFACES BETWEEN MODELS

The need to use suites of models to answer some questions and the issue of interfacing models are discussed on page 14 (item 3) but are never seriously addressed elsewhere in the plan. Important problems like compatibility of space and time scales and dimensionality are ignored. Interfacing requires much more thought and effort than simply making certain that the inputs and outputs of different codes are compatible. Interfacing cannot be done by considering the codes individually. It requires planning in the definition and development stages. The plan should reflect the special testing required to ensure that such interfacing is not only feasible but also makes physical and computational sense.

10 IS THE PLAN ACHIEVABLE?

The plan is presumably achievable given adequate time, funding, and usable input data; however, such constraints will loom rather large if the deadlines set by the National Waste Policy Act of 1982 are to be met. Much will depend on the degree of uncertainty in model predictions that NRC will be willing to accept.

Cross-listing of computer programs from different mainframe computers is one area in which major problems could arise. In ONWI's compartmentalized approach to performance assessment, a number of computer programs will be used, each one for a different part of the analysis. As indicated in both the Verification and Validation Plan and Performance Assessment Plan, the programs operate on several different computers. It is probably not practical to convert all of these codes to run on one machine or to make separate runs on different machines. The plan should contain additional information on what, who, when, and where. For example, more information should be provided on where and on what types of computers the work will be done, and how the computing will be coordinated.

Another problem affecting whether the plan is achievable has to do with using nested or linked codes that require different inputs. For example, some codes use averaged values, some use parametric inputs, and some use data in a finite-element format. More information on how this problem area will be handled would be helpful. This issue should possibly be addressed in the Performance Assessment Plan.

Also important in this regard are resource requirements, for what looks to be an enormous data-gathering and computing exercise. The plan should discuss funding, personnel, and equipment requirements. Once ONWI selects its subset of models to support the Performance Assessment Plan and after all the codes have been verified and validated, INTERA Environmental Consultants should be asked to make a first-cut estimate of the time and cost required to simulate the behavior of the entire repository system, given the range of possible scenarios.

For a typical model like the Far-Field State Model (FFSM) (INTERA, 1983a), the time and cost required to run each submodel and the minimum number of simulation runs necessary to provide meaningful output would need to be estimated. The time and cost associated with obtaining the input data required for each FFSM submodel should also be estimated. The combined time and cost estimates for data acquisition and model runs for each model of the final subset will yield an approximation of the overall time required and cost of the modeling effort separate from the up-front expenditures of time and dollars required to verify and validate the models. If such an overall prediction were available now, it would help in assessing whether the plan is achievable.

It is probably possible to verify most of the codes, at least for simplified cases where analytical solutions are available. Validation is much more difficult. Indeed, it may be impossible to truly validate many of the codes because of the long times or the large geometric scales involved. The question raised earlier as to how much verification and validation is necessary for each code and when that decision needs to be made is germane here as well.

Another potential problem in completing verification and validation activities is the need for interaction with other components of the ONWI program. Results from in situ, site-specific, or laboratory tests may require that existing performance assessment codes be modified to include processes or couplings not well understood at present. Such feedback and resulting code modifications may require revisions in the milestone schedule.

Figure 4.1 indicates that plans are not yet formulated for nearly one-half of the codes on the list. No information is given as to who is formulating these plans, when these plans will be formulated, or what criteria are being used in formulating the plans. Also needing discussion is how these plans fit into the ONWI project as a whole.

Finally, suppose that a code were to be validated by comparison with results of an in situ test. If the comparison were found to be inadequate, some strategy is needed for resolving the problem. That is, the plan should include at a minimum some limit on expenditure of effort and funds for resolving such questions and criteria for finally rejecting a code if it cannot be validated against reliable in situ test data. An essential part of validation is deciding how good is good enough. This question should be addressed on a code-by-code basis. If a code is finally rejected, how will performance assessment proceed? For example, the rejection process should consider the consequences of not being able to predict changes in stress, deformation, or permeability.

11 IMPROVING THE TECHNICAL CONTENT OF THE PLAN

All aspects of NUREG-0856 should be taken into account when the authors revise the ONWI Verification and Validation Plan. By following NRC guidelines, the problems and deficiencies discussed below can be remedied.

11.1 LINKING VERIFICATION AND VALIDATION MILESTONES TO MILESTONES OF THE PROJECT AS A WHOLE

The relationships between milestones given in the Verification and Validation Plan and those of the overall ONWI salt project are not apparent. This is a serious oversight. Questions as to when verification and validation activities must be completed so as not to affect the salt project schedule negatively cannot be answered. A master chart should be presented that gives all of the significant performance assessment and code verification and validation milestones, as well as their relationships not only to milestones of the overall ONWI project, but also to major milestones of related efforts, such as those found in the ONWI Geochemistry Program Plan (Czyscinski et al., 1982; see microfiche copies inside the back cover of this report).

11.2 REVISING THE DISCUSSIONS OF THE TERMS "VERIFICATION" AND "VALIDATION"

Usually accompanying the various definitions of verification and validation available in the literature are discussions of the implications of the particular definitions. Although the definitions given in the plan's glossary are generally acceptable, they should be modified to conform more closely to those given in NUREG-0856. The following definitions are recommended as combining the best elements of both the NUREG-0856 and the ONWI definitions.

Verification -- test and evaluation to assure that a computer code correctly performs the operations specified in a mathematical model.

Validation -- test and evaluation to assure that a model as embodied in a computer code is a correct representation of the process or system for which it is intended.

What is missing in the plan is discussion of the definitions in terms of what constitutes verification and validation for the salt repository program. Also missing is discussion of the specific activities that will be required to accomplish verification and validation. In fact, what discussion there is in the plan deals almost entirely with verification. Validation of models of presently nonexistent systems and of processes with extremely long time scales will definitely strain existing validation frameworks and will require careful planning.

11.2.1 Verification

An important part of the verification process is making certain that the physics chosen to be modeled really addresses the proper problem. This issue is not emphasized enough in the plan and is one for which peer reviewers can provide useful input. The emphasis in the plan is on code design verification to the detriment of other aspects of verification. While the mechanics of code checking are certainly important, the discussion on pages 14-21 seems disproportionately long when compared with the discussions of more substantive verification questions.

While benchmarking may be an effective verification tool where two or more codes produce essentially comparable results, the emphasis on this technique seems inordinate. Also, how one resolves disparities in results from different models purporting to do the same thing should be discussed. Finally, advocating computer animation (pp. 22-23) is appropriate in the context of verification tools, but the technique seems to be presented as an end rather than as a means.

Missing are discussions of (1) techniques for determining numerical errors; (2) criteria for deciding how much error is acceptable and under what scenarios such error tests should be conducted; (3) use of sensitivity and response studies to gage code behavior (mentioned only in Sec. 3.5); (4) checks on nonstandard outputs (e.g., total mass, heat, and energy) to assess conformity with appropriate conservation laws; (5) problems of comparing discrete finite-difference or finite-element results with continuous experimental and analytical results or with output from other models; and (6) quantitative measures of agreement.

On pages 15 and 23, the text states that manual code design verification and other verification activities can be accomplished cost-effectively with peer reviews. Although peer reviews can provide valuable guidance by checking general approaches and general results, they cannot debug codes and catch other code design problems. Only those few people with extensive hands-on experience with a specific code can provide the level of review suggested in the text. If such people are not available, it will be expensive and time-consuming to provide the required expertise.

In conclusion, the details of the performance specification review on pages 12-13 seem vague and ill-defined, yet this is clearly an important aspect of verification. Although ONWI-432 (INTERA, 1983b) is a good example of clearly written performance specifications, it is not clear that other documents will handle this area as well without guidance from the plan. The criteria for model and code acceptance are not explained, nor are examples given, nor is responsibility for development of the criteria assigned. The sections on "range of applicability" and "input and output" are vague and omit temporal and spatial resolution and requirements to monitor intermediate computational results to gage code behavior.

11.2.2 Validation

The discussions on pages 11 and 25 of site-specific validation are brief and ignore important issues that deserve consideration, even though this exercise is scheduled for 1988. For example, sufficient experience from validation exercises in other disciplines is available to suggest that data acquired for engineering design are usually insufficient for code validation. The data base for validation should be obtained through activities designed from the outset for validation exercises. The results of sensitivity and response studies should be used to point the way toward those processes, as well as those parameters, that need in situ study. The modeling experience should drive the data acquisition plans.

11.3 IMPROVING THE DISCUSSION OF CODE DOCUMENTATION

Documentation of computer codes, one of the most important steps in a verification and validation program, is handled poorly in the plan. The discussion in Sec. 2.1.3 is vague and mostly irrelevant. There is no mention of users' manuals, no statement of the purpose of the verification tests performed, no specification of the parameter ranges over which tests have been carried out, and no quantification of test results. Also, determination of the requirements for documentation is left up to the code developer. While a certain amount of flexibility in this regard is beneficial, it is not clear that leaving documentation totally unguided, actually the present situation, will result in anything but confusion later. Here again, it is difficult to understand why NUREG-0856 was essentially ignored by the authors of the plan.

11.4 IMPROVING CODE STATUS REPORTS

Although the code-by-code summaries in the plan are clearly a first attempt to summarize the current status of the several codes, a few specific changes are needed, even at this early stage. In general, the headings "Development and Documentation Stage" (Review?) and "Performance Specification and Code-Design Review" should each be broken into their two parts. There are no good reasons to combine these items and good reasons to have them separate. More explicit descriptions of the reviews and reviewers under the several headings would be helpful. Sample review statements for each of these four areas for a given model would be a useful addition to the introductory material in Sec. 4.

The heading "Validation and Field Applications" should also be split into two headings. Each item is distinct, and it is important not to confuse them. Applications of a code may provide useful insight as far as code operation and response, but they do not constitute validation. A particular application may be for distinctly different circumstances than those encountered in salt repository work.

In general, reports of verification, benchmarking, validation, and peer review should emphasize results and not be merely descriptive. For example, saying that "the model was verified using experimental results from MIT" (p. 52) conveys very little. Verified with respect to which parameters and under what conditions? The peer review statements are also generally weak and will not connote acceptance unless the review groups are identified and their actions explained. For example, does the fact that the code has been successfully tested by the National Energy Software Center constitute peer review (p. 70)?

To illustrate the inadequacies of the code status reports, the FFSM code status report (see Sec. 4.6) is discussed in detail in the paragraphs that follow. The FFSM code is based in part on Pacific Northwest Laboratory's Geologic Simulation Model (GSM), although the model and code are entirely new (INTERA, 1983a, ONWI-436). The following comments, which are keyed to the eight subheadings used in each code status report, suggest that the code status reports need to be written with more care and attention to detail.

1. Description. The description of the FFSM code given in Sec. 4.6 of the plan is not consistent with that given in ONWI-436, as can be seen by comparing the description given in the plan with that given in the software summary for the FFSM code.
2. Development and Documentation Stage. The FFSM code, as developed for INTERA by Arthur D. Little, Inc., is structured for general application rather than for a salt-site simulation. Indeed, ONWI-436 states on page 8: "Since the model considers a broad set of natural and human phenomena, for a detailed specific site simulation, the code may need to be modified and upgraded." This important information should appear in Sec. 4.6 under the above heading.
3. Performance Specification and Code Design Review. The statement that "internal review was completed" is clearly insufficient.
4. Verification Tests. The description of verification tests in Sec. 4.6 is not quite the same as that given on page 81 of ONWI-436. Particularly puzzling is the statement that purports to describe certain verification tests that were performed: "(3) Comparison of simulations of individual submodels with simulations of all submodel interactions." No evidence of such a verification test appears in ONWI-436.

5. Benchmarking. The plan says that "...only a partial benchmarking between the codes [GSM and FFSM] is possible..." Two things are wrong with this statement: (1) the authors of ONWI-436 state that FFSM is an entirely new code, making partial benchmarking inapplicable, and (2) it is pointless to talk further of GSM, as it is a different code.
6. Validation and Field Applications. The plan states that Pacific Northwest Laboratory's GSM has been applied to a reference site in the Columbia Plateau basalts. This statement has no relevance for the intended application of FFSM to a salt site and should be removed from the plan. The plan goes on to give the same caveats as the authors of ONWI-436 respecting the impossibility of completely validating FFSM. The plan then says that "...peer review of the individual process formulations and the overall modeling approach is the main mechanism to obtain model acceptance..." This statement ignores what was said by the authors of ONWI-436, that is, "it has been suggested that additional validation evidence may be able to be obtained by applying the models to the historic evolution of a site using part of the historical data and testing for confirmation of additional historical data." This appears to be a good approach for testing several of FFSM's submodels, and the authors of the plan should recast the foregoing quoted statement from ONWI-436 and make it one of the procedures to be followed under the above heading.
7. Peer Review. It is again inappropriate to refer to formulation and review of the GSM submodels. This very misleading statement should be deleted. At issue here is a code for a salt site, not a basalt site. Because there are new submodels and a whole new code, a completely new peer review process for FFSM is needed.
8. References. NUREG-0856 should be referenced.

12 DEGREE TO WHICH CODE DOCUMENTS SUPPORT THE PLAN

A preliminary examination was made of each code document to assess its support of the ONWI Verification and Validation Plan. Detailed reviews were conducted for only three typical documents — one for the very near field, one for the near field, and one for the far field. The results of the detailed reviews are presented in Sec. 12, whereas the comments on the preliminary examinations of the other code documents are summarized in Sec. 13. In addition to assessing the degree of support of the plan, the commentary on each of the three codes provides a summary of the code and its apparent applicability to performance assessment. Such summaries are useful for performance assessment in general, as well as for verification and validation. An Argonne special advisory report will provide this level of summary for the remaining code documents.

12.1 WAPPA: WASTE PACKAGE PERFORMANCE ASSESSMENT MODEL

12.1.1 Description

General Model

The Waste Package Performance Assessment (WAPPA) model (INTERA, 1983c, ONWI-452) is a very near field model that covers the major processes responsible for waste package degradation. The five submodels -- radiation, thermal, mechanical, corrosion, and leach -- determine the integrity of the barriers designed to isolate the waste form from the repository. Radionuclide fluxes at the waste package/repository interface are calculated as a function of time. The code can handle up to 17 barriers, including a backfill layer, and can be applied to waste forms that are homogeneous, brittle, and uniformly leachable. Cladded spent-fuel assemblies and CERMET waste forms may not be accurately treated because of structural inhomogeneities and deviations from cylindrical symmetry.

From a systems point of view, the WAPPA code transforms output data from codes that provide information on (1) nuclide inventory and the heat generated within a particular waste form as a function of time and (2) temperature, mechanical stress, and fluid flux boundary conditions as a function of time at the waste package/repository interface into heat and nuclide fluxes at that interface for use as input to other models treating transport in the near field. Although all of the codes that sequentially process input and output information are operated independently, the waste package/repository system is naturally coupled, and the boundary conditions at the waste package/repository interface cannot be determined in a self-consistent manner without proper treatment of the coupling.

The WAPPA model assumes cylindrical symmetry, which seems satisfactory for an isolated waste package but ignores the possibility that the distribution of waste packages within the repository may significantly alter that symmetry.

The code operates over a sequence of 30 time steps that covers geologic periods of up to 10 million years. During each time step, the five process models operate independently and simulate degradation of the barriers. At the end of each time step, the effects of all processes on the barriers are integrated, and the status of all barriers is updated. During the next time step, the process models operate on the updated barriers. Operation of the process codes is thereby coupled. A restart option allows users to add or insert additional time steps to obtain better resolution.

Process Submodels

The radiation and thermal process submodels are driven internally from the nuclide inventory and heat generated within the waste form. The corrosion and leach process submodels are driven externally by mechanical stresses and fluid fluxes. Although corrosion rates can be enhanced by radiation, possible degradation of the mechanical properties of barrier materials by radiation damage is not treated. Also, corrosion originating internally is not considered. The corrosion model begins operation when the user input data indicate that the backfill has been wetted. In other words, the user must provide a time when the repository becomes saturated. The leach model doesn't begin operation until all barriers have been breached and fluid from the repository contacts the waste form, which is continuously subject to radiation and mechanical damage.

The radiation process submodel requires a user-specified data set, including nuclide inventory and heat generation data as a function of time for the waste form of interest. This data set must be obtained from a detailed code like ORIGEN2 (Croff, 1980) that treats the characteristics of a waste form after irradiation of the waste products. The radiation process model takes data directly from a look-up table if the time steps are properly chosen (20 for ORIGEN2) or interpolates for other times. Gamma ray attenuation by the package components, radiation damage to the waste form, and corrosion and leach enhancement resulting from radiolysis processes all require empirical input data.

The thermal process submodel treats heat flow across concentric annuli using the power input from the ORIGEN2 code or its alternatives. All three basic forms of heat transfer are considered.

The mechanical process submodel calculates radial and axial stresses, and canister and waste form fracturing. Required inputs include the state of stress at the waste package/repository interface and thermal input from the thermal process submodel. Only tensile stress fracturing of the waste form is treated.

The corrosion process submodel comprises five corrosion submodels: general corrosion, localized pitting and crevice corrosion, stress corrosion, galvanic corrosion, and dry oxidation. Of these, pitting and crevice corrosion, and stress corrosion, are assumed to be catastrophic. In other words, if they are operative for a particular barrier within a given time step, that barrier is assumed to be breached or completely destroyed during that time step. Three important limitations to the corrosion process submodel are apparent. First, internal corrosion is ignored, which may be a nonconservative assumption. Second, only galvanic corrosion between pairs of metal barriers is considered. Thus, single-barrier galvanic corrosion is ignored, which may also be a nonconservative assumption. Third, the effects of corrosion films are ignored, which is presumably a conservative assumption.

The leach process submodel calculates the mass transport of nuclides across the waste package/repository interface by both diffusive and advective transport. The backfill is treated by this model as a "mixing cell." In other words, the backfill is considered to be instantaneously and uniformly wetted by new fluid entering it from the repository or by contaminated fluid entering from the interior waste package. The boundary condition at the interface is assumed to be of the "swept-away" type. In other words, any nuclides crossing the interface are immediately swept away so that no accumulation occurs. Making this assumption means that the effluent from one waste package never influences adjacent waste packages. The consequences of ignoring cumulative effects (nonzero nuclide concentrations in the near-field repository) have not been addressed.

Sophisticated numerical methods are not used in any of the process submodels. Most are closed-form analytical expressions requiring empirical input data. The leach process submodel solves four simple simultaneous equations using the Gauss-elimination technique.

12.1.2 Model Status

Documentation

The WAPPA code has been documented by INTERA Environmental Consultants in accordance with NUREG-0856. The theory of each of the five process submodels is explained in detail, as is the verification procedure. A detailed user's manual is provided, along with a code listing on microfiche. The documentation is quite complete, although not without problems.

Although the overall structure of the code is clear enough, the interactions among the five independent process submodels cannot be fully appreciated. While the required information is all there, it tends to be buried in the descriptions of the individual process submodels, and one is not always sure which interactions are included and how they are implemented. For example, the mechanical submodel assumes that, once the backfill stress limit

is exceeded and the backfill "fails," the backfill shall be treated as an incompressible fluid. The reader is left to wonder what happens, if anything, to all the other properties of the backfill in this failed state. Also, the influence of stress on the solubility of the waste form is not mentioned in the mechanical model. Finally, although the need for more flexibility in the choice of corrosion film growth models is emphasized, how the growth of films might influence the outcome of any calculations is not discussed. In fact, it appears that the growth of such films is calculated, but the effects of such growth are subsequently ignored.

Although most of the physical processes treated by the five process submodels are described, the descriptions of physical processes in many cases do not give a clear picture of what is going on. For example, the backfill barrier is described in terms of a "mixed-cell" model in which "new" and "old" fluids are instantaneously mixed. In other words, the resistance to flow in the backfill is so much lower than that in the remainder of the waste package that any deviation from cylindrical symmetry is removed. However, one wonders whether only radial flows or more complex flows in the repository are envisioned, and whether the backfill region is intended to serve as a transition from a more complex flow pattern to one of radial flow within the interior waste package.

The documentation carefully lists the assumptions and limitations of each of the process submodels as well as the verification tests. However, explanations of why certain processes are treated while others are ignored are often missing. Several examples are given below. (Page numbers are from ONWI-452.)

1. It states on page 15 that "the material properties for the mechanical model and leach model are not assumed to be temperature dependent." This statement needs both clarification and justification.
2. Because both wet and dry corrosion processes are limited to the exterior surfaces of barriers, no consideration is given to corrosion of interior surfaces. Also, no consideration is given to formation and transport of gases within the waste form. If these processes are assumed to be negligible, some justification is needed.
3. It states on page 38 that only certain physical properties of the waste form are considered to be degraded by radiation. No justification is given for not considering the degradation of barrier materials.
4. It states on page 80 that "the waste form fractures only under tensile loading." Why are compression fractures ignored?

5. It states on page 124 that "Galvanic corrosion due to local cells on one single barrier is not considered in the present model, nor could it be practically modeled." Why?
6. It states on page 131 that "the Galvanic Corrosion Submodel should not be employed unless previous breach (as opposed to failure) of a metallic barrier has occurred. Such breaching of barriers can occur only by localized corrosion, or by breach by other models (a stress fracture in the mechanical submodel)." If local corrosion is assumed not to occur, the operation of the galvanic corrosion submodel may be suppressed as well. Is this justified?
7. Very little is said about chemical reactions between the repository constituents and the barrier materials. All of the corrosion and leaching processes are treated by empirical relationships, which means that the chemistry is buried in the empirical rate factors. Hence, it is not clear what is and what is not taken into account.

Finally, it appears that there is some need for careful technical editing of the entire theory section. For example, the following errors were noted in Sec. 7 of ONWI-452.

1. At the top of page 147, a constraint equation should appear but only an expression is given.
2. At the bottom of page 149, the term "mass accumulation" is used, which implies an integration. However, the word equation suggests process rates only.
3. In Eq. 7.1-9, a sign separating two terms is missing.
4. In Eqs. 7.1-11 and 7.2-2, parentheses are missing.
5. In Eq. 7.2-4, parentheses are missing from two terms.
6. The terms "leach rate coefficient for diffusion" and "leach rate coefficient for dissolution" require some explanation.

Input Data Requirements and Status

The input data consist of waste-package-design data, empirical data for various process rates, radionuclide-inventory and heat-generation-rate data, and boundary-condition data for the waste package/repository interface. The

availability of empirical-rate data for the various corrosion processes seems uncertain because of the extensive data required and because of the uncertain applicability of what are often short-term data to long-term processes. As noted in the code documentation, short-term data may indicate that certain package materials are not subject to pitting or crevice corrosion. Yet, in the long term, such corrosion may take place and lead to catastrophic failure of the barrier. Radionuclide and heat-input data are relatively readily available from runs of ORIGEN2 (Croff, 1980) or similar codes.

Specification of time-dependent boundary conditions is probably the input requirement posing the greatest difficulty. This information will probably be available only through operation of near-field repository heat transfer, fluid transport, and mechanical stress codes whose input requirements will be difficult to satisfy. In view of the intrinsically coupled nature of the waste package/repository system, how the boundary conditions at the interface will be handled needs clear definition.

Nature and Suitability of Model Output

Model output includes tabulations of heat and nuclide fluxes at the waste package/repository interface as a function of time. This information will presumably be required as input for near-field repository models. However, the output is cylindrically symmetric, being based on input and algorithms possessing the same symmetry. Further, the model assumes a swept-away boundary condition so that the concentration of nuclides in the repository at the interface with the waste package is assumed to be zero.

Code Verification

Two types of verification were performed for each of the five process submodels of the WAPPA code. First, hand calculations were performed, with the results compared with those resulting from operating each of the process submodels in a stand-alone fashion. All results agreed to within the accuracy of the hand calculations. Second, using a much more complex test problem, calculations were carried out with the entire WAPPA package, and the results for the calculations involving the particular process submodels were printed out. These results were then compared with those obtained by manually feeding the input data obtained from the WAPPA package into the same process models operated by themselves. Comparisons were very good, indicating that the system properly transmits data to and from each process submodel during each time step.

There remains one point of uncertainty in the verification procedure. How can one be sure that the integrated system code has been verified? Is a given barrier breached when it is supposed to be, given the concerted action of all of the processes? Is the effect of that breach properly handled in

subsequent time steps by all of the process submodels? A clearer demonstration is needed that the integrated system has been verified.

Benchmarking

No benchmarking has been reported for WAPPA.

Model Validation

No model validation studies have been reported. According to the ONWI Verification and Validation Plan, individual submodels will be validated with data from laboratory experiments by FY 1985. However, no indication is given of the nature, extent, or applicability of these experiments to the salt repository problem. The plan says: "Field or validation of the radiation, thermal, and the thermomechanical submodels will be completed by FY 87 with data to be obtained from the Engineering Test Facility." The statement suggests that "field" and "validation" can be used interchangeably or are in some sense equivalent. This notion is in direct conflict with the literature on model validation and with NUREG-0856's definition of validation. It is true that a field application followed by a comparison between predictions and observations may constitute partial validation of a model, but this sequence does not imply interchangeability of the phrases "field study" and "validation study." In fact, field applications often do not involve any measurements at all. Nor should extensive use of a model for various field applications be interpreted as evidence for the validity of a model. The question of what constitutes an acceptable alternative to validation of the model, especially as far as the ability of the model to make long-term predictions, needs to be addressed.

Peer Review

Peer review is to be complete by September 1985, following documentation of the revised version. This revised version is also mentioned in the ONWI Verification and Validation Plan under the heading "Development and Documentation."

12.1.3 Proposed Application and Potential Limitations

According to the ONWI Performance Assessment Plan, two applications of WAPPA are planned: corrosion analyses of metallic barriers surrounding the waste form and assessment of leach rates. The corrosion process submodel embedded in WAPPA actually consists of several submodels of individual corrosion processes. Also contained in WAPPA is a leach process submodel for estimating the flux of nuclides at the waste package/repository interface. The effects of radiation and thermal output from the waste form on corrosion

and leaching processes are also included in the WAPPA code. However, certain processes that may be important are not considered (see Secs. 12.1.1 and 12.1.2).

Given the considerable degree of complexity of the model, it is not clear how and under what conditions the individual submodels can be run "simply and quickly." If the running of the individual models, such as in the case of a short study of dissolution effects only, requires the user to supply data to all seven of the input data files, then the practical uses of the WAPPA model may be severely limited. Only those familiar with the entire computer code would be able to use it effectively, which would also make it more difficult for modelers and data generators to interact.

A statement on page 113 of ONWI-452, in the context of corrosion models, reads: "It has been decided that empirical corrosion rates for a given barrier material in a given solution and temperature environment are more accurate than corrosion rates determined theoretically, largely because present theory and supportive theoretical data are not good enough to permit calculation of more reliable rates." As a practical matter, the authors are correct: if the theory is not good enough, one must resort to empirical data. However, the WAPPA code is based to a large degree on empirical relationships and data. Such dependence shows in parameters such as "enhanced" and "non-enhanced leach rates" (p. 33), curve-fitting coefficients in the thermal submodel (pp. 49 and 54), modes of crack formation in the mechanical submodel, and rates of corrosion in the corrosion submodel. It also shows in the arbitrary choice of a chemical kinetic equation for the dissolution rate (pp. 146ff.).

The weakest aspects of ONWI-452 are (1) no explanation of the relative importance of the individual submodels to the performance of the waste package, (2) no discussion of the environmental factors that are most likely to affect the conditions assumed in the model, and (3) no analysis of reliability and errors in the empirical and theoretical parameters used in the mathematical relationships within the individual submodels.

Two concerns arise about the correctness of the theory behind the model -- one relates to the mechanical submodel and the other to the leach submodel. In the mechanical submodel (INTERA, 1983b, pp. 70 and 76), a backfill that has failed under stress is subsequently treated as incompressible. There should be major consequences as far as hydraulic transport characteristics and adsorption/retention properties if the backfill fails. What are they and how are they treated in the model? On page 78, an equation is given for the macroscopic surface area of the fractures, but there is no discussion of the difference between this surface area and the reactive surface area, nor any discussion of the possible effects of deformation on the solubility of the waste form and other components of the waste package.

The leach submodel (INTERA, 1983b, pp. 143-153) is based on one mass-transfer equation, the general applicability of which can be seriously

questioned. The treatment of the backfill as a "mixing cell" is a misnomer, given the correct form of Eq. 7.1-7. Dissolution of the waste form is responsible for transport of the radioactive and inert components from the source outward. The present leach submodel is too restrictive, in that it does not allow for any chemical interactions between the individual components of the waste package. The degree of mathematical sophistication involved in computations of a multilayer system may hardly be justified, given our current lack of knowledge of what may be happening within the waste package during its degradation. For example, chemical reactions between the steel canister and dissolved silica may create an armor layer of a new silicate phase; silica dissolved from a glass waste form may be reprecipitated farther out within the waste package, cementing the backfill and other spaces. Theoretically, a similar cementation process could be visualized for the iron components of the metallic barriers.

The transport characteristics within the waste package and the chemical reaction rate parameters are likely to be strongly affected by environmental conditions such as temperature and the salt concentration in the brine. How are these conditions taken into account in the leach submodel? On page 155 of ONWI-452, what is the meaning of "leach rate coefficient for diffusion" and "leach rate coefficients for dissolution"?

The WAPPA model should provide a clear and concise summary of the numerical results generated for certain sets of limiting values for the more important parameters. The important thing is to see whether the most conservative estimates of the individual parameters of the entire model can be shown to be in compliance with 10 CFR 60 and related U.S. Environmental Protection Agency criteria. A tabular or graphic summary of parameter values would also be helpful to those who will need to interact with the modelers.

A drawback of ONWI-452 is the absence of easily understandable results computed from the model. This deficiency can be corrected by including such results in a companion volume.

ONWI-452 is more heavily focused on radiation damage and corrosion processes than on the happenings after the structural integrity of the canister has been compromised. There should be more emphasis in the interactive model on the chemical and physical roles of other engineered and geological barriers. Such emphasis can be achieved through a careful revision of the leach submodel and its handling of the chemical characteristics of the brines coming in contact with the waste package.

In view of the great complexity of the degradation processes that may take place and the great differences in the environmental conditions between the different sites, it seems impractical to try to construct a generic model that would apply to nearly any conceivable combination of conditions. From

the user's point of view, practical considerations dictate a need for somewhat simpler models that can do at least the following:

1. Predict the performance of the waste package within the range of the environmental conditions expected for the site.
2. Provide information to those responsible for collection and analysis of data in the laboratory and in the field.
3. Allow for a high degree of flexibility in modifying the basic algorithms of the individual models so that the code can be adapted to the continuously improving state of our knowledge.

The outstanding feature of the WAPPA code is the attempt to create an interactive model. However, it is precisely the interactive aspects of the model that are in need of more explanation. Although a large amount of information on constraints and assumptions is found in the text, it must be made more palatable to interested readers.

12.1.4 Degree to Which WAPPA Supports the Verification and Validation Plan

WAPPA supports the Verification and Validation Plan in that it was prepared in the NUREG-0856 format. The model itself was designed to treat the performance of waste packages in isolated geologic repositories and is therefore generally applicable to ONWI's intended application. As already noted, however, there are some deficiencies in the code documentation and perhaps in the code itself. On page 76 of the plan, it states that "improvements are underway to remove errors and to expand capability." In the absence of any details, it cannot be judged whether the improvements will address the deficiencies described above.

The extent to which the code or model is specifically applicable to ONWI's proposed application and the question of applicability itself are never addressed in the plan. However, the plan states on page 76 under "Performance Specification and Code-Design Review" that "internal review was completed." This statement does not explain what was addressed in the review. The discussion in Sec. 3 of the plan, which presumably covers the subject matter to be discussed in the internal review, is so poorly written as to be almost incomprehensible. Did ONWI in fact address the following questions? What are the performance specifications of the WAPPA code? Are they correctly implemented in code? How do those specifications relate to the specific requirements of ONWI's particular application to salt repositories?

Given the brevity of ONWI's status report, it cannot be said with confidence that ONWI-452 meets the Verification and Validation Plan's

requirements. There are two important issues that should be addressed. First, what are the particular concerns surrounding repositories in dome salts and how are they accounted for by the WAPPA code? Second, in view of the total lack of validation and the likelihood that only very limited validation will be possible in the next few years, how will the uncertainties in the model's validity be handled?

12.2 DOT: DETERMINATION OF TEMPERATURE MODEL

12.2.1 Description

The Determination of Temperature (DOT) code (INTERA, 1983d, ONWI-420) predicts temperature as a function of time and position for two-dimensional planar or axially symmetric systems. Input consists of (1) material properties (thermal conductivity, heat capacity, and mass density, with thermal conductivity [either anisotropic or isotropic] and heat capacity specified as functions of position and temperature, and mass density specified as a function of position only); (2) initial and boundary conditions; and (3) internal heat generation rate per unit volume as a function of time and position. The code solves the partial differential equation for time- and space-dependent heat flow using a finite-element method. Limitations of the code include the restriction to two dimensions and the assumptions that heat transfer is only conductive (not radiative or convective) and that there is no phase change in the pore fluid. The code is written in Fortran IV for use on a CDC CYBER 176 computer.

12.2.2 Documentation

The documentation is quite good and follows NUREG-0856 guidelines. It could be improved by making the following, generally minor, changes:

1. On page 2, change "Q = heat generation rate" to "Q = heat generation rate per unit volume."
2. On page 2, change "C = specific heat capacity" to "C = specific heat capacity per unit mass."
3. On page 3, insert a statement pointing out that while q_n is the heat flow in the direction of n , $\partial T / \partial n$ is evaluated in the direction opposite to n . (Here, n is the outward normal to the surface.)
4. On page 3, point out that N must be an odd integer.
5. On page 19, replace " $\partial T / \partial n$ " by " $\partial T / \partial x_2$."

6. Insert a brief section, perhaps in Sec. 3, that discusses the applicability of the model to a geologic repository. The comments in Sec. 1.2 are too brief and too general.
7. In Sec. 4, "Verification Tests and Results" should be expanded along the lines indicated in Sec. 7.2.5.
8. The symbol V should not be used for both "Radiation View Factor" (p. 10) and "Volume" (p. 19).
9. On page 10, "Radiation View Factor" should be explicitly defined.

12.2.3 Availability of Input Data

Input data can be generated by another code or obtained from observed initial and boundary conditions plus known internal rates of heat production.

12.2.4 Nature and Availability of Model Output

The model generates a steady state temperature distribution ϕ_1 , for a transient problem, a set of temperature distributions at various times.

12.2.5 Code Verification

Two types of verification tests have been applied to the DOT code: (1) comparison, for various problems, of the DOT solution to a problem with the analytic solution to the same problem and (2) comparison, for various problems, of the DOT solution to a problem with the solution to the same problem generated by an independent code. These tests and the test results are summarized in Table 1. The following conclusions can be drawn from the test results:

1. There appear to be no major or systematic errors in the DOT code.
2. There is good to excellent agreement for all tests, with the exception of one spatial point in the second type-2 test. In this case, the comparison code may be inaccurate.
3. In the third type-1 test, it is troublesome that the observed discrepancy is increasing with time. Could this increase be reduced by reducing the size of the

Table 1 Verification Testing of DOT Code

Test Type	Test	Result
1	Steady state heat conduction in a square plate	Excellent agreement (i.e., essentially no discrepancy at all on visual inspection of the comparison plot)
1	Steady state heat conduction in a long hollow cylinder	Excellent agreement
1	Internal heat generation in a parallel-sided slab	Discrepancy between the two solutions is $\leq 2\%$ from $t(\text{time}) = 0$ out to $t = 0.32$ s, but is increasing with t (What is the cause of this discrepancy and will it continue to increase with t ?)
1	Transient heat conduction in a semi-infinite solid subjected to a unit surface heat flux	Excellent agreement in the case of the temperature vs depth plot; discrepancies range from 0-4% in the case of the surface temperature versus time plot
1	Transient heat conduction in a finite length rod	Agreement within $\sim 1\%$
1	Transient heat conduction in an infinite parallel-sided slab	Excellent agreement
2	Nonlinear transient heat conduction through an infinite parallel-sided slab	Agreement within 1%
2	Nonlinear transient heat conduction in a square concrete column uniformly exposed to American Society for Testing and Materials fire	Close agreement at two spatial points but only within $\sim 10\%$ at a third (The reason for this difference is not completely clear.)

time step? What is the reason for it? The authors of the code should comment on this.

4. Overall, the DOT code appears to be quite accurate.

12.2.6 Model Validation

The DOT model has been used to predict temperatures in underground heating experiments conducted in granite at Stripa, Sweden (Chan et al., 1980). Temperatures predicted by the model agreed well with observed temperatures. The model has not been validated for a salt formation.

12.2.7 Proposed Application

The proposed ONWI application of DOT is to predict the temperature distribution within a salt repository.

12.2.8 Potential Problems in Applying DOT to a Salt Repository

The DOT model is limited in applicability to physical systems that are two-dimensional planar or axially symmetric. Also, the model assumes negligible radiative heat transfer. Because salt is transparent at infrared wavelengths, this assumption may well be invalid. Finally, DOT assumes that there is no phase change in the pore fluid. For example, water in the interstices of the salt formation is assumed not to vaporize. At sufficiently high temperatures, however, vaporization could take place, with the result that convective heat transport (assumed by the model to be negligible) could become significant.

12.2.9 Relationship of DOT to Other Codes

The temperature field produced by DOT is used as input to the thermo-mechanical stress analysis codes VISCOT, MATLOC, and UTAH 2.

12.2.10 Degree to Which DOT Supports the Verification and Validation Plan

The ONWI-420 document is in need of slight improvement in two respects. First, there are two issues having to do with verification. In the case of internal heat generation in a parallel-sided slab, the discrepancy between the analytic and DOT solutions, which increases with time, should be accounted for. Then, although Sec. 4.10 (Discussion of Verification Tests) is excellent as far as it goes, a sentence or two should be added at the end stating that the verification test results are such that the code can be considered to be "verified" with reasonable certainty or, if this is not the case, that further verification tests are required.

The second respect in which ONWI-420 needs improvement is that the documentation should discuss more thoroughly the applicability of DOT to salt. For instance, given the fact that salt is transparent at infrared wavelengths, is it reasonable for DOT to neglect radiative heat transfer? (It is much to the credit of the author of ONWI-420 that he noted that transparency.) Also, the validation experiment reported in ONWI-420 was an experiment conducted in granite, not salt. While the experimental results and DOT results are in close agreement and while such agreement does constitute significant validation of the model, ONWI-420 should state that the experiment was not a salt validation. Further, the document should address whether the granite experiment constitutes sufficient validation. If not, a validation experiment in salt should be suggested in the Verification and Validation Plan.

In view of the above comments, some additional work is needed before it can be said that ONWI-420 adequately supports the plan.

12.3 FFSM: FAR FIELD STATE MODEL

12.3.1 Description

The Far Field State Model (FFSM) (INTERA, 1983a, ONWI-436) predicts the approximate climatic state and geologic environment of a nuclear waste repository site over relatively long periods of geologic time. Certain events and barriers are represented quantitatively. The model treats both natural and man-induced changes in these barriers within a probabilistic framework, and it accounts for cumulative and interactive effects of multiple phenomena. The name of the model indicates that events and barriers are modeled in the realm not only beyond the wastes but even beyond the influence of the repository.

Submodels cover the effects of undetected features, climatic change, resumption of worldwide glaciation, local glaciation, folding, salt diapirism, magmatic events, faulting, regional deformation, geomorphic processes, dissolution fronts, breccia pipes, solution mining, and future drilling activities.

12.3.2 Model Status

Documentation

The format used in ONWI-436 for documentation conforms in most respects to that required by NUREG-0856.

Input Data Requirements and Status

An extensive data base will be needed for each submodel for simulation of specific salt sites. No site-specific data have yet been assembled.

Model Output

Extensive appendixes are provided that cover typical model outputs.

Code Design Review

On page 46 of the Verification and Validation Plan, it states that internal review has been completed. For the response of the Argonne peer review panel to this statement, see Sec. 12.3.6.

Code Verification Status

The accuracy of FFSM coding was tested by (1) simple tests on individual submodels and on the system model with dummy submodels and (2) construction and application of three test problems. Some of the results were verified directly by hand calculations. Only the three test problems are documented; tests on the individual submodels and on the system model with dummy submodels were too numerous to document. Perfect agreement was found between the results obtained from the test problems and those expected on the basis of hand calculations. No other details of FFSM verification are given.

Benchmarking

Although benchmarking was done on GSM, the forerunner to FFSM, it has not been done on FFSM.

Model Validation Status

The code has not been validated. Complete validation is not possible because the model simulates natural processes over thousands of years. However, comparison with geologic evidence is possible. Consequently, peer review of the individual process formulations and the overall modeling approach is the main mechanism for obtaining model acceptance.

Peer Review Status

According to page 46 of the plan, GSM submodels, precursors of FFSM submodels, were formulated and reviewed by expert consultants and then peer

reviewed. According to the plan, peer review of FFSM is scheduled for FY 1985.

12.3.3 Proposed Application and Potential Limitations

The FFSM code will be used to simulate the geologic environment in the far field and climatic conditions at a nuclear waste repository site in bedded or domed salt over the next 10,000 years. Limitations in the model for this application include:

1. Large quantities of data are necessary to carry out a simulation for a specific site.
2. A large number of simulations are necessary to gain useful information beyond the most likely occurrences or perturbations at a particular site.
3. The model does not contain a component that would permit the results of simulations to be summarized in terms of the effects of significantly varying natural conditions on the groundwater regime.
4. The code will need to be modified and upgraded for application to specific salt sites.

12.3.4 Understandability of FFSM Document

The ONWI-436 document is well organized and generally understandable. However, it seems to have been put together rather hurriedly. Specific errors and more general suggestions for improvements are discussed below.

The abstract needs to be rewritten, with particular attention to the following points.

1. All references to the "biosphere state" should be deleted. No such submodel is described in the report. Only a refinement of the climate submodel is discussed.
2. The reference to "evaluating a site in the Pasco Basin under the AEGIS Program" should be deleted.
3. Specific information about the current status of verification and validation of this model should be added.

The first sentence of Sec. 1.1 (Code Purpose) is not a good statement of purpose and contributes little to the understandability of the report. The

statement of purpose must confirm that the code will permit prediction of hypothetical events in the far field surrounding a salt repository, including both the atmosphere and the geosphere. Paragraph two of Sec. 1.1 covers approach, not purpose, and should be so titled. Paragraphs three through five in Sec. 1.1 are concerned with background, not purpose, and should be either moved or retitled. It is not apparent why the authors keep referring to a biosphere state submodel when there isn't any such submodel and none is called for by the CRWM Program. The submodel being discussed deals with climate and should be retitled.

The first part of the third sentence of Sec. 1.3 promises rather more than can be delivered by FFSM. The sentence should be rewritten, perhaps as follows: "FFSM has been developed to predict conditions in the geologic environment in the far field and changes in climate at a high-level waste repository site in bedded or domed salt."

In the introduction to the performance specifications on page 11, it states in the first sentence of paragraph two that the model can determine the future state of the system. The model doesn't determine anything -- it only estimates the probable future state of the far field.

12.3.5 Critiques of Specific Submodels

Climate and Biosphere State Submodels

In the climate submodel, mean annual temperature and precipitation are chosen for each of the future time steps (p. 25). It is inappropriate to use only mean annual data to specify a climate, because variance of both temperature and precipitation during the seasons is of utmost importance for specifying botanic and geomorphic responses. Further, it is appalling that the Köppen climatic classification system is suggested for the biosphere state submodel. This classification was derived some 80 years ago and, although still widely used in introductory textbooks, it is coarse, antiquated, and empirically based. A far better system would be one based on physical principles.

Further, no comment is made on how future climatic parameters will be determined. Even worse is the statement in the first paragraph of page 25 that the forecast values of the climatic parameters are to be checked for consistency against values found throughout the world today. This comparison arbitrarily assumes that future climates will be composed solely of those in existence today. It must be remembered that some of the climatic characteristics from as little as 13,000 years ago have no analog in today's climate.

Predictions of future climates should be derived from models that calculate climates as a function of changes in long-term solar/earth radiation and energy balances. The Milankovitch periodicities of the earth's orbital

characteristics around the sun must be taken into account. These periodicities range from about 10,000 years to 90,000 years and have been shown by the CLIMAP research to explain most of the variance in paleoclimates over the last several hundred thousand years. Therefore, they could be used as a predictor for the next like interval of time, although they would have to be modified to take into account changes in land use, warming resulting from increased carbon dioxide in the atmosphere, changes in surface albedo, and other relevant factors.

If future changes in radiation are predicted based on the Milankovitch equations, estimates of temperature equilibria at the earth's surface can be made, yielding values that could be outside the range of those presently measured. Although latitudinal advection also influences temperature, for a first approximation, the effect of future advection may be assumed to be equivalent to that of today. Evidence strongly suggests that the centers of large-scale surface circulation systems were essentially constant throughout the Holocene and Pleistocene (Bryson and Wendland, 1967; Wendland, 1978). In other words, subtropical anticyclones over the oceans, winter subpolar anticyclones over high-latitude continents, and subpolar cyclones over high-latitude oceans will undoubtedly remain at about their present locations well into the future. One may therefore assume that the circulation pattern about these centers will also remain essentially unchanged (Bryson, 1966; Wendland and Bryson, 1981).

The advantages of using a physical model for predicting climate are obvious. A much more credible product will result than would result from predicting mean data from a probability density function.

Developing a model to predict the radiation budget as a function of the Milankovitch periodicities is relatively easy, because the algorithms have already been developed and explained (Berger, 1978). Translating the radiation budget into specific climatic parameters is more difficult but can be done. Even if the methodology to predict the climatic parameters from Milankovitch periodicities is regressive, it is at least as credible as what is proposed in ONWI-436 and has the advantage of being physically based. The importance of a physical model cannot be emphasized too strongly, because the climatic research community will appropriately reject long-term predictions based only on present analogs and, in particular, those based on the empirical Köppen system.

The following relatively minor, but still important, comments need to be considered. (Page numbers are from ONWI-436.)

1. On page 5, the sentence in the first line should read "...but the most unlikely occurrences."
2. In the second to last line of page 24 and in the sixth line of the first paragraph on page 25, the model is described as "choosing" appropriate climatic parameters.

In the last line of that first paragraph on page 25, we are told that a new consistent pair of values will be "picked." This terminology is imprecise at best. "Estimated" or "predicted" would be more appropriate, because the values are based on a deterministic model.

3. Near the bottom of page 25, the acronym ACLLIN is used without prior definition.
4. The discussion at the top of page 27 assumes a constant correlation between local and global glaciation. Climate forecasts for tens or hundreds of thousands of years into the future cannot be so restricted.
5. When discussing the Biosphere State Submodel on page 51, mean temperature and precipitation are again mentioned as the only climatic predictors (also see Fig. 2-14). The radiation gradient must be added, as must humidity, because these parameters are important when estimating the work done on geomorphic surfaces by climatic forces.

Geomorphic Processes Submodel

Because the geomorphic processes submodel is only one of 15 submodels and because the model was apparently designed to be applicable under a variety of circumstances, each submodel must be relatively simple in concept. However, if too many simplifying assumptions are made, the results may be unrealistic.

It would appear that the geomorphic processes submodel did not benefit from the input of a geomorphologist. For example, gradual erosion is probably intended by the author of the submodel to be equivalent to geologic erosion, but this equivalency is unclear. Use of the term "catastrophic erosion" to describe erosion by "glacial meltwaters" or by "coastal drainages under conditions of lowered base level" is exaggerated. These kinds of fluvial erosion would in no way approach the magnitudes suggested by the term "catastrophic." Only massive erosion, such as that produced by the rapid draining of Glacial Lake Missoula, could truly be considered catastrophic. Furthermore, glacial meltwater is not free of sediment, as stated by the author, but contains high concentrations of suspended sediment. Although some channel incision could reasonably be assumed to result from the influx of large volumes of meltwater, most such events are accompanied by accumulations of large quantities of sand and gravel, indicating a depositional rather than an erosional mode.

The geomorphic submodel interfaces with the climate and glaciation submodels to generate values for new climatic variables and changes in sea

level. It also interfaces with submodels dealing with uplift (including folding), faulting, and regional deformation. The author assumes that uplift will result in increased erosion and stream incision. However, depending on the spatial relationships between existing drainage systems and the area of uplift, such increases may not occur. For example, if uplift occurs in the downstream portion of a large drainage basin, erosion will be reduced. Or, again, if one were looking at the effects of renewed activity along the Nemaha Uplift on the Platte River system, uplift would not result in increased denudation.

The author also assumes that the amount of erosion is equal to the sum of all uplift processes and that rates of downcutting keep up with rates of uplift over long periods of time. Although such assumptions may be required to simplify the model, they cannot be substantiated in the geomorphic literature. The elements of time and geomorphic response enter into the problem. Although the situation is simply too complex to discuss here, Schumm (1963) reported average denudation rates of 0.1-0.3 ft/1000 yr, with a maximum of 3 ft/1000 yr, and an average modern rate of orogeny of about 25 ft/1000 yr. Other geologic evidence indicates that rates of uplift and downcutting are sometimes different.

The effects of climatic change are also much more complicated than the treatment afforded by the model. The effects of climatic conditions on erosion and sediment yield are discussed by Langbein and Schumm (1958) and Schumm (1965, 1968), among others.

Finally, the amounts and types of input required by the user seem unrealistic. Data are simply not available to generate a probability density function for the erodibility of various rock types. (A point of confusion, however, is that the input for this category as shown on page 173 is a simplified scale of "relative" erodibility.) Consequently, poor input will certainly result in poor output. If the user knew denudation rates for all of the climatic types and for all of the rock types in the area, he would have little need for such a model.

Folding Submodel

Within the time frame of the model, folding such that surface features might be affected would appear to be unlikely in all but tectonically active areas. For the 10,000 year period germane to NRC licensing requirements, the probability that this type of folding could affect the salt sites under active consideration appears exceedingly low. Therefore, it will be extremely conservative, in a geologic sense, to apply this submodel to these salt sites.

The discussion of the folding submodel does not address the possibility of using this submodel to simulate salt dome formation or reactivation, processes that could affect surface features. Such surface disturbances could be the end result of diapirism as discussed in Sec. 2.7.6. It would seem

possible to simulate a dome rising at depth by choosing fold axis coordinates that are relatively close together. The geometry of the resulting fold would be that of an elongate dome. For salt dome sites under consideration, the application of this submodel to salt dome formation appears to be more relevant over the next 10,000 years than the application of the submodel to tectonically induced folding. The example of subsidence caused by removal of subsurface fluids is not appropriate for the Paradox or Palo Duro basins but may be relevant for some of the candidate salt domes. The equation $\Delta h = 2d\Delta H/W$ is not easily linked with Fig. 2-10. And, finally, additional labeling in Figs. 2-9 and 2-10 would make this model more understandable to the general reader.

Local Glaciation Submodel

The local glaciation submodel simulates the movement of a continental glacier assumed to be covering part of the study area. It models the glacier's effects on point elevations (isostatic response) and on the occurrence of faulting. Because the bedded and domed salt sites presently under consideration for repository development were not subject to continental glaciation in the past, this submodel is irrelevant unless modified to include the effects of mountain glaciation. Even for the Paradox Basin sites, however, the threat from renewed mountain glaciation is probably quite small.

Magmatic Events Submodel

Two types of igneous events have been confused or combined by the authors — magmatic and volcanic. While a submodel for volcanic events might be relevant for sites on the Columbia Plateau, a submodel for intrusion of magma might be more applicable for salt sites. A good example of such an event is the inferred magma rise below the Long Valley caldera in Mammoth Lakes, Calif., which has resulted in an area of uplift and seismic activity (Kerr, 1983). As far as potential salt sites are concerned, areas where magmatic events that have the potential to disrupt a repository could occur have essentially been screened out. The assumption in the submodel that a magmatic event is characterized first by the occurrence of a volcanic event appears faulty. Also, the authors must explain how volcanic activity would be relevant to the Biosphere State Submodel. However, volcanism would be relevant to a climate submodel.

Faulting Submodel

The faulting submodel appears to be fairly useful. If there is a way to simulate strike-slip movement, this application should be explained.

Regional Deformation Submodel

The regional deformation submodel appears to be more sensible and, therefore, more practical than the folding submodel. It could be usefully applied to any of the candidate areas. Because FFSM has a time frame of 10,000-1,000,000 years (p. 12), assuming only one change in the large-scale regional stress regime is plausible, especially for the 10,000-year time frame that is pertinent for licensing. Having several possible changes as in the folding submodel is not realistic.

Breccia Pipe Submodel

The breccia pipe submodel appears to be particularly relevant for the Palo Duro Basin. The first sentence in Sec. 2.7.13.3 is not precise; the second sentence is much better. The content of the two should be combined.

12.3.6 Degree to Which FFSM Supports the Verification and Validation Plan

To help determine whether ONWI-436 supports the plan, the sentence under the heading "Performance Specification and Code Design Review" was consulted (p. 45 of the plan). It reads: "Internal review was completed." Who conducted the review and what were the conclusions of the review? Many of the questions raised in Sec. 12.3.5 suggest that there is some inadequacy with respect to the FFSM internal review process. In fact, Argonne comments on FFSM submodels indicate that the conceptual designs of several of them are inadequate and that certain others cannot be usefully applied to bedded or domed salt. For this reason, and because of items three and four in Sec. 12.3.3, it is reasonable to conclude that considerable work remains to be done on the model before a revised version of ONWI-436 could be said to adequately support the plan.

A final consideration with respect to the degree to which the code documents support the plan relates to Sec. 10.2.4 of the Regulatory Guide (Performance Assessment Issues). The Regulatory Guide requires a description of "those analytical techniques that are expected to be important for evaluating the performance of the site but that still require significant additional developmental work at the time the SCR is prepared." These "analytical techniques" include computer codes. Because a supporting code document like ONWI-436, or some of those referred to in Sec. 13, may still require significant additional developmental work at the time the SCR is prepared, it could be argued that such codes do not fully support the plan. This point should be addressed at an appropriate place in the plan.

13 COMMENTS ON OTHER SUPPORTING CODE DOCUMENTS

Many of the remaining supporting code documents were examined by the Argonne peer review panel but in less detail than those discussed in Sec. 12. However, panelists did try to determine, at a minimum, how well the reviewed documents support the Verification and Validation Plan. All of the supporting code documents will receive a uniform level of review with respect to support of the plan in an Argonne special advisory report.

13.1 ORIGEN2: A REVISED AND UPDATED VERSION OF THE OAK RIDGE ISOTOPE GENERATION AND DEPLETION CODE

13.1.1 Description

ORIGEN2 (Croff, 1980, ORNL-4628) is a point depletion and decay computer code for use in simulating nuclear fuel cycles and calculating the nuclide compositions of fuel-cycle materials. The code is an updated version of the ORIGEN code that was distributed by Oak Ridge National Laboratory (ORNL) in the early 1970s. It is designed for application to a wide variety of fuel-cycle flow sheets and fuel-reactor combinations. The code generates, as a function of time after irradiation, spent fuel and waste characteristics, including nuclide composition, radioactivity, thermal power, etc. This information is needed for the design of fuel-reprocessing plants, spent-fuel and waste-shipping casks, and waste-treatment and disposal facilities. Outputs also include radioactive ingestion and inhalation toxicity, and chemical ingestion toxicity.

The buildup and depletion of nuclides in materials during irradiation is calculated using point geometry and quasi-one-group neutron cross sections. The model does not account for spatial or resonance self-shielding effects or changes in the neutron spectrum other than those initially encoded. However, provision is made to incorporate appropriate cross sections from more sophisticated reactor physics codes.

The buildup and depletion processes are represented by a system of first-order ordinary differential equations with constant coefficients. This system is solved using a matrix exponential numerical method that requires considerable computer memory. A recursion relation is used to reduce the memory requirements. To maintain numerical accuracy and minimize computing time, only the long-lived isotopes are treated with the matrix exponential method.

13.1.2 Documentation

The documentation includes a brief description of ORIGEN2, a technical description of the original ORIGEN code, and a user's manual for ORIGEN2. The description of ORIGEN2 summarizes the differences between ORIGEN2 and ORIGEN, but it is not a stand-alone documentation of the ORIGEN2 code. Documentation does not conform to NUREG-0856.

13.1.3 Availability of Input Data

The ORIGEN2 code requires three data libraries that must be prepared from master libraries at ORNL by ORNL staff. In addition, user-supplied input data are required. Output from other, more sophisticated reactor physics codes may also be required. The Verification and Validation Plan gives no indication of the input data requirements or of the availability of data.

13.1.4 Nature and Suitability of Model Output

The plan gives no indication of whether the present output would be suitable or how well it fits assessment needs.

13.1.5 Code Verification

Code verification is not discussed in the available code documentation. The plan indicates that ORNL has been requested to provide documentation on verification tests, implying that ORNL has already performed such tests.

13.1.6 Benchmarking

The plan indicates that ORNL has been requested to provide documentation on verification tests. Nothing is said about benchmarking per se.

13.1.7 Model Validation

The plan states that "ORNL is using this code for reactor license application evaluations. ORNL is requested to provide necessary information." The fact that the code is being used to satisfy a regulatory requirement is irrelevant as far as validation is concerned, although it does imply some sort of acceptance by the regulatory agency.

13.1.8 Proposed Application

The plan does not indicate what specific problems require the use of ORIGEN2, except to mention general waste-package subsystem analyses. Given that several other models have been selected for specific roles in the waste-package assessment plan, it appears that ORIGEN2 will serve as the source-term generator for those other models. This being the case, it would be worthwhile indicating how well that role is satisfied by ORIGEN2 and, in particular, what modifications, if any, are required to satisfy that role and make the output of ORIGEN2 compatible with subsequent codes.

13.1.9 Sensitivity Analysis

The general subjects of uncertainty and sensitivity analysis are mentioned briefly in the Performance Assessment Plan but are not addressed at all in the Verification and Validation Plan. No specific information regarding sensitivity analysis of the ORIGEN2 code is given in either the latter plan or in the other major code documentation cited. Because ORIGEN2 appears to be the source-term generator, it is likely to be the first code to be used in a sequence of computations required to assess total system performance. Hence, uncertainties in the input data, to which ORIGEN2 is particularly sensitive, could make a major contribution to the uncertainty of the overall analysis.

13.1.10 Peer Review

No peer review is planned because it is an NRC-supplied code. Does this mean that NRC has formally accepted ORIGEN2 for this ONWI application?

13.2 PHREEQE: A GEOCHEMICAL SPECIATION AND MASS TRANSFER CODE SUITABLE FOR PERFORMANCE ASSESSMENT OF NUCLEAR WASTE REPOSITORIES

The PHREEQE code (INTERA, 1983e, ONWI-435) calculates chemical speciation in aqueous solutions and mass transfer between an aqueous solution and mineral solids. The methodologies used have been developed by geochemists over the last 20 years and are well known, both in terms of applications and limitations. The applications are well developed in the document, with examples of species calculations and comparisons with other calculations by computer and by hand.

Perhaps the most recognized limitations of this approach are the omission of reaction kinetics and inability to consider nonequilibrium mineral phase assemblages. Also, the PHREEQE code is unable to accurately calculate speciation in high ionic solutions, because activity coefficients are not well known when they depart substantially from unity. How will this latter limitation, which is not discussed in the document, affect PHREEQE's application to

repositories in salt? Perhaps this specific problem derives from the absence of a detailed description of how the code will be used to assess nuclear waste disposal in salt. Finally, Sec. 6 of the PHREEQE document (System Assessment Integration) is exceptionally brief and sketchy, which is inconsistent with the greater detail shown in other sections.

13.3 EQ3/EQ6: A GEOCHEMICAL SPECIATION AND REACTION PATH CODE PACKAGE FOR PERFORMANCE ASSESSMENT OF NUCLEAR WASTE REPOSITORIES

The EQ3/EQ6 code (INTERA, 1983f, ONWI-472) is well written but rather inefficient compared with other available codes. It does attempt to come to terms with the effects of salinity on speciation, but no existing code is capable of dealing with concentrated brines.

13.4 SALT-4: A TWO-DIMENSIONAL DISPLACEMENT DISCONTINUITY CODE FOR THERMOMECHANICAL ANALYSIS IN BEDDED SALT DEPOSITS

Earlier versions of this sequence of codes used results from Project Salt Vault (PSV) to calibrate the code. Is SALT-4 (INTERA, 1983g, ONWI-429) entirely independent of PSV data? More particularly, how should the input value of the "creep effective stress coefficient" be chosen? If SALT-4 is not independent of PSV data, it is not appropriate to validate the code against these data.

13.5 NETFLO: A NETWORK GROUNDWATER FLOW CODE

The formulation of NETFLO (INTERA, 1983h, ONWI-425) is straightforward, and the approach is easily implemented for rectangular arrays of segments. Multiple, nonrectangular node connections, however, would appear difficult to handle because of problems in defining conductance values. The NETFLO approach is presumed equivalent to the two-dimensional, integrated finite-difference methods used by Witherspoon's group at Lawrence-Berkeley Laboratory and very closely akin to standard finite-element methods. This approach is questionable, because it takes about the same computational effort as standard two-dimensional models.

13.6 TRIPM: A TWO-DIMENSIONAL FINITE-ELEMENT MODEL FOR THE SIMULTANEOUS TRANSPORT OF WATER AND REACTING SOLUTES THROUGH SATURATED AND UNSATURATED POROUS MEDIA

The mathematical formulation of TRIPM (Gureghian, 1983, ONWI-465) and its numerical implementation are consistent with currently used techniques in geohydrology. The methodologies and theory are well established, and the model appears to be quite comprehensive.

13.7 MMT: A RANDOM-WALK ONE-DIMENSIONAL MULTICOMPONENT MASS TRANSPORT CODE

The MMT code document (INTERA, 1983i, ONWI-432) is an excellent example of a well-conceived and well-executed verification and validation document. It is informative but concise, and emphasizes the key technical elements of verification. Its table of contents and the substance of the text should serve as a model for other verification and validation documents. The report includes particularly clear, jargon-free discussions of code limitations, applicability, and error generation, as well as information on important procedural matters, such as custodianship, and a clear user's manual. This report may have an advantage over other ONWI computer code reports in that it is not a code development report. (Two such reports already exist for this code.) It has been prepared by people who know the code thoroughly and are familiar with verification and validation.

The MMT code status report on page 54 of the Verification and Validation Plan illustrates some of the generic shortcomings of the status report format as discussed in Sec. 11.4. Moreover, several items clearly stated in ONWI-432 were omitted from the status report. For example, the sentence under "Description" says "...dispersion in heterogeneous porous media,..." but ONWI-432 says that the code handles only a uniform groundwater flow system with constant transport and hydrologic properties. Also, spatially uniform retardation factors are assumed. Other important descriptors that are omitted include a requirement that porous media flow be saturated and that time-dependent sources are allowed. Under "Performance Specifications Review," it should mention that application to salt, where dissolution is possible, is not appropriate (ONWI-432, p. 10). It should also be noted that verification tests were carried out against analytical solutions by Lester et al. (1975). The ONWI-432 document states explicitly that no formal validation has been attempted, although several code applications have been made, a fact not clear in the plan's status report.

13.8 LAYFLO: A ONE-DIMENSIONAL SEMIANALYTICAL MODEL FOR THE MIGRATION OF A THREE-MEMBER DECAY CHAIN IN A MULTILAYERED GEOLOGIC MEDIUM

The Gureghian and Jansen (1983, ONWI-466) document is not a verification and validation document in the sense of the MMT document (INTERA, 1983i). It deals primarily with code development, the mathematical model, code design, and a few, though important, benchmarking verification tests. It does not have a user's manual or even a code listing, and it does not even consider most of the verification and validation elements addressed in ONWI-432. Presumably, ONWI-466 will provide the basis for a future verification and validation document in the form of ONWI-432.

The LAYFLO code status report on page 52 of the Verification and Validation Plan is misleading. In the section entitled "Description," the solution is "semianalytical" not "analytical," and an infinite number of

layers can be handled only in the "nondispersive form" not "for the dispersive case." No clue is given that this report does not include much in the way of performance specifications and nothing about code design. The code status reports for MMT and LAYLO show few differences with respect to these items. Yet, examination of ONWI-432 and ONWI-466 reveals vast differences. Verification tests need greater explanation. Discussions on pages 37-38 of ONWI-466 suggest that comparisons with other results range from total agreement to fair agreement, a fact not reflected in the plan's code status report.

- 13.9 DACRIN: A COMPUTER PROGRAM FOR CALCULATING ORGAN DOSE FROM ACUTE OR CHRONIC RADIONUCLIDE INHALATION, AND
 PABLM: A COMPUTER PROGRAM TO CALCULATE ACCUMULATED RADIATION DOSES FROM RADIONUCLIDES TRANSPORTED TO AQUATIC AND TERRESTRIAL PATHWAYS IN THE BIOSPHERE

Dose analysis codes like DACRIN (INTERA, 1983j, ONWI-431) and PABLM (INTERA, 1983k, ONWI-446) are based on the well-known ICRP-2 (International Commission on Radiological Protection) methodology, which has been used successfully for more than 20 years. Because the dosimetry model is independent of the origin of the radionuclides, DACRIN, PABLM, and related codes are applicable to a nuclear waste repository in salt.

The DACRIN model asks for the radionuclide release rate of each nuclide and some atmospheric parameters. It predicts downwind airborne concentrations and outputs committed dose equivalent to organs of interest. The PABLM model asks for concentrations of each nuclide in soil and water, and makes a set of standard assumptions about radionuclide transfer to plants and animals, consumption rate by man, etc., and outputs the committed dose equivalent.

Although it is important to be sure that each model is properly coded, there are no unique aspects to their application for a waste repository in salt. It is probably impossible to compare a predicted dose to the "real" dose received by a person. In this sense, dose assessment models cannot be validated. Codes such as DACRIN and PABLM can give an acceptable estimate of the relative dose for any input of nuclide-specific source terms. The real issue is whether the other performance assessment codes can accurately predict the required source terms.

The Performance Assessment Plan states on page 133 that codes reflecting ICRP-30 recommendations would be used. Neither DACRIN nor PABLM use ICRP-30 methodology; both are based on ICRP-2 models. However, because DACRIN and PABLM are well documented and well understood, and represent a rather large investment, arguments can be made to use these codes until ICRP-30 codes are developed to a comparable level of trust. But, ICRP-30 cannot be ignored. Section 2.4 (Advantages and Limitations of the Approach) in PABLM provides an honest defense of PABLM's use of ICRP-2. DACRIN, which is also based on ICRP-2, should have a parallel discussion.

DACRIN and PABLM are versatile and adaptable codes. Because users can select a number of options, one concern is that users could change options and assumptions within an iterative assessment, thereby making comparisons invalid. For example, the design of a facility, procedure, or operation might be modified because the predicted airborne release rate of a certain mix of nuclides resulted in an unacceptable dose commitment. To make a valid comparison between dose commitments for the original release rate and the new ones, all of the assumptions related to dose assessment should be the same for both cases. It is recommended that something be built into the dose-assessment protocol or into the codes themselves to ensure that all dose assessments are based on the same set of assumptions.

Another concern relates to scenarios for release of radionuclides from a repository in salt. For example, could a minor accident during repository loading result in acute releases that are more important than long-term transport of nuclides by groundwater? When will the total spectrum of release scenarios be considered and prioritized?

Finally, all of the dose-assessment codes mentioned in the Performance Assessment Plan and Verification and Validation Plan are used to predict dose commitments to the general public after radionuclides enter the biosphere. The Performance Assessment Plan also discusses assessment of dose to operating personnel for each unit operation. When will detailed scenarios for planned and accidental releases, with exposure of operating personnel, be developed? How will the validity of these scenarios and the release rates and predicted radiation exposures be tested? How does this aspect of dose assessment fit into performance assessment and the verification and validation of computer codes?

14 PAGE-BY-PAGE COMMENTARY

<u>Page</u>	<u>Line(s)</u>	<u>Comments</u>
v	14	The term "baselining" should be defined, perhaps in the glossary.
v	26	Consider changing "provide" to "permit."
v	30	The term "in situ" is inappropriate.
v	32-34	The timing and coordination of this process should be carefully planned and explained in detail in a combined performance assessment and verification and validation plan.
1	10	How is "adequate" defined?
5		Revise Fig. 2.1, perhaps as suggested on the next page, to include the verification and validation stages of code development.
6	17	Change heading to read "Verification of Code Design Description."
9	1-4	The paragraph should be rewritten to add substance. A schematic of the management structure is needed.
9	7-11	The meaning of this sentence is unclear.
9	16-19	Identify the code custodian.
11	7-12	This paragraph needs to be rewritten. Lines 10-12 may be technically incorrect.
11	14-16	Different data bases are usually involved in design and validation.
12	27-28	It is confusing to have the word "process(es)" appear twice in the sentence.
13	10-12	Who will develop the criteria -- developer or evaluator?
13	13-15	What about integrated effects?
13	22	Design review by whom?

Fig. 1 Suggested Modification of Fig. 2.1: Scheme for Creation, Development, Verification, Validation, Documentation, and Maintenance of a Computer Code

<u>Page</u>	<u>Line(s)</u>	<u>Comments</u>
13	28	"Numerical" should probably be substituted for "mathematical" in the subtitle.
14	26-28	The sentence is difficult to understand.
14	34	The Adrion et al. reference is confusing unless it applies to all of the testing. Is this the case?
15	1-3	Rewrite the first complete sentence.
15	5	What is the meaning of "identify valid functional domain inputs."
15	14-15	It is generally unwise to expect that peer review can accomplish "code verification."
16	16-17	It is incorrect to say that most of the ONWI performance assessment codes are already documented. In terms of NUREG-0856, they aren't.
21	11	What are "test coverage analyses"?
22	23-24	Code-to-code comparisons are very important and should be highlighted.
22	28-29	"Computer animation" is a tool for examining codes, not a means for verifying them.
24	28-30	Rephrase sentence beginning with "while."
25	5-13	The relationship of such experiments to real-world problems should be discussed.
27	1-2	The section title tries to cover too much.
27	26-28	Who determines the importance of the analyses?
28	15	Tell where in the text the "information below is provided."
30		In the legend, replace the circle with an octagon. It is doubtful that the many codes shown as having been documented according to NRC guidelines have in fact been so documented.

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APPENDIXES

APPENDIX A

**U.S. DEPARTMENT OF ENERGY LETTERS
REQUESTING PEER REVIEW**

**Department of Energy
National Waste Terminal
Storage Program Office
505 King Avenue
Columbus, Ohio 43201**

JUN 10 1983

Wyman Harrison, PhD
EES-362
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dear Dr. Harrison:

**PEER REVIEW OF THE JUNE DRAFT OF THE VERIFICATION AND VALIDATION PLAN FOR
PERFORMANCE ASSESSMENT TECHNOLOGY FOR A NUCLEAR WASTE REPOSITORY IN SALT**

Enclosed are fifteen copies of the June draft of the Verification and Validation Plan (VVP) for Performance Assessment Technology for a Nuclear Waste Repository in salt.

I request that this plan be reviewed in accordance with Work Package No. ANL 053 00 83. The reviewers should be the same as those who reviewed the performance assessment plan. Copies of a number of ONWI reports which document some of the computer codes referred to in the VVP have been supplied to you for use by the reviewers in their review of the VVP. This review of the VVP does not include review of any given code therefore comments on any of these supporting code documents should relate only to general understandability and how well they support the VVP. The VVP also does not address all computer codes used in the ONWI program. Rather it is limited to codes which may be used for performance assessment in salt repositories and the final selection of codes will not be made prior to publishing the VVP. However it is expected that the final selection of codes will be a subset of the codes listed in the VVP. The review requested is of the plan itself and not of issues related to the subject area of the plan (e.g. it would not be appropriate to speculate on the final choice of codes). Therefore it would be appropriate to address at least the following points:

- 1) Are the scope and purpose of the document clear?
- 2) Are the milestones most appropriately identified? Are there key activities that have been overlooked?
- 3) Is the plan achievable?
- 4) Are the VVP milestones clearly linked to the ONWI project as a whole?

- 5) Are the descriptive parts of the plan necessary and appropriate to make the VVP effective in making the plans clear?
- 6) Is it clear what the plans are code by code and for the ONWI project as a whole?
- 7) Will the V & V plans if carried out result in confidence in the results of ONWI's performance assessments?

I look forward to receiving the draft results of your coordinated review within three weeks of your receipt of the fifteen copies of the VVP.

Maxwell Blanchard

Max Blanchard
Director
Site Exploration
and related GO Science Research
NWS Program Office

NPO:MB:LAC:kgH

Enclosure: June Draft of the Verification and Validation Plan for Performance Assessment Technology for a Nuclear Waste Repository in Salt

ST# 346-83

**Department of Energy
National Waste Terminal
Storage Program Office
505 King Avenue
Columbus, Ohio 43201**

March 23, 1983

Wyman Harrison, Ph.D.
EES-362
Argonne National Laboratory
Argonne, Illinois 60439

Dear Dr. Harrison:

**PEER REVIEW OF ONWI PRELIMINARY PERFORMANCE ASSESSMENT PLAN FOR A NUCLEAR
WASTE REPOSITORY IN SALT**

Enclosed are fifteen copies of the ONWI Preliminary Performance Assessment Plan for a Nuclear Waste Repository in salt. We request that this plan be reviewed in accordance with Work Package No. ANL 053 00 83. Performance assessment in the ONWI project has two functions 1) to address the issue of health and safety of the public that is the focus of the MRC licensing process and 2) to support through analysis all parts of the repository system under development for the ONWI project.

Therefore, it would be appropriate to address at least the following points:

- 1) Is the scope of the plan clearly bounded/delineated?
- 2) Are the major milestones to achieve the objectives correctly identified? Are there key activities that have been overlooked?
- 3) Is the plan achievable?
- 4) How could the work in this performance assessment plan best be described to the lay public assuming they have no knowledge of math modeling or radioactive materials behavior?
- 5) Should any descriptive material (e.g. appendices) be added or subtracted to make the document more useful?
- 6) Are interfaces with other parts of the ONWI project clear?

- 7) Are the main technical issues identified?
- 8) Are the technical statements of the problems accurate?

Sincerely,

M. B. Blanchard
Director, Site Exploration and
Related Geoscience Research
NWTs Program Office

NPO:LAC:ds1

Enclosure: As Stated

ST# 147-83

95/96

APPENDIX B

CONCURRENCE SHEETS

CONCURRENCE SHEET - PART 1

I concur that the Argonne National Laboratory report on ONWI's Preliminary Performance Assessment Plan fairly represents my comments, where incorporated, to the peer review panel.

David F. Fenster

F. P. Sargent

Wyman Harrison

Martin G. Seitz

George F. Pinder

W. Sha

M. J. Robinet

CONCURRENCE SHEET - PART 2

I concur that the Argonne National Laboratory report on ONWI's Verification and Validation Plan fairly represents my comments, where incorporated, to the peer review panel.

John D. Ditmars
John D. Ditmars

Donald M. Rote
Donald M. Rote

Dorland Edgar
Dorland E. Edgar

James E. Russell
James E. Russell

David F. Fenster
David F. Fenster

F.P. Sargent
F.P. Sargent

Wyman Harrison
Wyman Harrison

Martin G. Seitz
Martin G. Seitz

Abraham Lerman
Abraham Lerman

William T. Sha
William T. Sha

George F. Pinder
George F. Pinder

Edward W. Walbridge
Edward W. Walbridge

McLouis J. Robinet
McLouis J. Robinet

Wayne M. Wendland
Wayne M. Wendland

APPENDIX C

CREDENTIALS OF PEER REVIEW PANEL MEMBERS

John D. Ditmars

Princeton University: B.S.E., Civil Engineering (1965)

California Institute of Technology: M.S., Civil Engineering (1966)

California Institute of Technology: Ph.D., Civil Engineering (1971)

Dr. Ditmars is leader of the Geophysics and Engineering Section of the Geoscience and Engineering Group of the Energy and Environmental Systems Division at Argonne National Laboratory. Measuring and modeling portions of the hydrosphere impacted by energy technologies and natural resource development has been the main research area of this section. Particular attention has been given to evaluations of model performance and to experimental designs for the acquisition of data at prototype scales for performance evaluation. Dr. Ditmars has extensive experience in modeling and measurement of transport and mixing processes in the hydrologic environment. He was for several years responsible for the annual literature review in the area of "Mixing and Transport" for the *Journal of the Water Pollution Control Federation* and is presently the Chairman of the Paper Awards Committee of the Hydraulics Division of the American Society of Civil Engineers. He is also the Chairman of the Task Committee on Verification of Models of Hydrologic Transport and Dispersion for the Hydraulics Division of the same society and, as such, has been concerned with the generic aspects of verification and validation as well as with those aspects of particular models.

Before joining Argonne in 1977, Dr. Ditmars was Assistant Professor of Civil Engineering at the University of Delaware. From 1970 to 1972 he was Visiting Assistant Professor in the Water Resources and Hydrodynamics Division of the Civil Engineering Department at MIT. His teaching and research activities at the University of Delaware and MIT focused on hydraulic engineering and fluid mechanical processes in the natural hydrologic environment, and involved analytical and numerical modeling as well as laboratory and field experiments. He is author of more than 45 technical publications in these areas.

Dorland E. Edgar

Central Missouri State University: B.S., Geology (1968)

Colorado State University: M.S., Geology (1973)

Purdue University: Ph.D., Geology (1976)

Dr. Edgar joined the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory in 1978. Since that time he has worked as a geologist and hydrologist on programs related to waste management and energy and mineral resources development. From 1981 through 1983, he participated in studies of the geologic setting of crystalline rocks of the northeastern and Lake Superior regions of the United States for the purpose of assessing their suitability as sites for a high-level radioactive waste repository. His primary areas of responsibility on this project were surface-water and groundwater hydrology, geomorphology, and surficial geology.

From 1978 to 1981, Dr. Edgar was affiliated with Argonne's Land Reclamation Program and Environmental Control Technology Program, where he studied the relationships between surface mining and reclamation activities, and geomorphic processes, hydrology, water quality, and erosion and sedimentation. Dr. Edgar also served as a U.S. Department of Energy representative to an interagency group that reviewed comments and drafted revised regulatory guidelines for the U.S. Office of Surface Mining.

Before coming to Argonne, Dr. Edgar was employed at Oak Ridge National Laboratory, where he conducted research on surface and subsurface hydrologic and geologic conditions, and their relationship to the shallow land disposal of low-level radioactive waste. One project involved the study of the hydrologic and geomorphic processes involved in transporting radionuclides from burial sites through an instrumented watershed. Dr. Edgar's graduate research was directed primarily toward the relationships between hydrology and the geomorphic processes operating within alluvial stream channels and drainage basins.

Dr. Edgar has authored approximately 25 scientific and technical publications, and is a member of two professional societies.

David F. Fenster

City College of the City University of New York: B.A., History (1967)
University of Illinois: M.A., History (1968)
Queens College of the City University of New York: M.S., Geology (1975)
Certified Professional Geologist (No. 4668), American Institute of Professional Geologists
Certified Professional Geologist (No. 85), State of Indiana

Mr. Fenster joined the staff of the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory in 1982. He is currently Technical Project Manager and member of the multidisciplinary core peer review panel of the technical data base for the salt host-rock portion of the National Waste Terminal Storage program. He also served as a technical reviewer for parts of Argonne's Lake Superior regional report related to siting high-level radioactive waste repositories in crystalline rocks.

Prior to coming to Argonne, Mr. Fenster was a Project Geologist with Dames & Moore, Park Ridge, Ill. He had been with Dames & Moore since joining the staff of the Cranford, N.J., office in 1974. During his tenure with Dames & Moore, Mr. Fenster acquired extensive experience in seismotectonics, structural geology, radioactive and hazardous waste disposal, regional geology, engineering geology, hydrogeology, and general geologic field mapping. For example, Mr. Fenster was Principal Investigator for Stratigraphy for the Generic Environmental Impact Statement concerning disposal of radioactive waste in bedded salt, granitic rocks, and argillaceous formations for Oak Ridge National Laboratory. He also worked on a revised draft (unpublished) of a national-screening-level, site-selection investigation for high-level radioactive waste isolation in crystalline rocks.

Mr. Fenster also worked on geologic investigations related to nuclear power plant siting and licensing. He is familiar with U.S. Nuclear Regulatory Commission review and licensing procedures, having worked on early site reviews, preliminary safety analysis reports, final safety analysis reports, and detailed fault investigations.

Mr. Fenster has published on high-level radioactive waste repository siting, midcontinent tectonics, and structural geology in the Northeast, and has worked on over 30 consulting reports. He is a member of five professional societies, including the Association of Engineering Geologists.

Wyman Harrison

University of Chicago: S.B., Geology (1953), after three years of undergraduate work at Stanford University

University of Chicago: S.M., Geology (1954)

University of Chicago: Ph.D., Geology (1956)

Registered Geologist (No. 2476), State of California

Certified Professional Geologist (No. 134), American Institute of Professional Geologists

Dr. Harrison is Associate Director for Geoscience and Engineering at Argonne National Laboratory's Energy and Environmental Systems Division. He directs a 25-person group that performs analytical and experimental studies related to management of energy and mineral resources and to development and deployment of related technologies. Major activities of the group include (1) acquisition of geophysical and geotechnical data bases, (2) analysis of the data of geoscience to support the design and deployment of energy technologies, and (3) development of physical and mathematical models of geophysical/geotechnical systems.

Dr. Harrison's group recently completed comprehensive surveys of the geoscience data on crystalline rock complexes in the northeastern and Lake Superior regions of the United States to help assess their potential as possible sites for repositories for high-level radioactive waste. Dr. Harrison has conducted numerous other geological and geotechnical studies at Argonne, ranging from estimating petroleum resources of the Soviet Union to determining near-shore circulation in Lake Michigan.

From 1971 to 1975, Dr. Harrison was Professor of Geography (Associate Department Chairman) at the University of Toronto, where he specialized in geophysical studies related to the siting of supertanker ports and slope stability in sedimentary terrains. Prior to that, he was Associate Director for Physical, Chemical, and Geological Oceanography at the Virginia Institute of Marine Science and a Professor of Marine Science at the University of Virginia. Dr. Harrison was Director of Environmental/Science Services Administration's (now National Oceanic and Atmospheric Administration's) Land and Sea Interaction Laboratory from 1964 to 1968. Before that he was on the faculty of Dartmouth College's Department of Geology and a geologist with the Indiana Geological Survey.

An author of over 100 papers, reports, reviews, and books, Dr. Harrison was made Senior Scientist at Argonne in 1976.

Abraham Lerman

The Hebrew University: M.Sc., Geology (1960)

Harvard University: Ph.D., Geology (1964)

Dr. Lerman joined the Department of Geological Sciences at Northwestern University in 1971 as Associate Professor and has been Professor since 1975. Dr. Lerman has extensive experience in aqueous geochemistry, geochemistry of brines, isotope geochemistry, and radionuclide migration. He is a resource consultant on waste packaging and geochemistry for the Basalt Waste Isolation Project Overview Committee. During 1980 Dr. Lerman was a member of the Backfill Evaluation Panel for Battelle's Pacific Northwest Laboratory.

While associated with Northwestern University, Dr. Lerman has served, at various times, as a visiting professor at several European universities. Prior to joining the faculty at Northwestern, he was a Research Scientist in Chemical Limnology at the Canada Centre for Inland Waters (1969-1971), a Visiting Investigator and Senior Scientist in Isotope Research at Weizman Institute of Science (1966-1969), an Assistant Professor of Geology at the University of Illinois at Chicago Circle Campus (1965-1968), a Visiting Investigator (geochemistry) at Lamont-Doherty Geological Observatory of Columbia University (Summer, 1965), and a Lecturer and Assistant Professor of Geology at the Johns Hopkins University (1964-1965).

Dr. Lerman has published extensively in the areas of geochemical processes in water and sediments, halite and brines, chemical limnology, geochemical cycles, and radionuclides in sediments. He is a member of five professional societies and a Fellow of the Geological Society of America.

George F. Pinder

University of Western Ontario: B.S., Geology (1965)

University of Illinois: Ph.D., Geology (1968)

Dr. Pinder is Chairman of the Department of Civil Engineering and RC Professor of Energy Resources at Princeton University. He joined the faculty at Princeton in September 1972 as an Associate Professor and Director of the Water Resources Program and was promoted to Professor in September 1977. Dr. Pinder's prior experience was with the U.S. Geological Survey, Water Resource Division (1969-1972) and with the Nova Scotia Department of Mines (1968).

Dr. Pinder has had prior National Waste Terminal Storage Program experience while serving as a consultant to the Office of Nuclear Waste Isolation. He has had extensive experience in applying mathematical modeling techniques to groundwater flow and containment transport problems. His leadership in the field of groundwater modeling and numerical analysis has been recognized by the American Geophysical Union (Horton Award, 1969) and the Geological Society of America (O.E. Meinzer Award, 1975). Professor Pinder is an editor of "Advances in Water Resources" and has served on the editorial boards of "Numerical Methods in Fluids," "Advances in Engineering Software," and "Applied Mathematical Modeling."

Professor Pinder has published extensively in the areas of aquifer analysis, groundwater modeling, mass transport in groundwater, and numerical simulation. He is a member of five professional societies.

McLouis J. Robinet

Xavier University: B.S., Physics (1955)

DePaul University: M.S., Physics (1965)

Mr. Robinet is currently a senior health physicist for the Occupational Health and Safety Division at Argonne National Laboratory, where he has worked since 1967. During his tenure at Argonne, Mr. Robinet has been the health physicist for the Materials Science Division, Biology and Medicine Division, Reactor Operations Division, and Applied Physics Division. He has experience in the safety aspects of systems and facility design, in the preparation of safety analysis reports, and in internal dosimetry and atmospheric dispersion calculations. He is a team captain on the Radiological Assistance Team and was a member of the DOE Emergency Response Team for the Three Mile Island incident. He has also participated in developing health physics procedures for the decontamination and decommissioning of the New Brunswick Laboratory in New Jersey.

Mr. Robinet participated in the preparation of the *Generic Handbook on Environmental Monitoring for Low-Level Radioactive Waste Disposal Sites* (1968) and *Draft Programmatic Environmental Impact Statement Related to Decontamination and Disposal of Rad Waste Resulting from March 28, 1979, Accident, TMI Nuclear Station, Unit 2*, NUREG-0683 (1980). He holds the patent for an x-ray diffraction interlock system used on most x-ray diffraction units at Argonne and has been associated with implementing several health physics instrument developments. He was the lead health physicist in development of the thermoluminescent dosimeter finger-ring system now used at Argonne.

Mr. Robinet has taught at DePaul and Xavier universities (1957-1960).

Donald M. Rote

Cleveland State University: B.E.S., Engineering Science (1960)
Case Western Reserve: M.A., Theoretical Physics (1963)
Case Western Reserve: Ph.D., Theoretical Nuclear Physics (1967)

Dr. Rote is a geophysicist in the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory. He has served as principal investigator since 1970 on numerous projects sponsored by the U.S. Environmental Protection Agency, U.S. Air Force, and Federal Aviation Administration concerned with development, verification, validation, and documentation of models used for air pollution assessment. He has also directed a number of field programs that required the acquisition, analysis, and interpretation of air-quality, meteorological, and source data.

Dr. Rote has concurrently served as an advisor on model validation, model applications, monitoring, and data analysis techniques to the above institutions. In addition, he has given series of lectures on these subjects at both the Majorana School of Physics of the Planetary Boundary Layer held at Erice, Sicily, and the Korean Institute for Science and Technology at Seoul, Korea.

Dr. Rote has published over 60 reports, book chapters, and journal articles.

James E. Russell

South Dakota School of Mines and Technology: B.S., Civil Engineering (1963)

South Dakota School of Mines and Technology: M.S., Civil Engineering (1964)

Northwestern University: Ph.D., Theoretical and Applied Mechanics (1966)

Professor Russell joined the faculty of Texas A&M University in 1978 as Professor of Mining Engineering and Geophysics, and has been a Brockett Professor of Engineering since 1982. He has had extensive experience in the analytical/numerical, laboratory, and field rock mechanics aspects of mining, underground construction, and underground storage. Much of his research has involved in situ experiments related to waste repository design, radioactive waste isolation in salt, creep models for salt, thermal loading in waste repositories in salt, benchmark problems in salt using different numerical methods, coal gasification, and lignite mining.

Dr. Russell currently serves as rock mechanics consultant to ONWI and Oak Ridge National Laboratory; resource consultant for rock mechanics to the Overview Committee for the Basalt Waste Isolation Project; coinvestigator of an ONWI-sponsored project at Texas A&M University to develop constitutive equations for salt; and member of the Performance Constraints Working Group for RE/SPEC, Inc., and ONWI. During 1979 he served as a member of the Peer Review Group for DOE, Nevada Nuclear Waste Storage Investigations.

From 1972 to 1976, he was Vice President and Resident Consultant at RE/SPEC, Inc. From 1977 to 1978, just prior to accepting the position at Texas A&M, Professor Russell was the Project Manager for Rock Mechanics at the Office of Waste Isolation, Union Carbide Corporation. From 1967 to 1976, Dr. Russell served as Assistant Professor of Civil Engineering; Associate Professor of Civil Engineering, Mining and Civil Engineering, and Mining Engineering; and Professor of Mining Engineering at the South Dakota School of Mines and Technology. From 1966 to 1967, he was Senior Research Engineer at Southwest Research Institute.

Professor Russell has published extensively in the fields of rock mechanics, mining engineering, lignite mining, coal gasification, and waste isolation. He is a member of six professional and honorary societies, and has served on 11 national committees.

F. Peter Sargent

University of Exeter: B.Sc., Chemistry (1961)

University of Leeds: M.Sc., Chemistry (1963)

University of Leeds: Ph.D., Chemistry (1965)

As head of the Geochemistry and Applied Chemistry Branch at the Whiteshell Nuclear Research Establishment at Pinawa, Manitoba, Dr. Sargent is responsible for research to immobilize high-level fuel waste in solid material, such as glass and glass ceramic material. This work involves development of suitable products and the processes to manufacture them, and assessment of their performance under geologic disposal conditions. He also participates in geochemical research to determine the interactions of fuel wastes within a disposal vault and to assess the multibarrier concept of waste management.

Dr. Sargent joined the Research Chemistry Branch at Whiteshell Nuclear Research Establishment in 1969, and in 1977 he moved to the Chemical Technology Branch. He was then appointed head of the Geochemistry and Applied Chemistry Section in 1978 and to his present position in 1981. In 1965 he joined the National Research Council as a Post-Doctoral Fellow at the University of Saskatchewan and then returned to Britain to the University of Leeds in 1967 as a Post-Doctoral Fellow.

Martin G. Seitz

University of Missouri: B.S., Engineering Physics (1966)

Washington University: Ph.D., Geophysics (1971)

Dr. Seitz is a geochemist in the Geochemistry Group of the Chemical Technology Division of Argonne National Laboratory, where he manages applied and basic experimental programs. Ongoing applied programs related to nuclear waste disposal are to investigate interactions of materials proposed to be used in disposing of nuclear waste and to learn how backfill materials would be affected by the conditions of nuclear waste disposal. The basic research program of the group is to study trace-element migration in the earth's crust. Current work focuses on the role of organics in mobilizing heavy metals and on the movement of phenol compounds through water-bearing rock.

In the past year, Dr. Seitz served with seven others on the Panel to Assess the Technical Basis of 10 CFR 60, the proposed U.S. Nuclear Regulatory Commission rule for licensing a high-level waste repository. Dr. Seitz also completed experimental work on radionuclide retention in salt (Waste Isolation Pilot Plant) and helped develop logging methods in bore holes to detect petroleum. He has organized workshops on nuclear and hazardous waste disposal and has done geologic field work with university and U.S. Geological Survey staff.

Before coming to Argonne, Dr. Seitz worked as a fellow at the Geophysical Laboratory of the Carnegie Institution of Washington, where he studied the chemical partitioning and solid diffusion of trace elements in igneous rock. Having received a National Defense Act fellowship for graduate work, Dr. Seitz determined rock ages from products of spontaneous fission and studied the distributions of uranium and thorium in igneous rocks.

Dr. Seitz has published over 60 papers in scientific journals, primarily on geochemical topics.

William T. Sha

Polytechnical Institute of Brooklyn: B.S., Mechanical Engineering (1958)
Columbia University: Ph.D., Nuclear Engineering (1964)

As Senior Nuclear Engineer and Director of the Analytical Thermal Hydraulic Research Program at Argonne National Laboratory, Dr. Sha has developed computational methods for thermal/hydraulic analysis of reactor systems, solar energy storage applications, and combustion processes. He recently completed development of a porous media formulation for multiphase systems and a boundary-fitted coordinate transformation for thermohydraulic analysis in arbitrary three-dimensional geometries.

Before joining Argonne in 1967, Dr. Sha was a Fellow Scientist for the Reactor Physics and Mathematics Section at Westinghouse Atomic Power Division at Pittsburgh. During a seven-year tenure, he developed computational methods for reactor physics, thermal hydraulics, and integral nuclear-thermal-hydraulic analysis of a pressurized water reactor core.

From 1957 to 1960, Dr. Sha was a mechanical engineer for Combustion Engineering, Inc., in New York City. His work there involved components of convectional and supercritical steam power plants.

Dr. Sha has authored 185 publications dealing largely with nuclear reactor systems and computer programming.

Mary W. Tissue

Beloit College: B.S., Geology (1961)

Yale University: M.S., Geology (1963)

Ms. Tissue has been employed since 1979 as a technical editor for the Energy and Environmental Systems Division of Argonne National Laboratory. From 1981 through 1983, she was part of a research team that gathered geologic information on the crystalline rocks of the northeastern and north-central United States, with a view to assessing their suitability as sites for repositories for high-level radioactive waste. Other projects have involved the editing of reports, journal articles, conference papers, and proposals on such topics as transportation, decision analysis, particulate control, industrial process energy conservation, economics of gasohol, chemistry of synthetic fuel process waters, environmental studies of ocean thermal electric conversion, recycling, petroleum geology and resource assessment, and socioeconomic impact of energy development.

Prior to accepting a position at Argonne, Ms. Tissue worked as a technical writer and marketing assistant for an instrument company and as an editor for the Metals Research Laboratory of what was then the Olin-Mathieson Chemical Corporation.

Ms. Tissue is a member of the Society for Technical Communication and the Association of Earth Science Editors.

Edward W. Walbridge

University of Chicago: B.S., Physics (1959)

University of Chicago: M.S., Physics (1960)

University of Chicago: Ph.D., Physics (1967)

Dr. Walbridge has worked in the area of applied physics in the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory since 1979. In 1983 he accepted an invitation to be a Visiting Scientist at MIT for two months. His projects have included evaluating laser satellite power system concepts; developing, verifying, and validating computer models of natural gas reservoirs; evaluating a proposed new method for gamma-ray logging of oil wells; and upgrading computer codes used in nuclear reactor experiments.

The natural gas reservoir models studied were so-called zero-dimensional models that consisted basically of a material-balance equation coupled to various water-drive equations. Such models produce input data for reservoir economic analysis codes. One of the Argonne zero-dimensional gas reservoir models is in standard use at MIT. In the course of evaluating the proposed new gamma-ray logging method, Dr. Walbridge developed a "master integral" for the counting rate of unscattered gammas.

Before coming to Argonne, Dr. Walbridge was on the faculty of the University of Illinois at Chicago. Prior to that he studied lunar surface phenomena at the High Altitude Observatory at Boulder, Colo.

Wayne M. Wendland

Lawrence College: B.A., Chemistry (1956)

University of Wisconsin, Madison: Ph.D., Meteorology (1971)

Dr. Wendland is Head of the Climatology and Meteorology Section of the Illinois State Water Survey in Champaign and Adjunct Associate Professor of Geography at the University of Illinois, Champaign-Urbana. Before assuming his present position, Dr. Wendland was Assistant Professor in the Departments of Meteorology and Geography at the University of Wisconsin, Madison. From 1956 to 1964 he was a weather officer with the rank of captain in the U.S. Air Force. His research has ranged from analysis of measured net radiation values in Canada and reconstruction of late and postglacial climatic changes in central North America to studies of geomorphic responses to climatic forcing during the Holocene.

Currently Chairman of the American Meteorology Society's Committee on Applied Climatology, he is also an active member of the American Quaternary Association and the Tree-Ring Society. He has published approximately 30 research papers in scientific journals and six reviews of books on climate or meteorology.