ANL/EES-TM-316

RADIOACTIVE WASTE ISOLATION IN SALT:
PEER REVIEW OF THE OFFICE OF NUCLEAR WASTE ISOLATION'S
DRAFT REPORT ON AN ISSUES HIERARCHY AND DATA
NEEDS FOR SITE CHARACTERIZATION

by

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Contributing Off-Site Peer Review Panelists[†]

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*Now with Roy F. Weston, Inc., Washington, D.C.

[†]Listed alphabetically on pages x-xii

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November 7, 1986

NOTICE TO READERS

At the request of the Salt Repository Project (SRPO), Argonne National Laboratory conducted an independent peer review of a report by the Battelle Office of Nuclear Waste Isolation entitled "Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization (Draft)."* This report provided a logical structure for evaluating the outstanding questions (issues) related to selection and licensing of a site as a high-level waste repository. It also provided a first estimate of the information and data necessary to answer or resolve those questions. As such, this report is the first step in developing a strategy for site characterization.

Since the time of the Argonne review, the DOE Office of Civilian Radioactive Waste Management's Mission Plan, and its list of issues, was finalized. Subsequently, the Salt Repository Project modified its set of issues to match those of the Mission Plan, and developed a preliminary issue resolution strategy based on them*. Continuing the evolutionary process, the Department of Energy has recently issued a Common Issues Hierarchy to be used by all projects in developing their Site Characterization Plans. These Site Characterization Plans will include in the strategy for issue resolution a performance allocation analysis based on expected characteristics of the multi-barrier mined geological disposal system.

Many of the Argonne peer review comments have been incorporated in the development of the SRP issue resolution strategies; others will be considered during the drafting of the SRP Site Characterization Plan. Appendix C of this peer review report shows the resolution of major comments.

A handwritten signature in black ink, appearing to read "J.O. Neff", with a large, sweeping loop underneath the name.

J.O. Neff
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* Microfiche copies of these reports are attached to the inside back cover of this report.

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 requirements of the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, as enunciated in 40 CFR Part 191 and 10 CFR Part 60, respectively, as well as those of the Nuclear Waste Policy Act of 1982. 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 mined repository in salt for high-level radioactive waste. This report summarizes Argonne's review of a February 1985 draft report by ONWI entitled *Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization*.

Argonne was requested by DOE to review this report on March 15, 1985 (see App. A). The review procedure involved obtaining written comments on the report from eight members of Argonne's core peer review staff and from 31 off-site peer review panelists who are experts in relevant research areas. The core peer review panel met at Argonne on May 7, 1985, and reviewer comments were integrated into this report by the review session chairman, with the assistance of Argonne's core peer review staff. Panelists did not contact ONWI personnel, and none of the panelists have 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. All of the peer review panelists were asked whether they concur in the way in which their comments, where incorporated, are represented in this report (see App. B). A draft of this report was sent to SRPO on May 30, 1985. The resolution of ONWI's response to this review report is detailed in App. C.

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) (revised July 1984)
ANL/EES-TM-246	Peer Review of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (May 1984)
ANL/EES-TM-254	Peer Review of the Office of Nuclear Waste Isolation's Reports on Preferred Repository Sites within the Palo Duro Basin, Texas (June 1984)
ANL/EES-TM-256	Special Advisory Report on the Status of the Office of Nuclear Waste Isolation's Plans for Repository Performance Assessment (Oct. 1983)
ANL/EES-TM-258	Peer Review of the Office of Nuclear Waste Isolation's Plan to Decommission and Reclaim Exploratory Shafts and Related Facilities (July 1984)
ANL/EES-TM-259	Peer Review of the Office of Nuclear Waste Isolation's Final Report on the Organic Geochemistry of Deep Groundwaters from the Palo Duro Basin, Texas (Aug. 1984)
ANL/EES-TM-260	Peer Review of the Texas Bureau of Economic Geology's Report on the Petrographic, Stratigraphic, and Structural Evidence for Dissolution of Upper Permian Bedded Salt, Texas Panhandle (Aug. 1984)
ANL/EES-TM-261	Peer Review of the Office of Nuclear Waste Isolation's Report on Functional Design Criteria for a Repository for High-Level Radioactive Waste (Aug. 1984)
ANL/EES-TM-262	Peer Review of the D'Appolonia Report on Schematic Designs for Penetration Seals for a Repository in the Permian Basin, Texas (Sept. 1984)
ANL/EES-TM-263	Peer Review of the Office of Nuclear Waste Isolation's Report on Multifactor Life Testing of Waste Package Materials (Sept. 1984)
ANL/ES-147	Rationale and Methodology for Argonne-Conducted Reviews of Site Characterization Programs (July 1985)

PREVIOUSLY PUBLISHED REPORTS IN THE SERIES

"RADIOACTIVE WASTE ISOLATION IN SALT" (Cont'd)

- ANL/EES-TM-290 Geochemistry of Brine in Rock Salt in Temperature Gradients and Gamma-Radiation Fields -- A Selective Annotated Bibliography (July 1985)
- ANL/EES-TM-292 Peer Review of Westinghouse Electric Corporation's Report on Reference Conceptual Designs for a Repository Waste Package (Oct. 1985)

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

1. *Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, preliminary draft (Feb. 1985).
2. *Issues Hierarchy, Resolution Strategy, and Information Needs for Site Characterization and Environmental/Socioeconomic Evaluation*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, draft (July 1986).

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The credentials of the panel members are summarized in App. D.

*Member of core peer review staff.

†Former member of core peer review staff.

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

ACKNOWLEDGMENTS

Mary F. Warren is thanked for her thorough editing of this report and for her considerable work in assembling and rewriting Sec. 4. Lynda B. Williams provided general assistance to Argonne's core peer review staff during the drafting of the report.

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SUMMARY OF MAJOR COMMENTS AND RECOMMENDATIONS

The Office of Nuclear Waste Isolation draft document entitled *Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization* is deficient because:*

1. The issues raised do not completely address the major postclosure requirements under development by the U.S. Environmental Protection Agency (EPA).
2. The hierarchical structure is not consistently maintained, especially with regard to regulatory requirements.
3. The relationships between the issues/subissues and the information/data needs are often weak.
4. The iteration among performance objectives, issues, and information/data needs required by the performance assessment approach is not evident.
5. Inadequate attention is given to the reasonableness of costs associated with construction, operation, closure, and decommissioning of a repository in salt.

Examples of areas of concern include:

6. Part (b) of issue 1.1 addresses the overall containment requirement of EPA, whereas part (a) addresses the groundwater travel time requirement of the U.S. Nuclear Regulatory Commission (NRC). Groundwater travel time is only one aspect of the containment requirement.

*Items are numbered sequentially for ease of reference in App. C.

7. The groundwater protection requirements in 40 CFR [Code of Federal Regulations] 191.15, Working Draft No. 5 (U.S. Environmental Protection Agency, 1985), are not addressed.
8. The "drilling scenario" is discussed independently of, and at a higher level than, the overall containment requirement of which it is a part.
9. The information/data needs are almost never based on how the issues are to be addressed. Data needs tend to be presented as shopping lists under general technical headings, without regard for the quantity and quality of data needed to perform particular analyses.

The peer review panel recommends recasting the issues as follows:

10. Issue 1.1 Assuming anticipated processes and events, will the waste packages contain the waste for 300-1000 years after permanent closure of the geologic repository, as required in 10 CFR 60.113(a)(1)(ii)(A) (U.S. Nuclear Regulatory Commission, 1984)?
11. Issue 1.2 Assuming anticipated processes and events, will the engineered barrier system limit the postcontainment release of radionuclides to no more than one part in 100,000 per year of the inventory calculated to be present 1000 years following closure, as required by NRC in 10 CFR 60.113(a)(1)(ii)(B)?
12. Issue 1.3 Will the preemplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment be at least 1000 years, as required by NRC in 10 CFR 60.113(a)(2)?
13. Issue 1.4 Will the undisturbed performance of the geologic repository limit, for 1000 years after closure, the average annual radionuclide concentrations in any significant source of groundwater outside the controlled area to less than the limits established by EPA in 40 CFR 191.15, Working Draft No. 5?
14. Issue 1.5 Will the geologic repository limit the likelihood and magnitude of 10,000-year cumulative releases of radionuclides to the accessible environment to less than the limits established by EPA in 40 CFR 191.13, Working Draft No. 5?

15. Issue 4.1 Are the properties and characteristics of the site such that repository construction, operation, closure, and decommissioning are feasible, using available technology?
16. Issue 4.2 Are the repository design and planned operations sufficiently flexible to allow modification of ongoing operations, which may be required by unexpected site properties, to be made with available technology?
17. Issue 4.3 Will the engineering considerations, materials, and service requirements of the repository allow construction, operation, closure, and decommissioning to be accomplished with available technology?
18. Issue 4.4 Will meeting the requirements to protect the health and safety of repository workers allow construction, operation, closure, and decommissioning of the repository to be accomplished with available technology?
19. Issue 4.5 What are the costs of repository construction, operation, closure, and decommissioning, and are the costs reasonable?

A step-by-step approach is recommended for developing the subissues and related information and data needs. The approach, which follows the issues suggested above, involves needing to:

20. Precisely define the governing factors for each issue.
21. Establish the method to be used to resolve each issue.
22. Develop conceptual models that link the processes and events to the quantities that must be evaluated to resolve each issue.
23. Identify processes or events that need further investigation to provide quantitative assessment of their influence on repository performance.
24. Develop mathematical models (if needed) to estimate the quantities needed to resolve each issue.
25. Identify site-specific parameters that will be needed either to apply the mathematical models or to evaluate their applicability and validate their performance.

26. Apply the mathematical models to estimate the quantities (and uncertainties in these quantities) needed to resolve each issue so addressed.

Specific examples related to this approach are provided to show what should be considered when developing subissues and information/data needs under each of the redefined issues under key issue 1.

A list of comments on the internal logic of the issues hierarchy document is also presented. The main recommendations are:

27. Avoid the terms "designated area," "major sources of groundwater," and "sole source aquifers" in the revised document because they no longer apply.
28. Use terminology consistent with major regulatory and programmatic documents.
29. When addressing subissue concerns, distinguish the information and data needs that pertain to salt as opposed to other rock types.
30. Indicate that the definition of "engineered barrier system" used throughout the document is DOE's definition and that it differs from the one used by NRC.
31. Treat explicitly the likelihoods of the various disruptive scenarios in the subissues and related information and data needs.
32. Define "containment period" as the period during which containment is "substantially complete" and agree upon a confidence level.
33. Clarify the purpose of the containment period and how loss of containment is defined.
34. Consider rewording subissue 1.2.6 to read: "What is the probability that mechanical failure of the waste package will result in loss of containment during the first 300-1000 years?"
35. Develop a subissue, and related information and data needs, that goes beyond subissue 4.1.9 in dealing specifically with assessing problems related to retrieval of waste packages from a repository in salt.
36. Consider consolidating the 10 sections of information and data needs under subissue 4.1.10 under two sections entitled "Site preparation and facility location" and "Facility construction."

37. Consider rewording subissue 4.1.11 to read: "What characteristics of the site require long-term monitoring?" and, under subsections 4.1.11.1.A and B, consider providing lists of the parameters to be measured.
38. Delete issue 4.5 because it is largely a restatement of key issue 4 and because it attempts to integrate points already covered in issues 4.1-4.4.

1 INTRODUCTION

As used in the Civilian Radioactive Waste Management Program, issues are technical questions that must be resolved in order to satisfy regulatory performance requirements for a mined repository in salt for high-level radioactive waste. Such issues must be resolved before the U.S. Nuclear Regulatory Commission (NRC) will issue a construction authorization to the U.S. Department of Energy (DOE). The issues hierarchy prepared for DOE's Salt Repository Project (SRP) will be used in preparing a site characterization plan (SCP) for the recommended salt site. Information and data needs that are linked to the issues hierarchy are intended to provide direction for site characterization activities. The SCP must be submitted to NRC before site characterization work begins. Battelle Memorial Institute's Office of Nuclear Waste Isolation (ONWI) is responsible to DOE's Salt Repository Project Office (SRPO) for preparing the issues hierarchy and related information and data needs.

The purpose of the peer review conducted by Argonne National Laboratory was to provide an independent, multidisciplinary evaluation of the ONWI issues hierarchy document, which covers key issues 1 and 4 of DOE's (1984) draft *Mission Plan for the Civilian Radioactive Waste Management Program*. The major thrust of Argonne's review was in accord with SRPO's concerns expressed in its letter of guidance of March 15, 1985 (see App. A). The review covered the logical development and completeness of the issues hierarchy and information/data needs as related to stated performance objectives.

Thirty-nine peer review panelists contributed written comments, which are reflected in this report, on the aspects of the issues hierarchy that bore upon their respective discipline areas. Section 2 deals with the extent to which the issues hierarchy document addresses regulatory requirements and programmatic and performance assessment considerations. It also presents an alternative approach based more directly on regulatory requirements for developing an issues hierarchy and specifying logically related subissues and information/data needs. Section 3 comments upon the internal logic of the issues hierarchy document, and Sec. 4 addresses its relevance, completeness, and understandability. Ways to improve the overall presentation, including recommendations for material to be included in an introduction to the issues hierarchy document, are suggested in Sec. 5.

2 RECOMMENDATIONS CONCERNING THE LOGIC AND COMPLETENESS OF THE ISSUES HIERARCHY

The structure of ONWI's draft report entitled *Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization* is deficient in several respects:

1. The issues raised do not completely address the major postclosure requirements set by the U.S. Environmental Protection Agency (EPA).
2. The hierarchical structure is not consistently maintained, especially with regard to regulatory requirements.
3. The relationships between the issues/subissues and the information/data needs are often weak.

Examples of areas of concern include:

1. Part (b) of issue 1.1 addresses the overall containment requirement of EPA, whereas part (a) addresses the groundwater travel time requirement of NRC. Groundwater travel time is only one aspect of the containment requirement.
2. The groundwater protection requirements in 40 CFR [Code of Federal Regulations] 191.15, Working Draft No. 5 (U.S. Environmental Protection Agency, 1985), are not addressed.
3. The "drilling scenario" is discussed independently of, and at a higher level than, the overall containment requirement of which it is a part.
4. The information/data needs are almost never based on how the issues are to be addressed.

Section 2 of this report is based on the premise that key issues, issues, and subissues should be derived directly from regulatory and programmatic considerations and that a site characterization program should be based on the subissues and resulting information/data needs.

Performance assessment activities will provide a means for assessing the degree to which issues have been resolved. According to DOE's draft Mission Plan (U.S. Department of Energy, 1984), performance assessment is not only a means for assessing compliance with regulatory requirements, it is also a means for evaluating additional data needs and design requirements in the context of sensitivity and uncertainty analysis. A fundamental shortcoming of the present issues hierarchy is that, in general, information/data needs are not based on how to address the issues and subissues. Argonne's recommendations for improving the logic of the issues hierarchy are based on all of the concerns stated above.

2.1 REGULATORY REQUIREMENTS AND PROGRAMMATIC CONSIDERATIONS

All repository exploration, siting, construction, operation, closure, and post-closure activities must be conducted according to myriad federal and state regulations. It is important to determine which regulations are pertinent in developing issues for an SCP. Many regulations are clearly procedural in content and are not pertinent to this particular task. Other regulations pertain to technical concepts and require technical evaluation, and seemingly require specific consideration at different stages in the lengthy sequence of events leading up to repository decommissioning and postclosure actions.

The siting guidelines in 10 CFR 960 (U.S. Department of Energy, 1983) and in the draft Mission Plan (U.S. Department of Energy, 1984) outline DOE's strategy for meeting the regulatory requirements and guidance in 10 CFR 60 (U.S. Nuclear Regulatory Commission, 1984), Regulatory Guide 4.17 (U.S. Nuclear Regulatory Commission, 1982), and 40 CFR 191, Working Draft No. 5 (U.S. Environmental Protection Agency, 1985). The issues hierarchy document was reviewed in light of the above considerations.

2.1.1 DOE Draft Mission Plan

Volume II of DOE's (1984) draft Mission Plan presents a hierarchy of information needs with the stated purpose of making "apparent the logic of site investigations and design activities and thereby ensure that no significant issues are overlooked or extraneous information collected." Four key issues are presented, as are several subordinate issues and information needs. The two key issues in the issues hierarchy document are identical to key issues 1 and 4 in the draft Mission Plan. However, key issues 2 and 3, which pertain to regulatory requirements, and supporting issues and information needs, are not addressed in the issues hierarchy document. It is assumed that key issues 2 and 3 in the draft Mission Plan will be addressed elsewhere.

The issues identified under key issues 1 and 4 in the issues hierarchy document and the draft Mission Plan are quoted in Table 1. It is readily apparent that the issues in the issues hierarchy document do not correspond with those in the draft Mission Plan. Both sets of issues correspond with the siting guidelines in 10 CFR 960 and address the major concerns expressed in 10 CFR 60. However, because the two hierarchies diverge at all levels below the key-issues level, the conceptual correspondence between the two, as well as the comparative advantages and disadvantages of each from a regulatory perspective, cannot be readily evaluated. Because of the programmatic importance of the draft Mission Plan, a serious attempt should be made to resolve the differences between the two hierarchies. The final hierarchy of issues that will appear in the SCP should agree in content with the hierarchy appearing in the draft Mission Plan.

2.1.2 10 CFR 60

The revised technical criteria for the disposal of high-level radioactive wastes in geologic repositories published by NRC, as required by the Nuclear Waste Policy Act of 1982 (Public Law 97-425), as 10 CFR 60 (final rule) are of major programmatic

TABLE 1 Issues Contained in the Issues Hierarchy and DOE's Draft Mission Plan

Issues Hierarchy	Draft Mission Plan
<p>Issue 1.1 Under expected conditions will the geologic setting of the repository (a) meet the performance objective of 1,000 year pre-waste-emplacement groundwater travel time from the disturbed zone to the accessible environment and (b) support the overall repository system performance objective for releases to the accessible environment?</p>	<p>Issue 1.1 Will the present and expected geohydrologic setting at a site be compatible with waste containment and isolation?</p>
<p>Issue 1.2 Under expected conditions will the waste packages contain the waste form 300 to 1,000 years after closure?</p>	<p>Issue 1.2 Will the expected geochemical characteristics of the site be compatible with waste containment and isolation?</p>
<p>Issue 1.3 Under expected conditions will engineered barrier system limit its post-containment release of radionuclides to no more than one part in 100,000 per year of the 1,000-year inventory or such other fraction as may be approved by NRC?</p>	<p>Issue 1.3 Will the waste packages meet the performance objectives of (a) waste containment for the 300 to 1000 years after waste emplacement and (b) an acceptable rate for radionuclide releases from the engineered-barrier system after the containment barrier is breached?</p>
<p>Issue 1.4 Under disruptive conditions resulting from the drilling scenario will the engineered barrier system and the geologic setting of the site continue to provide the required containment and isolation of the emplaced waste?</p>	<p>Issue 1.4 Can the underground facility be placed at a depth such that surface erosion will not lead to releases greater than those allowed by regulations?</p>

TABLE 1 (Cont'd)

Issues Hierarchy	Draft Mission Plan
Issue 1.5 Will future climatic conditions at a site lead to radionuclide releases greater than those allowed by regulations?	
Issue 1.6 Will any subsurface rock dissolution within the geologic setting of the site lead to radionuclide releases greater than those allowed by regulations?	
Issue 1.7 Will future igneous activity or tectonic processes or events within the geologic setting of a site lead to radionuclide releases greater than those allowed by regulations?	
Issue 1.8 Is it possible to protect the repository from future human activities that could adversely affect waste containment and isolation?	
Issue 4.1 Are the properties and characteristics of the site such that repository construction, operation, and closure are feasible on the basis of available technology and are the associated costs reasonable?	Issue 4.1 Will the waste package designed for use at a site be cost effective and compatible with the regulatory requirements for safe transportation, handling, emplacement, and retrieval?

TABLE 1 (Cont'd)

Issues Hierarchy	Draft Mission Plan
Issue 4.2 Are the repository design and planned operations sufficiently flexible to allow modifications to ongoing operations, which may be required by unexpected differences in site properties, to be made with available technology and at reasonable cost?	Issue 4.2 Will the surface characteristics and conditions at the site allow the construction and closure of a repository to be accomplished with available technology and at reasonable cost?
Issue 4.3 Will the engineering considerations, materials, and service requirements of a repository allow construction, operation, and closure to be accomplished with available technology and at reasonable cost?	Issue 4.3 Is the repository horizon of sufficient lateral extent, thickness and depth -- and are the planned operations of sufficient flexibility -- to allow a cost-effective repository to be developed?
Issue 4.4 Will the requirements to protect the health and safety of repository workers allow construction, operation, and closure of the repository to be accomplished with available technology and at reasonable cost?	Issue 4.4 Are the hydrologic conditions at the site compatible with the construction and operation of a cost-effective repository?
Issue 4.5 Can a repository meet the multiple goals of complying with regulatory requirements, being based upon available technology, and being cost effective?	Issue 4.5 Are the effects of expected tectonic phenomena, igneous activity, tornadoes, hurricanes, and other natural phenomena and man-induced ground motion compatible with cost-effective repository construction, operation, and closure?

TABLE 1 (Cont'd)

Issues Hierarchy	Draft Mission Plan
Issue 4.6	Can a repository be designed, constructed, and operated to perform its functions of waste receipt and disposal and protect the health and safety of the workers in a cost-effective manner?
Issue 4.7	Can the repository be closed in a cost-effective manner?

importance. Subpart E, Technical Criteria, is of primary concern in this regard, although technical considerations are also presented in other subparts of 10 CFR 60. Subpart E, Sec. 60.131(b)(9), of 10 CFR 60 states that the design of the geologic repository operations area should incorporate relevant requirements in 30 CFR, Chapter I, Subchapters D, E, and N (U.S. Mining Safety and Health Administration, 1984), which support the Federal Mine Safety and Health Act of 1977. Furthermore, NRC's Regulatory Guide 4.17 recommends that the conceptual repository design be included as Chapter 6 of the SCP. Although many of the information/data needs identified in the issues hierarchy document would provide some of the requisite information for repository design and would indicate if Mine Safety and Health Administration (MSHA) requirements would be met, there are no issues pertaining explicitly to MSHA requirements. The issues and subissues in the issues hierarchy document are directed toward addressing the major regulatory concerns regarding overall system performance, waste containment, and radionuclide release rates, as well as design and operational considerations.

It is difficult to determine absolutely if the existing issues hierarchy will ultimately satisfy all pertinent regulatory concerns in 10 CFR 60. Initially, it appears that major concerns, as noted above, are addressed. However, the connection between specific information/data needs and an issue or subissue is not always obvious. It is possible, therefore, that an issue or subissue could agree conceptually with a regulatory requirement, but, because of complications in the natural system and uncertainties in testing methods and data, all possible ramifications of the requirement might not be adequately resolved.

2.1.3 40 CFR 191, Working Draft No. 5

Key issue 1 of the issues hierarchy document refers directly to the requirements set forth by EPA, and issue 1.1 relates to overall repository system performance regarding releases to the accessible environment. Consequently, 40 CFR 191, Working Draft No. 5, is addressed by the issues hierarchy. However, the issues and subissues are a qualitative expression of overall performance and do not explicitly address the quantitative content of 40 CFR 191, Working Draft No. 5. It is not clear that site characterization guided by the existing issues hierarchy will provide the information necessary to demonstrate compliance with the EPA standards for cumulative releases to the accessible environment. Evaluating repository performance in terms of these standards requires major reliance on performance assessment activities; however, it is not readily apparent that the issues hierarchy as presented will ensure that the necessary information will be obtained to conduct these assessments, particularly with respect to the probabilistic components of 40 CFR 191.

Section 191.15 of 40 CFR 191, Working Draft No. 5, states requirements for groundwater protection in quantitative terms. In its present form, the issues hierarchy does not appear to address this regulation.

2.2 PERFORMANCE ASSESSMENT CONSIDERATIONS

Performance assessment considerations cut across many activities of the Salt Repository Project and are particularly important with regard to the issues hierarchy and data needs for site characterization. However, the role of performance assessment is not manifest in the reviewed document. The primary regulatory and programmatic impetus for considering performance assessment is reviewed briefly in Sec. 2.2, and the relationship of essential performance assessment elements to the issues hierarchy and data needs is discussed.

Part (b) of issue 1.1 -- "Under expected conditions will the geologic setting of the repository. . . (b) support the overall repository system performance objective for releases to the accessible environment?" -- is a general statement of Sec. 13 of 40 CFR 191, Working Draft No. 5, regarding EPA's containment requirements. Section 191.13 says that disposal systems shall be designed to provide a reasonable expectation, "based upon performance assessments," that the cumulative releases of radionuclides to the accessible environment be limited. In 40 CFR 191, Working Draft No. 5, EPA defines performance assessment as "an analysis that (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events." Important aspects of this definition relate to the terms "processes," "events," and "uncertainties."

The term "performance assessment" is used in an even broader sense within the Civilian Radioactive Waste Management Program. As indicated in Sec. 2.6 of Volume II of the draft Mission Plan (U.S. Department of Energy, 1984), performance assessment is an important part of the systems task and is carried out by a separate organization to provide a check on the efforts of the systems engineering and design groups. Performance assessment can apply at the system or subsystem level in preclosure and combines an evaluation of the engineered and natural barriers for long-term performances of the repository in postclosure. In regard to the issues hierarchy and data needs associated with site characterization, the draft Mission Plan states that "the performance assessment input for the site-characterization plans (SCPs) will be based on data and designs as they become available but will concentrate on the evaluation of additional data needs and design requirements rather than [on] an assessment of compliance with regulatory criteria." In addition, the draft Mission Plan indicates that "sensitivity and uncertainty analyses will be made to provide feedback to the research programs and subsystem design groups by specifying additional data needs and to determine the best use of design and operating margins for the engineered barrier system." It is important to note that the draft Mission Plan not only extends the use of the term performance assessment beyond the bounds of the containment requirements, but it also emphasizes that performance assessment will provide the means for evaluating additional data needs and design requirements in the context of sensitivity and uncertainty analyses.

Many of the essential elements of performance assessment indicated in 40 CFR 191, Working Draft No. 5, and the draft Mission Plan are not addressed in the issues hierarchy document. The area addressed most directly is that of identification and

examination of processes. Many physical and chemical processes are identified in generic terms in the information/data needs. More often than not, processes can be inferred from lists of properties and parameters included in the data needs. However, no consistent attempt was made to identify the means of relating processes to issues by means of conceptual or numerical modeling. The failure to come to grips with information needs regarding the "how" of assessing the effects of processes is a significant shortcoming and raises a serious question about the utility of the lists of data needs.

The U.S. Environmental Protection Agency requires identification and examination of "events" as well as of "processes." Information/data needs related to events receive sparse coverage in the issues hierarchy document. With the exception of issue 1.4, which attempts to evaluate "the drilling scenario," events in the performance assessment sense of the word are ignored.

Uncertainties regarding both processes and data are not mentioned explicitly in the issues hierarchy document. In addition to general statements of uncertainty that could be made with regard to all measurement activities, the relationships between uncertainties in model predictions of process effects and uncertainties in data should be identified. Such relationships dictate the varying levels of uncertainty that should be assigned to information and data needs.

The issues hierarchy document does not convey the impression that the relationship between performance assessment and data needs is being addressed as mandated by the draft Mission Plan. Data needs tend to come in the form of shopping lists under general technical headings without regard for the quantity and quality of data needed to perform particular analyses. The iteration among performance objectives, issues, information needs, and data needs required by the performance assessment approach is not evident in the document.

2.3 RECOMMENDATIONS

2.3.1 Key Issue 1

The regulatory, programmatic, and performance assessment concerns discussed above lead to the following approach, rationale, and examples for revision of the issues hierarchy under key issue 1.

Key issue 1 -- Will the geologic repository, consisting of multiple natural and engineered barriers, isolate the radioactive waste from the accessible environment after closure, in accordance with applicable requirements set forth by EPA and NRC? -- refers specifically to the need for postclosure performance of the geologic repository to meet EPA and NRC requirements. Therefore, the issues under key issue 1 should directly address the requirements set forth by EPA and NRC. The five issues listed below are designed to address the major relevant NRC and EPA requirements.

- Issue 1.1* Assuming anticipated processes and events, will the waste packages contain the waste for 300-1000 years after permanent closure of the geologic repository, as required by NRC in 10 CFR 60.113(a)(1)(ii)(A)?
- Issue 1.2* Assuming anticipated processes and events, will the engineered barrier system limit the postcontainment release of radionuclides to no more than one part in 100,000 per year of the inventory calculated to be present 1000 years following closure, as required by NRC in 10 CFR 60.113(a)(1)(ii)(B)?
- Issue 1.3* Will the preemplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment be at least 1000 years, as required by NRC in 10 CFR 60.113(a)(2)?
- Issue 1.4* Will the undisturbed performance of the geologic repository limit, for 1000 years after closure, the average annual radionuclide concentrations in any significant source of groundwater outside the controlled area to less than the limits established by EPA in 40 CFR 191.15, Working Draft No. 5?
- Issue 1.5* Will the geologic repository limit the likelihood and magnitude of 10,000-year cumulative releases of radionuclides to the accessible environment to less than the limits established by EPA in 40 CFR 191.13, Working Draft No. 5?

The seven steps that follow exemplify the thought processes that should guide the development of subissues and related information and data needs. Such a step-by-step approach should produce more relevant lists of information and data needs, that is, lists specifically tailored to address the issues.

1. Define precisely the governing factors involved for each issue. Examples of important factors are:
 - a. What is the appropriate measure of loss of containment?
 - b. What is the boundary of the engineered barrier system?
 - c. What is the expected 1000-year radionuclide inventory?
 - d. What is the boundary of the disturbed zone?
 - e. What is the boundary of the accessible environment?

- f. What is the boundary of the controlled area?
 - g. What significant sources of groundwater are located near the controlled area?
- 2. Establish the method to be used to resolve each issue. Examples of important considerations are:
 - a. What processes and events need to be considered?
 - b. What processes and events can be neglected?
 - c. What quantities will have to be calculated, or at least estimated?
 - d. What types of models (ranging from conceptual to numerical) will be needed to calculate the quantities?
- 3. Develop conceptual models that link the processes and events to the quantities that must be evaluated to resolve each issue.
- 4. Identify processes or events that need further investigation to provide quantitative assessment of their influence on repository performance.
- 5. Develop mathematical models (if needed) to estimate the quantities needed to resolve each issue.
- 6. Identify the site-specific parameters that will be needed either to apply the mathematical models or to evaluate their applicability and validate their performance.
- 7. Apply the mathematical models to estimate the quantities (and uncertainties in these quantities) needed to resolve each issue so addressed.

Both information and data needs should derive from the thought process described by the steps above. An example of an information need would be a requirement for a conceptual model of the migration of fluid inclusions. An example of a data need would be the percentage of fluid inclusions in a salt stratum. Thus, information needs will in general be concerned with processes and events, conceptual models, and mathematical models. Data needs will consist of requirements for selected items of data associated with geologic, geochemical, geoengineering, and geohydrologic parameters. Both information and data needs should include requirements for considering uncertainty.

Implementation of the procedure suggested above will lead to an issues hierarchy that is logically more consistent. That implementation has not been attempted here, but the following paragraphs show the types of items that are likely to need consideration for each issue.

Issue 1.1 Assuming anticipated processes and events, will the waste packages contain the waste for 300-1000 years after permanent closure of the geologic repository, as required by NRC in 10 CFR 60.113(a)(1)(ii)(A)?

- Establish the need for and nature of the containment period at a given site.
- Describe the characteristics of the waste package.
- Establish an appropriate definition of containment or loss of containment.
- Evaluate chemical and physical conditions in the vicinity of the waste package.
- Identify corrosion modes and estimate corrosion rates.
- Evaluate the probability of loss of containment as a function of time.

Issue 1.2 Assuming anticipated processes and events, will the engineered barrier system limit the postcontainment release of radionuclides to no more than one part in 100,000 per year of the inventory calculated to be present 1000 years following closure, as required by NRC in 10 CFR 60.113(a)(1)(ii)(B)?

- Establish the boundary of the engineered barrier system.
- Calculate the 1000-year radionuclide inventory.
- Identify relevant processes and events.
- Estimate chemical and physical conditions in the vicinity of the waste package.
- Estimate the time required for the engineered barrier system to be breached by external agents.
- Estimate radionuclide leach rates and the availability of radionuclides for transport.
- Identify groundwater flow paths from the waste form to the boundary of the engineered barrier system.

- Develop a conceptual model for groundwater and radionuclide transport within the engineered barrier system.
- Estimate hydrologic and geochemical conditions and parameters within the engineered barrier system.
- Develop and apply a mathematical groundwater and radionuclide transport model.

Issue 1.3 Will the preemplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment be at least 1000 years, as required by NRC in 10 CFR 60.113(a)(2)?

- Establish the boundary of the disturbed zone.
- Establish the boundary of the accessible environment.
- Identify relevant processes and events.
- Identify groundwater travel paths from the disturbed zone to the accessible environment.
- Develop a conceptual model for groundwater transport.
- Estimate hydrologic and geochemical conditions and parameters.
- Examine potential radionuclide transport paths.
- Develop and apply a mathematical groundwater transport model.

Issue 1.4 Will the undisturbed performance of the geologic repository limit, for 1000 years after closure, the average annual radionuclide concentrations in any significant source of groundwater outside the controlled area to less than the limits established by EPA in 40 CFR 191.15, Working Draft No. 5?

- Establish the boundary of the controlled area.
- Identify significant sources of groundwater near the controlled area.
- Identify relevant processes and events.

- Estimate radionuclide release rates from waste packages during the first 1000 years.
- Identify groundwater flow paths within the controlled area.
- Identify geochemical properties within the controlled area related to radionuclide transport.
- Develop a conceptual model for groundwater and radionuclide transport.
- Estimate hydrologic and geochemical conditions and parameters.
- Develop and apply mathematical groundwater and radionuclide transport model(s).

Issue 1.5 Will the geologic repository limit the likelihood and magnitude of 10,000-year cumulative releases of radionuclides to the accessible environment to less than the limits established by EPA in 40 CFR 191.13, Working Draft No. 5?

- Establish the boundary of the accessible environment.
- Identify anticipated and unanticipated processes and events, including the "drilling scenario."
- Estimate the likelihoods of these processes and events.
- Identify potential groundwater flow paths.
- Examine conditions and parameters that might influence radionuclide transport.
- Develop conceptual groundwater and radionuclide transport model(s).
- Develop a conceptual repository performance assessment model that addresses cumulative radionuclide releases to the accessible environment and their associated probabilities and uncertainties.
- Estimate waste package radionuclide release rates for these conditions.
- Estimate availability of radionuclides for transport.

- Develop mathematical groundwater and radionuclide transport model(s).
- Calculate groundwater and radionuclide transport velocities, fluxes, and travel times.
- Develop a mathematical repository performance assessment model.
- Calculate (estimate) cumulative radionuclide releases and their associated probabilities.

2.3.2 Key Issue 4

The issues hierarchy document does not adequately address the issues and subissues of key issue 4 with respect to the reasonableness of the costs associated with construction, operation, closure, and decommissioning of a repository in salt. References to costs seem to be merely "tacked on" at the end of issues 4.1-4.4. Likewise, in the subissues dealing with information and data needs, only the briefest mention is made of "evaluation of costs." Also, issue 4.5 is superfluous because it restates key issue 4 and attempts to integrate points already covered in issues 4.1-4.4. The following improvements relative to the logic and completeness of the hierarchy under key issue 4 are recommended: (1) remove all references to "reasonable costs" in issues 4.1-4.4, and (2) remove issue 4.5 from the hierarchy and substitute an issue that deals exclusively with cost considerations.

Table 2 illustrates one possible implementation of the above recommendations. In addition to providing an example of a subissue under substituted issue 4.5, Table 2 also provides an example of information/data needs under subissue 4.5.1 of that new issue. Finally, under subsection 4.5.1.5, an expanded example of one of the information/data needs is provided.

TABLE 2 Proposed Revision of Issues under Key Issue 4

Key Issue 4 -- Are repository construction, operation, closure, and decommissioning feasible on the basis of reasonably available technology, and are the associated costs reasonable?

- Issue 4.1** Are the properties and characteristics of the site such that repository construction, operation, closure, and decommissioning are feasible using available technology?
- Issue 4.2** Are the repository design and planned operations sufficiently flexible to allow modification of ongoing operations, which may be required by unexpected site properties, to be made with available technology?
- Issue 4.3** Will the engineering considerations, materials, and service requirements of the repository allow construction, operation, closure, and decommissioning to be accomplished with available technology?
- Issue 4.4** Will the measures taken to protect the health and safety of repository workers allow construction, operation, closure, and decommissioning of the repository to be accomplished with available technology?
- Issue 4.5** What are the costs of repository construction, operation, closure, and decommissioning, and are the costs reasonable?

Subissue 4.5.1 -- What are the costs of repository construction, and are the costs reasonable?

Information/Data Needs

- 4.5.1.1** Results of implementing models used for estimating the costs of civil engineering projects
- 4.5.1.2** Results of implementing models used for estimating costs of equipment and systems for the energy industry
- 4.5.1.3** Results of implementing mining models used for estimating costs of surface and underground operations, surface buildings, and related equipment
- 4.5.1.4** Results of implementing funding models used to assist in planning engineering and project expenditures, establishing funding needs, and providing for the effects of inadequate or changing funding profiles

Table 2 (Cont'd)

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- 4.5.1.5 Results of implementing DOE models used for estimating costs for Waste Isolation Pilot Plant (WIPP) repository construction
- A. Main surface facilities
 - 1. Hoists and headframe structure
 - 2. Heating, ventilation, and air conditioning of the waste building
 - 3. Office maintenance, storage, and support services
 - 4. Repository ventilation and atmospheric protection systems
 - B. Shafts
 - 1. Waste handling
 - 2. Rock handling and construction
 - 3. Ventilation
 - C. Site development
 - 1. Land and mineral rights
 - 2. Off-site developments (e.g., roads, rail lines, water sources, and electric power)
 - 3. On-site developments (e.g., clearing, grading, controlling drainage, roads, and parking facilities)
 - D. Underground facilities
 - 1. Shaft pillar area
 - 2. Shaft stations and mine entries
 - 3. Underground warehouses and shops
 - 4. Storage rooms and haulage ways
 - 5. Mine heating, ventilation, and air conditioning
 - 7. Waste hauling and emplacement equipment
 - E. Surface support facilities and utilities services
 - 1. Substations and electrical distribution
 - 2. Safety and security systems
 - 3. Emergency power
 - 4. Yard piping and pumphouses
-

3 INTERNAL LOGIC OF EXISTING ISSUES HIERARCHY AND INFORMATION/DATA NEEDS

The following comments deal exclusively with the logic of the issues hierarchy document. None of the comments concern the revised logic proposed in Sec. 2.

3.1 COMMENTARY FOR KEY ISSUE 1

3.1.1 Issue 1.1

Issue 1.1 (also issues 1.2 and 1.3) refers to repository performance under "expected conditions," while 10 CFR 60 (Secs. 60.112 and 60.113) refers to performance under "anticipated processes and events." If these expressions were intended to have the same meaning, they should be made consistent; if not, the differences should be clarified because the terms might have different consequences with respect to the logical development of subissues under issues 1.1, 1.2, and 1.3.

Subissue 1.1.1

Logically, the information and data needs should be specific for the various rock types at a given site. For example, several of the items under subsection 1.1.1.1.B are not relevant to salt, which is not normally fractured or jointed. However, items B.2, 8, 9, and 13 could pertain to other rocks in the section. Also under subsection 1.1.1.1.B, the elastic (3 and 4) and inelastic (14) deformation responses and strength responses (5a, b, and c) are rate dependent for salt and may have little practical value. However, all of these responses will be needed for rocks other than salt.

Subissue 1.1.2

The rationale for including the extent of the "designated area" as an information/data need is not clear because such a designation is not recognized by DOE (10 CFR 960) or NRC (10 CFR 60). Although EPA advanced the concept of a designated area in early drafts of 40 CFR 191, it is not clear why it was included in the issues hierarchy. In any case, the terms "designated area," "major sources of groundwater," and "sole source aquifers" have been deleted from 40 CFR 191, Working Draft No. 5, and need not be included in a revised issues hierarchy.

Subissue 1.1.3

As stated, this subissue refers to the stability of the position of the waste, yet one of the subsequent information needs refers to the stability of the position of the canister. It is not clear whether this subissue refers to the stability of the position of the waste form, the canister, or the entire waste package.

Subissue 1.1.4

Subissue 1.1.4 should specify the paths along which the groundwater travels. It should be clear whether the paths are from the disturbed zone to the accessible environment, as would be indicated by issue 1.1; from the engineered barrier system to the accessible environment, as alluded to in subissue 1.1.6, from the waste package to the accessible environment.

Subissues 1.1.4 and 1.1.5 consider both preemplacement and postemplacement groundwater travel paths, fluxes, and velocities. The term "postemplacement" should be reconsidered. Key issue 1 relates to postclosure repository performance. These subissues should therefore refer to postclosure groundwater travel paths, fluxes, and velocities.

Subissue 1.1.5

Subissue 1.1.5 declares the need to predict groundwater velocities and fluxes for both preemplacement and postemplacement conditions. Groundwater velocities for preemplacement conditions are clearly needed to predict the groundwater travel times explicitly required by issue 1.1. However, the need for the other quantities (preemplacement fluxes and postemplacement velocities and fluxes) does not follow logically from issue 1.1, probably because part (b) of issue 1.1 is not very specific.

Subissue 1.1.6

Subissue 1.1.6 refers to the radionuclide release rate from the engineered barrier system. According to the NRC definition in 10 CFR 60 (Sec. 60.2), the engineered barrier system does not include shafts, boreholes, or their seals. However, according to the DOE definition in 10 CFR 960 (Sec. 960.2), the engineered barrier system does include the "barriers used to seal penetrations in and into the underground facility." These definitions are inconsistent. Because releases of radionuclides through seals are just as important as releases through other parts of the engineered barrier system, the revised document should clarify that the DOE definition is intended here.

Subissues 1.1.6 and 1.1.7 refer to the radionuclide release rate and flux from the engineered barrier system through the host formation. The need for these quantities does not follow directly from issue 1.1, probably because part (b) of issue 1.1 is not very specific. Also, single values for release rate and flux may not satisfy the final EPA standards. Rates and fluxes may have to be predicted for individual nuclides or groups of nuclides.

Subissue 1.1.7

Subissue 1.1.7 vaguely refers to the radionuclide flux into and through the host formation. The term "host formation" is not defined in the issues hierarchy document, but the term "host rock" is defined in 10 CFR 60 (Sec. 60.2). If this definition or a

similar one is intended, the subissue may be too restricted. It may prove necessary to predict radionuclide fluxes not only into and through the host formation/rock but possibly through adjacent formations until either the accessible environment is reached or (if proposed EPA standards are implemented) travel times longer than 100,000 years are encountered. Limits should be established that specify how far or over what period the movement of radionuclides must be predicted.

3.1.2 Issues 1.2 and 1.3

The draft Mission Plan issue 1.3 is subdivided in the issues hierarchy document into: 1.2 -- "Under expected conditions will the waste packages contain the waste from 300 to 1000 years, after closure?" and 1.3 -- "Under expected conditions will engineered barrier system limit its postcontainment release of radionuclides to no more than one part in 100,000 per year of the 1000-year inventory or such other fraction as may be approved by NRC?" This separation should be retained at the issues level because it results in a more straightforward approach, is simpler, and uses different sets of subissues. As presently stated, issue 1.3 is oriented more toward systems analysis and modeling than material properties. Also, as presently stated, the two issues address two separate regulatory concerns.

Subissue 1.2.3 requires that "post-emplacement" conditions be determined, which is in accord with issue 1.3 of the draft Mission Plan. At the same time, subissue 1.2.5 refers to predicted canister strength for "post-closure" conditions. If these two sets of conditions are intended to indicate the same situations, identical terminology should be used to avoid confusion.

3.1.3 Issue 1.4

Subissue 1.4.3

This subissue could more logically be treated as part of subissue 1.4.2.

Subissue 1.4.4

As stated, this subissue refers to the predicted release under "the drilling scenario." The preceding subissues (1.4.1-1.4.3) examine the likelihood and effect of various drilling scenarios, but they do not identify criteria for selecting "the drilling scenario." If issue 1.4 is actually intended to consider a suite of drilling scenarios, there should be another subissue (perhaps between subissues 1.4.1 and 1.4.2) that reads: "Which drilling scenarios are the most likely to occur and have significant effects on repository performance (ability to contain and isolate waste)?"

Subissue 1.4.4 refers to the predicted radionuclide release rate from the engineered barrier system under the drilling scenario. To avoid confusion, the text should point out that under certain drilling scenarios (those in which the engineered

barrier system is not penetrated or affected significantly), the release rate from the engineered barrier system may be unaffected and be the same as that resulting from the resolution of the subissues under issue 1.3.

3.2 COMMENTARY FOR KEY ISSUE 4

3.2.1 Subissue 4.1.9

Extending the retrievable phase to 50 or more years presents problems that are not solved by the present information/data needs. One approach is to keep the emplacement rooms open (no backfill) throughout the retrieval period, even though this alternative requires a lower waste placement density. No one agrees on what placement density is required to keep the rooms open by periodically slashing them back to their original sizes.

Another approach is to proceed with backfilling. If retrieval is necessary, the backfill would have to be removed. One problem with this approach is that the waste packages will probably have shifted from their original position to an extent that retrieval cannot be effected by standard vertical overcoring. A more serious problem is that evidence is lacking that waste packages at postemplacement temperatures can be retrieved by current technology. If the second approach is to be used, retrievability cannot be proven by subsurface characterization alone.

When NRC incorporated a long retrievability period, it imposed a difficult problem for repositories in salt. The public is encouraged to believe that proper site characterization and good design will give the highest practical probability of a safe repository. However, the problem cannot be solved by site characterization alone. In fact, the scientific community has not agreed on the design and maintenance elements necessary to keep salt emplacement rooms open during the retrievability period, nor has it incorporated plans to demonstrate the practicality of retrieval from thermally hot backfill.

The above considerations suggest that subissue 4.1.9 cannot address retrievability data needs. Logically, a separate subissue is required for that purpose.

3.2.2 Subissue 4.1.10

The information/data needs are so redundant that it is difficult to make detailed comments other than to suggest that subsections 4.1.10.1 through 4.1.10.10 be reduced to: (1) 4.1.10.1 entitled "Site preparation and facility location" (to include location, excavation embankments, fills, area pavements, roads and railroads, and surface drainage, including flooding), and (2) 4.1.10.2 entitled "Facility construction" (to include foundations, seepage control during construction, structures, electrical and mechanical service, and external loads, including earthquakes, tornadoes, wind, and snow). Such a division would follow typical construction-planning methods. Reducing the information/data needs from 10 to 2 would eliminate the entirely needless duplication in the data sets.

3.2.3 Subissue 4.1.11

This subissue should be reworded to read: "What characteristics of the site require long-term monitoring?"

Subsections 4.1.11.1.A and B

If the rewording suggested immediately above is adopted, then lists should be provided of the parameters to be measured. Such specifications are the real drivers of the information/data needs listed under this subissue. Indeed, subsections 4.1.11.1.A and B could be subdivided, and subsection 4.1.11.2 could be eliminated (see next paragraph).

Subsection 4.1.11.2

Subsection 4.1.11.2 is entitled "Effect of site characteristics on ability to monitor the long-term performance of the repository." What follows is a recitation of characteristics, except for subsection 4.1.11.2.G, which concerns the durability of instrumentation used to monitor the long-term performance of the repository. Actually, this item is the only one that relates to the "ability to monitor." Many of the listed rock characteristics are impossible to measure except under laboratory conditions. It is the in situ measurements that will be important for long-term performance monitoring. In situ measurement of many of the enumerated properties will be very expensive and will require techniques at or even beyond the current state of the art. Each parameter should be discussed as a function of its ability to be measured (i.e., whether it can be measured at all and under what conditions). It is also essential to consider how the measured characteristics will affect the ability to monitor repository performance.

4 RELEVANCE, COMPLETENESS, AND UNDERSTANDABILITY OF ISSUES HIERARCHY AND RELATED INFORMATION/DATA NEEDS

4.1 COMMENTARY ON KEY ISSUE 1

4.1.1 Issue 1.1

Subissue 1.1.1

The term "disturbed zone" should be defined, either in the text or by reference to the appropriate regulation.

***1.1.1.1.A.1.e.** The word "of" should be changed to "or."

1.1.1.1.A.1.f. Add "Total and effective porosity."

1.1.1.1.A.1.g. Add "Saturation."

1.1.1.1.A.2. Thermal properties should be measured over a range of temperatures. Also, a check should be made for temperature dependence.

1.1.1.1.A.2.b. Delete. Effective conductivity is not a unique property because the rate of convective heat transfer depends on the flow rate of the medium providing the cooling.

1.1.1.1.A.3.j. Add items pertaining to the overall layout (e.g., shaft pillars, ventilation ways, haulage ways, and underground shops and offices).

1.1.1.1.A.3.k. Add "Repository room backfill material."

1.1.1.1.B. Add "and of position." Also, several items under this subsection (i.e., B.2, B.8, B.9, and B.13) do not pertain to salt, which is not normally fractured or jointed. However, these information/data needs may be important for nonsalt rocks in the stratigraphic section. This distinction should be made.

The elastic (B.3 and B.4) and inelastic (B.4) deformation responses, and strength responses (B.5.a, b, and c), are rate dependent for salt and may have little practical value. However, these responses will be needed for the nonsalt rocks. Again, it is necessary to distinguish between rock types.

The site characteristics (B.2, B.8, B.9, B.13, and B.15) should be placed in a separate category called "Site characteristics."

*All comments in Sec. 4 preceded by an asterisk need to be "corrected" but do not need to be "resolved."

1.1.1.1.B.5. Delete the property "Strength." This property is irrelevant in a material like salt, which begins to creep at deviatoric stress levels as low as 150 psi.

1.1.1.1.B.6. Delete the property "Cohesion intercept" (see the comment for subsection 1.1.1.1.B.5).

1.1.1.1.B.7. Delete the property "Angle of internal friction" (see the comment for subsection 1.1.1.1.B.5). However, if "Strength" is retained, then delete the "Angle of internal friction" because a Mohr envelope is requested (B.5.c).

1.1.1.1.B.15. The more restrictive "creep law" should be changed to "constitutive law."

1.1.1.2.A.1. The intrinsic permeability tensor should be used instead of the hydraulic conductivity tensor.

1.1.1.2.A.2. The term "equivalent porosity" has no accepted technical meaning and should be defined or deleted. Total and kinematic porosities are needed for prediction.

1.1.1.2.A.3. For three-dimensional flow, specific storage (not storage coefficient) is needed, as well as its dependence on porosity, rock and fluid compressibility, and the effect of thermal stresses on those parameters.

1.1.1.2.A.5. Groundwater head is meaningless without corresponding information on temperature, pressure, and fluid density.

1.1.1.2.A.5,8,9,10. These items could be considered site characteristics rather than hydrologic properties.

1.1.1.2.A.6,7. The effects of temperature on viscosity and of salinity on density are needed.

1.1.1.2.A.10. In addition to percent saturation, changes in capillary pressure and permeability as a function of saturation are required.

1.1.1.2.B.1. The word "permeability" should not be used to mean "hydraulic conductivity." Further, "intrinsic permeability" is often a more appropriate parameter.

1.1.1.4. The relationship between subissue 1.1.1 and subsection 1.1.1.4 is not obvious. In general, it seems that subsection 1.1.1.4 does not deal with the effects of disturbance, but rather appears to be a general description of the thermochemical response of the host rock and groundwater. The needs as listed seem to make up a shopping list; it is not obvious that much thought has been given to the relevance of the various items. Some of the information will be difficult, if not impossible, to obtain in situ. Some of it could be obtained by carefully planned experiments or laboratory studies, but the hierarchy does not discuss the means for acquiring the information.

Rock properties affecting retardation of radionuclides are not listed. Also, the effects of changing chemistry on flow and transport properties need to be determined.

1.1.1.4.B.1. Add "and depth."

1.1.1.4.B.2. Determining the chemical composition of brines under such conditions poses considerable difficulties. The authors should rethink specifying data needs that may require costly, time-consuming research and development programs.

1.1.1.4.B.3. The dating of waters should be added wherever possible.

1.1.1.4.C.1. It seems doubtful that Eh can be measured or estimated with acceptable accuracy.

1.1.1.4.D. Determining such changes in chemical form could be quite difficult (see the comment for subsection 1.1.1.4.B.2).

Subissue 1.1.2

***1.1.2.1.** DOE, EPA, and NRC have to agree on the distance from the repository boundary to the accessible environment.

1.1.2.2. Delete. The term "designated area" is no longer relevant. Although Working Draft No. 4 of Final 40 CFR 191 (May 21, 1984) included this concept, the term is not defined in Working Draft No. 5 of Final 40 CFR 191 (March 21, 1985). After closure and decommissioning, the "designated area" is essentially the controlled area.

1.1.2.2.A. Delete. This subsection is similar to subsection 1.1.2.1.D.

1.1.2.2.B. Move this item to subsection 1.1.2.1.

1.1.2.2.C. Delete. This wording is the same as that in subsection 1.1.2.1.E.

1.1.2.3,4. Delete both subsections. Information/data needs 1.1.2.3 and 1.1.2.4 appeared in Working Draft No. 4 of Final 40 CFR 191 (May 21, 1984). However, Working Draft No. 5 of Final 40 CFR 191 (March 21, 1985) does not explicitly relate the boundary of the controlled-area/accessible-environment to the presence of a significant source of groundwater or to the presence of a sole source aquifer. Neither of these information/data needs is relevant to 10 CFR 60 or 10 CFR 960. Finally, "significant" rather than "major" sources of groundwater reflects current usage.

The use by EPA of 2 km as opposed to 10 km for defining the controlled area permits protection of more groundwater. The change was made in response to public comments that the boundary of an aquifer containing potable groundwater should be considered the boundary of the controlled-area/accessible-environment.

1.1.2.4.B. Change "less" to "more."

Subissue 1.1.3

Subissue 1.1.3 covers the stability of the waste within the salt as it may be influenced by thermomechanical and solutioning effects. It should probably also address

the influences of intrusives such as dikes. The information/data needs seem to be a shopping list, with little thought having been given to the relevance of individual items.

1.1.3.1.A.B. Temperature conditions and mechanical/thermomechanical responses in locations remote from the waste packages are irrelevant. Also, the expected spatial displacement of the waste container should be given.

1.1.3.1.A.1. The lithology and stratigraphy of horizons other than the repository horizon are irrelevant for thermal analyses in the very near field, which is the area of interest as far as the stability of the position of the waste package.

1.1.3.1.A.3. Add appropriate properties for the waste material and the package (e.g., density, thermal properties, and mechanical properties).

1.1.3.1.B. Add "and of position." Then, delete rock properties (e.g., strength properties as given in B.3-B.7) that are irrelevant for salt.

Subissue 1.1.4

It is evident that travel time, not only travel path, is important for this subissue. Equally important are the instantaneous and cumulative concentrations of radionuclides reaching the accessible environment. Subissue 1.1.4 should be reworded to read: "What are the potential routes by which radionuclides may reach the accessible environment, and what are their times of arrival and their concentrations?"

Subissue 1.1.4, which deals with predictions, should resolve fundamental issues of scale and spatial resolution of *measurement* versus scale and spatial resolution of *prediction*. Also, it should account for uncertainty in virtually every item mentioned.

The need for and the intended use of certain models are unclear. For example, in subsection 1.1.4.3, conceptual models are mentioned, but computational results are apparently required in subsection 1.1.4.3.E. Also, the "hydrologic model" in subsection 1.1.4.6 appears with no introduction.

1.1.4.1.A.5. The phrase "Geomorphology of surface units" is not sufficiently explicit. The surface units could be landforms or slopes. Perhaps morphometric analysis is meant.

1.1.4.1.A.6,7. Particular rock units should be specified for such parameters. For example, it should be clear for which units rock densities, specific gravities, and grain-size distributions are needed. Grain size is not meaningful for salt.

1.1.4.1.A.9. Add "Nature of bedding planes."

1.1.4.1.B.1. The discussion of joints and discontinuity features raises questions with regard to size and scale. For example, it is clearly not feasible, nor necessary, to obtain information about joints below a certain size or scale. Sizes or scales should be specified.

Add "Prehistoric seismicity (sand blows, disturbed lake sediments, and other geomorphic indicators)" between "e" and "f."

1.1.4.1.B.1.a. "Frequency of wave" and "degree of mixing" are not commonly used to describe folds; these terms should be defined or deleted.

1.1.4.1.B.1.b. The phrase "description -- rock type, grain size, etc." could refer to different things, including a rock unit on the opposite side of a fault or joint, or geologic materials filling faults or joints. Also, the comma after "filling" should perhaps be deleted.

1.1.4.1.B.1.f.g. It is not clear whether the word "magnitude" is used in its general sense or in a more specific sense (e.g., instrumental measurement of earthquakes to determine Richter magnitude).

1.1.4.1.B.2.c. The meaning of the word "magnitude" must be clear, especially if the word is being used in different ways.

1.1.4.1.C.1. Change to "Define structural, geomorphic, stratigraphic, and hydrologic features...." If hydrologic features are added, then add "groundwater salinity" and "character of groundwater salinity" to the list of factors indicating dissolution. The list of data needs is insufficient in other respects. Additional items that might indicate dissolution include: (a) missing salt units or salt sections (in addition to thinned salt sections), (b) salt springs and other surface manifestations of brine emissions, (c) saline plumes in groundwater aquifers, (d) fractured or structurally deformed shallow bedrock units caused by deeper dissolution, (e) subsurface breccia zones (not breccia pipes), and (f) insoluble residues and diagenetic features indicative of dissolution.

1.1.4.1.C.2.a-f. The data needs with regard to the items in this list are not stated explicitly enough, which leads to ambiguity. For example, merely specifying the latitude and longitude of dissolution features is probably insufficient. An accurate map showing specific locations should be required. Also, to characterize groundwater travel paths, specific locations of facies changes in stratigraphic units are needed.

1.1.4.1.C.2.d. The revised issues hierarchy document should clarify the events being referred to -- events that caused the dissolution, structural or other unspecified events that modified the hydrologic regime, or still other unspecified events. It should also clarify whether the sequence or chronology of events responsible for the dissolution is needed, or whether the sequence or chronology of the dissolution itself is important.

1.1.4.1.C.2.e. Hydrologic characteristics could be given for the dissolution features themselves or for the waters responsible for the dissolution. Also relevant here might be regional hydrological aspects that contributed to an environment conducive to dissolution. The authors should clarify what was meant.

1.1.4.1.C.2.f. Rock chemistry characteristics could be given for the host salt or an associated evaporite, either before or after dissolution, or for the residues and diagenetically changed materials left after dissolution. Alternatively, the authors may

be referring to chemical changes in nonsalt rocks that occurred because of the dissolution. Clarification is needed.

1.1.4.1.C.3. The term "structural discontinuity" is potentially confusing. The term is used here in regard to dissolution features; in subsection 1.1.4.2.B, it is used in regard to hydrologic properties. Also, using the word "structural" when structural geology (i.e., geologic structures) may not be involved adds to the confusion. The term "feature" as used later in the subsection would seem to be preferable.

1.1.4.1.C.4. Insert a subsection under "C" along the following lines: "Characterization of internal structure of salt and its bearing on the potential movement of fluids: 1. Inclusions of nonsalt rocks, 2. Large salt crystals and potential relation to brine migration, 3. Shear zones or faults, 4. Cavities in salt, 5. Other anomalous features, and 6. Explanations for presence and genesis of above features."

1.1.4.1.E. This item is not so much superfluous as it is seemingly out of place. Items "A-D" of subsection 1.1.4.1 all deal with the natural (geologic) characterization of the region and site, whereas item "E" deals with man-made effects. Item "E" would appear to be part of, or parallel to, subsection 1.4.1.1. Wherever it is placed, it should also include solution mining.

1.1.4.2. This subsection requires that hydrologic properties be related to both stratigraphic units and discontinuities; however, the items listed seem more appropriate to continuous units. The special features of discontinuities with regard to flow should perhaps be called out separately.

1.1.4.2.A. The information/data needs are inadequate. Omit the need for information about the "influence of structure on the regional occurrence of aquifers." Of potentially the same value would be the influence of stratigraphy on the occurrence of aquifers.

1.1.4.2.B. See the comment for subsection 1.1.4.1.C.3. Also, it should be determined whether the groundwater regime is characterized by steady or nonsteady state flow. Since flow fields at the regional scale are seldom in a steady state condition, geochemical and isotopic data should be included in the list under item "B." Also included in this list should be the relationship between the pores and fractures of the rock, and the scale of natural heterogeneities and discontinuities, as compared with the scales of the conceptual and computer models being considered for use.

***1.1.4.2.B.1.** "Present" saturation should be "percent" saturation.

1.1.4.2.B.4. "Brine inclusions" should be "brine pockets."

1.1.4.2.B.5. Add "Interaction between hydraulic budget and geologic structures such as joints and faults."

1.1.4.3.A. The terms "at the site" or "near the site" should be defined.

1.1.4.3.D. The alternative conceptualizations should be placed in a priority listing for proper evaluation. And, it is not clear how the alternative conceptual hydrologic models are to be evaluated (e.g., consensus of experts).

1.1.4.3.E.2. "Permeabilities" should probably be "intrinsic permeabilities."

1.1.4.4. The statement of the information/data need is wordy. End the statement after the word "system." Also, it might be useful to show that solution mining of salt is being considered in addition to conventional drilling for petroleum and water.

1.1.4.4.B. The major items of analysis (or modeling) required are inadequately developed.

1.1.4.4.C. The effects should include radiation and chemical effects as well as those related to the thermal field.

1.1.4.4.C.1.a.(6). Add "Total and effective porosity and saturation."

1.1.4.4.C.1.b.(3). Use the term "specific heat" or "heat capacity."

1.1.4.4.C.2. Liquid vapor "heat piping" effects are ignored.

1.1.4.4.C.3. Add "chemical" before "and mechanical" to account for solutioning and deposition in fractures. In addition, a definite statement or item should be added concerning changes in hydraulic conductivity, porosity, and storativity of rock units containing minerals that might be soluble at high temperature and low pH over the times involved in repository disposal.

1.1.4.4.D. A subsection should be added that addresses the effect of radiation on water quality. Although this aspect is briefly touched on in subsection 1.1.1.3, it is not addressed specifically.

1.1.4.5. Change to: "Estimates of, and bounds on, Quaternary or Neogene (Recent) processes relative to site stability."

1.1.4.5.A. This subsection suggests using the climate of the last million years to estimate the potential range of climatic change during the next 1000 years, regardless of the cause. This approach assumes that the variance in climate that occurred over the last million years adequately demonstrates the range of future climates. Because the trend of the immediate future may be one of warming (caused by increased atmospheric carbon dioxide), the climates of the last million years may not be appropriate analogs. They were an episode of environments that were primarily colder than today.

The interglacial periods and the Holocene have been suggested as analogs of future warming. Of these, the best analogs are probably the more recent ones, since more is known about them. The mid-Holocene Atlantic episode (about 8490-5060 years before the present [BP]) is often mentioned as an analog for carbon dioxide warming. (Although the cause of the warming remains unknown, it was probably not caused by carbon dioxide.) Also, this episode was climatically heterogeneous in that it experienced climatic variations at approximately 6050, 6910, and 7740 BP.

Another problem with using past climatic episodes as analogs for the future is that past warm or cold episodes were not alike. For example, Atlantic time was somewhat warmer than today, and precipitation over the Great Plains was less than that

at present. Another warmer-than-present time is the neo-Atlantic episode (about 800-1150 A.D.). During that time, precipitation over Nebraska was similar to or greater than that of today. Therefore, warmer-than-present episodes are not necessarily similar in either the magnitude or pattern of temperature, or in the magnitude or pattern of precipitation, relative to those of today.

Although analogs are an appropriate climatic reconstruction technique, they must be composed from a homogeneous episode, and the variance of that episode must be sufficiently large to encompass the probable ranges of temperature and precipitation for the period for which the analogs are to be used.

The variety of "proxy" climatic records for the Pleistocene must be expanded for a better understanding of Pleistocene climates (e.g., lacustrine units; eolian deposits; archeological evidence; mammalian bone assemblages; and paleoecological materials such as pollen, spores, plant macrofossils, and tree rings).

Finally, delete the word "cyclic." By definition, a cyclic function is periodic. Some climate variations are periodic, but the term does not apply to them all and is therefore misleading.

1.1.4.5.B,C. The other events with which erosion history is to be correlated are not specified. The word "event" has been used with regard to dissolution. The events could be those that are known to cause dissolution or those that are believed to be related to those causing dissolution. However, in subsection 1.1.4.5.C.5, the word "event" is preceded by the adjective "dissolution." Clarification is needed on whether these "events" are the same as, or different from, the "events" listed under subsections 1.1.4.5.C.3 and C.4?

1.1.4.5.D. This subsection has no itemized information/data needs and appears to have been added as an afterthought. Items mentioned therein are already included or could be included under subsections 1.1.4.5.C and E. In any case, including salt domes is confusing when the one salt site selected (Deaf Smith County) is clearly in a bedded sequence. However, the question of salt tectonics is important and should be included in an expanded form in some other appropriate section of subissue 1.1.4. Finally, the portion of the second sentence that reads "or history of beds being laid" does not make sense.

1.1.4.5.E.1. Add "Prehistoric seismicity (sand blows, disturbed lake sediments, and other geomorphic indicators)" between "e" and "f."

1.1.4.5.E.1.a. The terms "frequency of wave" and "degree of mixing" are not commonly used to describe folds and should be defined or deleted.

1.1.4.5.E.1.c. It seems inappropriate to consider diapirism again when subsection 1.1.4.5.D is devoted to this subject.

1.1.4.6. Reword the statement slightly to read: "Estimates of, and bounds on, postemplacement effect on the hydrologic flow system over the next 100,000 years." Some of the items in this subsection seem to be superfluous or to be duplicates of items

under subsection 1.1.4.5, especially with regard to predicting future activities and assessing the frequency and probability of certain processes taking place.

1.1.4.6.A.1. See the comment for subsection 1.1.4.5.A.

1.1.4.6.D. Major items of analysis are inadequately developed or detailed.

Subissue 1.1.5

The approach to be used to address this subissue is not clearly spelled out. Although a computation of some sort is probably envisioned, little information is provided about that computation. In general, this subissue does not deserve to be treated separately from subissue 1.1.4.

1.1.5.2. The distinction between groundwater velocities and radionuclide fluxes means that groundwater velocity is not sufficient to describe contaminant transport; therefore, particle tracking and geochemistry seem out of place. However, if retained, more specific information should be given about the anticipated role of the "particle tracker code." The requirements for using the computer model should be included. The statement that the code must reflect appropriate boundary conditions really says very little about the requirements for the model.

1.1.5.3. The listed data needs are indicative of an overly ambitious data-collection program. Even if the program were realistic, it could only be applied to past conditions -- certainly not to postemplacement conditions.

The items in subsections 1.1.5.3.A and B do not logically follow from the subheading. They are more appropriate for a preclosure hydrologic assessment. What should be included under subsection 1.1.5.3 are tracer studies and direct measurements of geohydrologic parameters along anticipated flow paths.

Subissue 1.1.6

Since the information/data needs for this subissue are said to be essentially the same as those for issue 1.3 (more specifically, subissue 1.3.6), any modification to issue 1.3 and its subissues should take this connection into account.

The term "engineered barrier system" should be defined precisely. The definition adopted should take into account the differences between the DOE and NRC definitions of this term.

No indication is given of the type of analysis or the procedure to be used to predict the release rate. Important requirements are the type of prediction needed to address this issue and the data needed to support that predictive approach.

Subissue 1.1.7

1.1.7.4.A.1.c. Add "Paragenetic sequence of minerals present."

1.1.7.4.B.3. Add "Measurement of radionuclide concentrations in groundwaters."

1.1.7.4.C.1.c. Change to "Influence on radionuclide release of organics in overlying aquifer waters."

1.1.7.4.C.1.e. Add "Burned fuels (diesel exhaust) and organics from human activities."

1.1.7.4.C.3. Altering the mineral assemblages may not increase the retention capability for all radionuclides.

1.1.7.4.D. See the comment for subsection 1.1.4.5.A.

4.1.2 Issue 1.2

Subissue 1.2.1

The following rewording is recommended: "For what period should containment be 'substantially complete' at the [to be specified] confidence level?"

1.2.1.1.G. Add "Power output versus time."

1.2.1.1.H. Add "Heat transfer characteristics."

1.2.1.2. Add "and radiation" after "temperature."

1.2.1.2.B. Add "and radiation" after "temperature" and "and attendant uncertainties" after "radionuclides."

1.2.1.2.C. Add "and radiation" after "temperature" and "and the uncertainties thereof" after "retardation."

1.2.1.2.D. Add "and radiation" after "thermal," "and composition" after "flow," and "and uncertainties thereof" after "package."

1.2.1.2.E. Add "Level of confidence of containment prediction versus time."

1.2.1.2.E.1. Add "Methodology to estimate confidence level of a prediction of a given level of containment for a specified set of waste package and repository properties over a particular time interval."

1.2.1.2.E.2. Add "Data base to test the above methodology to estimate confidence level at a self-consistent level of confidence."

Subissue 1.2.2

As written, the question cannot be answered because it presupposes that the purpose of a containment period is well defined, which is not the case. It might be better to ask: "What is the purpose of a containment period and how should loss of containment be defined?"

1.2.2.1. This item is not useful. In fact, it is misleading because it confuses mechanical structural failure (e.g., failure to support an imposed stress) with "loss of containment." A more appropriate breakdown of the reworded subissue suggested above would be: "What additional structural protection beyond that provided by the waste form itself is required to reduce the uncertainties in the repository performance and for what duration?"

1.2.2.2. Add "Given the uncertainties in the predicted repository performance, how much protection against fluid ingress to the waste form is required and for how long? A. What is a tolerable fluid flux to the waste form? B. What is the predicted fluid flux to the waste form and what is the uncertainty?"

1.2.2.3. Add "What additional barriers to transport of radionuclides across the waste-package/host-rock interface, if any, are required to reduce the uncertainties in the predicted repository performance and for how long? A. What is the allowed limit on the transport rate across that interface versus time? B. What is the predicted transport rate and the attendant uncertainties for just the waste form alone as a function of time?"

Subissue 1.2.3

Add "over time."

1.2.3.1.A. Insert "thermally induced" before "stress."

1.2.3.1.A.1.a.(4). The phrase within parentheses should read "(amount, type, and spatial variation of the impurities)."

1.2.3.1.A.1.c. Change to "Rock, waste package, and backfill material thermal properties and their spatial variation and temperature dependence."

1.2.3.1.A.1.c.(1). Change to "Thermal-conductivity/diffusivity versus water content."

1.2.3.1.A.1.c.(2). Change to "Heat transfer characteristics."

1.2.3.1.A.1.c.(3). Should be either "Specific heat" or "Heat capacity."

1.2.3.1.A.2.a. In situ stress is a site characteristic, not a property.

1.2.3.1.A.2.g. The property "Angle of internal friction" is redundant because a Mohr envelope is requested in subsection 1.2.3.1.A.2.e.(3).

1.2.3.1.A.2.a. Change to "Creep response of host rock and waste package materials at temperatures up to 250°C."

1.2.3.1.C. Using "tectonic or seismic stresses" is misleading. Nonlithostatic stresses may arise from other causes. "Residual stresses" may be a more appropriate term, because it would include all stresses other than lithostatic stress. In addition, since field observations would include the net stress, it is unclear why the lithostatic and tectonic stresses are listed separately.

1.2.3.1.E. Add "Tensile stresses on waste package components." The information/data needs list should include: 1. Magnitude and location of peak tensile stresses, and 2. Peak tensile stress in relation to material yield stress at temperatures up to 250°C.

1.2.3.3.A.2.e. Add "Hygroscopic water in exposed surfaces and backfill."

1.2.3.3.A.3.b. Reword to read: "Estimates of, and bounds on, void space (waste emplacement hole and repository) available for fluid storage versus time, which can be used as a basis for estimating the amount of fluid in the repository region at saturation."

1.2.3.3.A.4. Add "Effect of radiation on amount, phases, and distribution of fluids."

1.2.3.3.A.5. Insert subsection 1.2.3.3.B.3.

1.2.3.3.B. Replace "the water contacts" with "fluids contact."

1.2.3.3.B.3. Add "Amounts and phases of fluids contacting outer waste package surface versus time."

1.2.3.3.B.4. Add "Rate of corrosion or penetration of waste package components (statistical distribution)."

1.2.3.3.B.5. Add "Effect of radiation on the nature and amount of fluids transported to components versus time."

1.2.3.4. Add "as a function of time."

1.2.3.4.A.1. Insert "types, and phases" after "amounts[,]."

1.2.3.4.A.1.a. Reword to read: "Intergranular water, and gas and liquid content of fluid inclusions in salt."

1.2.3.4.A.1.e. Add "Hygroscopic water absorbed from atmosphere."

1.2.3.4.B.3. Change "temperature, fluid composition" to "temperature, radiation, and fluid composition."

Subissue 1.2.4

The word "sensitivity" is misused here. Also, several corrosion mechanisms may be operative, and their relative importance may change over time. It is more important to know the predicted corrosion or penetration rates and the estimated uncertainties for various corrosion processes as a function of repository conditions and time.

1.2.4.2. Reword to read: "Effects (related to corrosion processes) of, and attendant uncertainties in, the effects of radiation, . . ."

1.2.4.2.A.1. Change to "Composition of waste form, canister, overpack (or container), and packing (if any)."

1.2.4.2.A.4. Add "Material processing history."

1.2.4.2.A.5. Add "Number and location of welds."

1.2.4.2.A.6. Add "Microstructure changes in heat-affected zones of weldments."

1.2.4.2.A.7. Add "Magnitude and location of peak tensile stresses."

1.2.4.2.A.8. Add "Peak tensile stresses in relation to material yield stresses."

1.2.4.2.B.1. Change to "Uniform corrosion rate" and add "a. Delineate all factors likely to affect rate and evaluate extent of effects, and b. Evaluate probability of penetration and rate of loss of important mechanical properties of materials."

1.2.4.2.B.2. Reword to read: "Local corrosion, including stress corrosion cracking, intergranular corrosion, pitting and crevice corrosion, and hydrogen embrittlement." Also, the word "aperture" (misspelled in the text) should be defined in the text or in a glossary.

1.2.4.2.B.2.a. Add "Evaluate stress states and magnitude and location of peak tensile stress at temperatures up to 250°C."

1.2.4.2.B.2.b. Add "Enumerate the expected corrosion reactions and evaluate the rates as a function of conditions, including fluid composition and phase, temperature, radiation level, and stress state."

1.2.4.2.B.2.c. Add "Evaluate probability of penetration or rate of loss of important mechanical properties of materials."

1.2.4.2.B.3. Reword to read: "Evaluate the quantities, rates, and compositions of gases generated by the corrosion reactions under expected conditions and evaluate their effects."

1.2.4.2.B.4. Reword to read: "Evaluate the effects of hydrogen uptake and hydriding on corrosion behavior."

1.2.4.2.B.6. Add "Evaluate the effects of radiation and temperature on production of oxygen due to radiolysis."

1.2.4.2.C. Now included in reworded form under new subsection 1.2.4.4.

1.2.4.4. Add "Develop and test methodologies for extrapolating short-term laboratory and field data to long-term performance in a repository. Include evaluations of various methods to accelerate corrosion rates of the specific processes expected to occur under repository conditions."

Subissue 1.2.5

Reword to read: "What is the predicted strength of waste package components as a function of time under expected postclosure conditions?" Note that the term "thickness" has been deliberately deleted because its presence implies that it is the main determinant of strength. This may be true if uniform corrosion is the only important stressor; however, if other forms of corrosion predominate, then other properties (e.g., state of perforation, state of embrittlement, and extent of cracking along grain boundaries) may be more relevant than thickness.

1.2.5.2. Reword to read: "Extent of material property alteration as a function of time."

1.2.5.2.A. Reword to read: "Uniform corrosion depth."

1.2.5.2.B. Reword to read: "Extent of local corrosion."

1.2.5.2.B.1. Add "Statistical distribution of pitting and crevice depth."

1.2.5.2.B.2. Add "Extent of hydrogen embrittlement."

1.2.5.2.B.3. Add "Extent of stress corrosion cracking."

1.2.5.2.C. Add "Resistance to mechanical failure versus time as a function of temperatures up to 250°C."

1.2.5.2.C.1. Add "Identify mechanical failure modes."

1.2.5.2.C.2. Add "Estimate probability of failure versus time for each failure mode."

Subissue 1.2.6

The subissue is poorly worded and therefore difficult to interpret. First, the notion of containment, or loss thereof, is not well defined. Second, the question as worded implies that a relationship between strength and stress can be used to define loss of containment, which is fallacious. Mechanical structural failure, such as by buckling, could occur without "loss of containment." On the other hand, "loss of containment" could arise as a result of pit or crevice corrosion penetration or formation of continuous fluid pathways along grain boundaries without attendant mechanical failure. Third, the relationship between individual component properties and the response of the whole

waste package has yet to be addressed in the issues hierarchy. Consequently, subissue 1.2.5* should address individual component properties, and subissue 1.2.6 should address the response of the whole package.

Reword subissue 1.2.6 to read: "What is the probability that mechanical failure of the waste package will result in loss of containment during the first 300-1000 years?"

1.2.6.2,3. The approach embodied in these two information/data needs sets implies that strength versus time and stress versus time can be independently evaluated and then combined in some unspecified manner to estimate the time to failure. In fact, strength and stress are coupled in a complex way. The best approach would be to combine detailed analysis (aided by computer models) with appropriate experimental data. One or more modeling approaches must be defined and evaluated that treat the couplings between fluid phases and composition, radiation, stress state, and corrosion phenomena as a function of time. The data needs of the approach(es) must be specified. In keeping with these considerations, the following approach and information/data needs structure is suggested:

1.2.6.2

Response of waste package as a whole to imposed mechanical/thermomechanical stress.

A. Analytical approaches

1. Models -- select suitable candidates
2. Verification and validation
3. Identification of information/data needs for performance analysis of the whole waste package

B. Satisfy information/data needs (as identified in subsection 1.2.6.2.A.3)

1. Component data needs (resolution of subissue 1.2.5)
2. Specification of stresses (resolution of subsection 1.2.3.1)
3. Experimental responses of whole waste package

*As currently worded, subissue 1.2.5 refers only to "canister" strength versus thickness and time.

1.2.6.3

Failure-mode analysis and relationships to loss of containment

- A. Identify principal failure modes and probabilities of occurrence versus time and repository conditions
 - 1. Analytical approach (resolution of subsection 1.2.6.2.A)
 - 2. Simulation data (resolution of subsection 1.2.6.2.B)
- B. Relationship of mechanical failure to loss of containment
 - 1. Definition of loss of containment (resolution of subsection 1.2.6.1)
 - 2. Scenarios linking mechanical failure to loss of containment
 - 3. Computed probabilities, as a function of time, that mechanical failure will result in loss of containment

4.1.3 Issue 1.3

Subissue 1.3.1

1.3.1.1. The stated information/data needs describe the layout for waste emplacement. It is also necessary to know the locations of shafts and the below-grade connections to the shafts. The locations of entries, crossovers, and shaft and tunnel bulkheads (seals) also might be useful.

1.3.1.1.A. Delete. "Package emplacement geometry" seems to be a more general way of stating information/data needs given in subsections 1.3.1.1.D, E, and F.

Subissue 1.3.2

Subissue 1.3.2 should more properly refer to "conditions for radionuclide migration with groundwater in the vicinity of the waste package."

1.3.2.2. This subsection deals only with the fluid flux into the waste emplacement hole. It does not emphasize that water and brine flow into and out of the repository.

1.3.2.2.A.3.a. It is not clear how these items are appropriate for the shaft and borehole seals, although they may be appropriate for the host rock in the disturbed zone. "Hydrologic characterization" of shafts and borehole seals might require additional data, including the results of seal tests.

1.3.2.2.A.3.a.(1). Change to "Intrinsic permeability tensor."

1.3.2.2.A.3.a.(2). The term "equivalent porosity" has no accepted technical meaning and should be defined or deleted. Total and kinematic porosities are needed for prediction. For three-dimensional flow, specific storage (not storage coefficient) is needed, as well as its dependence on porosity and rock and fluid compressibility, and the effect of thermal stresses on those parameters.

1.3.2.2.A.3.a.(4). "Groundwater head" is a meaningless piece of data without corresponding temperature, pressure, and fluid density information.

1.3.2.2.A.3.a.(5). The effects of temperature on viscosity and of salinity on density are needed. In addition to percent saturation, changes in capillary pressure and permeability as a function of saturation are required.

1.3.2.2.A.3.c. Determining "time-dependent hydrologic parameters" is an ambitious undertaking and will require test procedures and analytical methods not presently available.

Subissue 1.3.3

Subissue 1.3.3. should be included implicitly as part of subissue 1.2.3. Or, if retained here, add "and the influence of the waste package contents." In general, the chemical and mineralogical composition of both the components of the waste package and the host rock are needed. Another alternative is to reword subissue 1.3.3 to read: "What is the predicted chemical composition of groundwater within, and in the vicinity of, the waste package?"

Nothing is said about the sensitivity of the different estimates. Also, information/data needs for preclosure and postclosure, and for postcontainment, are not distinguished.

1.3.3.1. Subissue 1.2.6 deals with physical stresses but is not directly related to failure. Also, "expected times" are what the data should provide.

1.3.3.2. Reword to read: "Results from resolution of subissue 1.2.3."

1.3.3.2.A.1. This information/data need should mention that water might enter from the surface environment.

1.3.3.2.B.2,3. Combinations of words (e.g., corrosion/leaching/whole package tests) are not clear and such constructions should be eliminated.

1.3.3.2.B.4. Add "Isotopic study of leach solutions."

1.3.3.2.C.5. Add "Changes in waste package solids as a result of irradiation."

1.3.3.2.C.6. Add "Isotopic composition of fluid and salt after irradiation."

Subissue 1.3.4

This subissue should be completely rewritten. The phrase "radionuclide leach rates (including solubility limits)" should be changed to "rates of release of radionuclides." Leach rates should never be mixed with solubility limits. Also, "sensitivity to uncertainties" is certainly an issue, but not in the same context as "release rates."

The list of information/data needs does not include the chemical, physical, and mineralogical data needed to predict radionuclide release. Also needed is the extent of containment failure, that is, whether pin holes or large areas of the container surface are involved.

1.3.4.2. This subsection should take into account flow through the waste package, not only flow in its vicinity. It should also include data needs related to how radionuclides are transported as colloids.

1.3.4.4. This subsection could be deleted. The detailed hierarchy in this subsection does not make sense.

1.3.4.5. The meaning of "Radiation flux versus time and space" is not clear.

1.3.4.7.E. Add "Isotopic systematics of brines and groundwaters."

Subissue 1.3.5

Reword to read: "What quantities of different radionuclides can be expected to be released?"

1.3.5.1,2,3,4. These information/data needs are insufficient to resolve the subissue. For example, add "radionuclide inventory for all waste types." Also, it should be clear how the data needed will be synthesized.

1.3.5.3. This information/data need is a rewording of subissue 1.3.3.

Subissue 1.3.6

The methods for obtaining the kinds of predictions suggested by the subissue are not explained. It is important to specify the modeling or computational framework under which such determinations are to be made to determine the information and data needs required to address this subissue.

1.3.6.1. This information/data need does not follow directly from the resolution of subissue 1.3.2 because that subissue does not specifically consider groundwater flux through the repository excavations and away from the repository. In fact, a fairly detailed model might be required to predict groundwater transport through the backfilled repository excavations following loss of containment. Loss of containment will supposedly occur more than 300-1000 years after closure, and the properties of the backfill will probably have changed significantly by then.

1.3.6.2. The information/data need is for groundwater and brine chemistry in the emplacement holes and repository excavations. This need is said to be fulfilled by the resolution of subissue 1.3.3. However, subissue 1.3.3 appears to deal only with the chemistry right at the waste package.

4.1.4 Issue 1.4

Issue 1.4 speaks of "the" drilling scenario, without its having been specified. Many readers will not know what is meant. A footnote referencing the source of the drilling scenario would be appropriate, as would a sentence or two of description.

Subissue 1.4.1

1.4.1.1. It should be clear what has been drilled. Also, a complete set of geophysical well logs and lithologic well logs, if possible, is needed.

1.4.1.1.G.5. Add "Pressure data from drill stem or production testing."

1.4.1.2. The assessment mentioned will require examination of known geological anomalies and estimation of whether future geologic, geochemical, and geophysical surveys will define additional anomalies of possible significance. Determination of known anomalies will require interpretation of existing stratigraphic, lithologic, structural, tectonic, and geochemical data, as indicated. Such interpretations are presumed to constitute information.

1.4.1.2.A.1.a,b,c,d. The word "unit" should be replaced with "all stratigraphic units."

1.4.1.2.A.1.e,f. Delete. These items are of very minor importance to determining geologic anomalies compared with subsection 1.4.1.2.A.1.d (lithology [rock types] within unit) and are therefore unnecessary for assessment of the probability of unexpected resources.

1.4.1.2.A.1.h. Add "Trace elements."

1.4.1.2.A.2.d,e. Delete. These items are irrelevant to the subissue, which is concerned with unexpected resources that might be found over the geologically short time interval of 10,000 years. However, "Breccia pipes" should be included.

1.4.1.2.B.1.b. Delete. This item is irrelevant to determining unexpected resources.

1.4.1.2.C. Delete. This item does not belong under subsection 1.4.1.2, which deals with the likelihoods of discoveries and not with the specifics of discovered resources.

1.4.1.3. This subsection appears twice.

1.4.1.3.A.1. "Location" should include "township and range."

Subissue 1.4.2

The wording should be changed to include the concept of travel time. Also, assumptions about times of occurrence of drilling must be specified so that drilling scenarios can be correlated with predictions of groundwater travel paths that will depend on future events. The goal is to examine the combined effects.

1.4.2.2.A.5. Add "Injection rates" to account for cases involving solution mining.

1.4.2.2.B.6. Add "Predicted flow rates into shafts and openings."

Subissue 1.4.3

Add "fluxes and" before "velocities." Also, this subissue could be treated as part of subissue 1.4.2. Wherever it is treated, however, the subissue should include an information/data need for a conceptual model of flow through the drilling-induced portion of the modified flow paths. Finally, the specific role of the "particle tracker code" should be described.

Subissue 1.4.4

It is impossible to determine whether the information/data needs are appropriate without a definition of the drilling scenario. Actually, the whole idea of drilling into a repository seems rather remote. One of the requirements of 10 CFR 60.122 (Siting Criteria) is that economic extraction of any commodity not be feasible currently or in the foreseeable future.

The logic of the sequence of information/data needs seems reasonable; however, the reasons for overspecifying certain information/data needs and ignoring others are unclear. Some appear to be lifted from other sections of the issues hierarchy, which introduces some redundancy. For example, the list of information/data needs in subsection 1.4.4.4.B.1.a-g is nearly identical to that in subsection 1.1.1.1.A.3.a-i. Other areas, such as subsection 1.4.4.4.A.4, need further development.

Brine migration is ignored, sources of water are poorly defined, corrosion testing under coupled thermal and gamma radiation loading is not mentioned, and radionuclide speciation and form of transport are not considered. On the other hand, the text implies that it is desirable that the postintrusion brine composition (subsection 1.4.4.4.A.2) be overly well characterized. Although composition is pertinent to the performance objective defining the required containment and isolation of the emplaced waste, the former considerations are also important.

1.4.4.4. The logical order of items under this heading is generally poor. Subsection 1.4.4.4 could logically be divided into two separate information needs: (1) the effect of the drilling scenario on radionuclide release from the waste package (to include the information/data needs already listed under subsection 1.4.4.4) and (2) the predicted transport of radionuclides within the engineered barrier system under the drilling

scenario (to include additional information/data needs such as some sort of model for transport). More specifically, the rate of release of radionuclides from canisters that have failed as a result of corrosion is not mentioned. Finally, the availability of radionuclides for transport upon rupture of a canister by a drill bit needs to be added.

1.4.4.4.A.1.a.(1)(a-d). Delete present subheadings and replace with the following: (a) Interbed water, (b) Intergranular water, (c) Hydrous minerals, and (d) Fluid inclusions.

1.4.4.4.A.1.b.(4). Add an item that addresses the combined effect of thermal and gamma radiation loading on corrosion processes.

1.4.4.4.A.1.c. Consider deleting pressure, which is generally considered a second-order effect.

1.4.4.4.A.1.c.(5). Add "Oxygen release due to radiolysis."

1.4.4.4.A.1.a. Add an item that addresses the amount of the brine that collects at the waste packages. Brine migration and the rate of water release from the four dominant sources listed in subsection 1.4.4.4.A.1.a.(1) should be considered.

1.4.4.4.A.2.b.(4). Simplify the characterization of the groundwater by deleting some of the 10 parameters listed.

1.4.4.4.A.3.b.(1-4). Delete. Replace with the following items: "(1) Uniform corrosion; (2) Local corrosion, including stress corrosion cracking, pitting, and hydrogen embrittlement; (a) Define likely stress states and the magnitude and location of the peak tensile stress; (b) Enumerate expected corrosion reactions and evaluate rates; (c) Evaluate the effect of temperature on corrosion processes; (3) Evaluation of the quantities, rates, composition, and gas generated from the corrosion reactions under expected conditions; (4) Evaluation of the effects of hydrogen uptake and hydriding on corrosion behavior; and (5) Effects of radiation and temperature on production of O₂ due to radiolysis." (If ferrous materials are involved, however, it may be that the effects of hydriding can be deleted.)

1.4.4.4.A.3.b.(2). If this item is retained, "rate of aperture growth" is not clear.

1.4.4.4.A.4. Include at least the following: a. Role of colloidal suspensions; b. Probable "apparent solubility"; (1) Anticipated extent of adsorption; and (2) Anticipated extent of precipitation.

1.4.4.4.B.1.d. A better word than "pitch" is needed. If retained, the word "pitch" should be defined in a glossary.

Subissue 1.4.5

The wording "through the repository host formation" is too vague. Because issue 1.4 is related to EPA concerns regarding containment and cumulative release to the accessible environment, as expressed in 40 CFR 191, the wording of this subissue can be more precise.

A computer model will be needed to predict the movement, and changes in movement, of radionuclides through the host formation. Although such a model is not specifically mentioned, it will probably be the same type of model discussed in subsection 1.1.5.2. For completeness, that model should be mentioned here as an information/data need.

***1.4.5.4.A.** An important comma is missing after the word "brine."

4.2 COMMENTARY ON KEY ISSUE 4

Decommissioning is mentioned in the wording of key issue 4 but does not appear in any of the subissue statements or in the lists of information/data needs.

4.2.1 Issue 4.1

Subissue 4.1.1

4.1.1.1.C. The 1000-year recurrent flood should be treated separately, and the information needs should ensure that several methods will be used, and their results evaluated, to determine this recurrence frequency. Recurrence frequencies for periods on the order of 10 times beyond the length of observation are extremely sensitive to the analytical technique used.

4.1.1.2.D.3. Add "(to include aeration, oxidation, hydration, and lamination)." These properties could cause sloughing and spalling of the shaft wall rock.

4.1.1.2.F.8. Add "Chemical composition of fluids, including pH, H₂S, dissolved H₂S, SO₂, and NH₃."

4.1.1.2.G.3. A climatology of relative humidity must be computed for specific hours of the day because the parameter is not diurnally conservative.

4.1.1.3.C. Add "of near-surface bedrock units and overburden."

4.1.1.3.C.2.g. Add "Characteristics of chemical fluids."

4.1.1.3.E.3. Add "Proximity of tectonic event, a. Volcanism, and b. Active faults."

4.1.1.6,7. There are no information/data needs for design of borehole seals as there are for the shaft liner and shaft seals. The same information/data needs (except perhaps item 4.1.1.7.J) should be included for borehole seal design as for shaft seal design.

4.1.1.7.C.6. Add "Rock wall condition." Contamination of the rock wall from buildup of diesel fumes is an example of a concern.

4.1.1.7.J. Reword to read: "Reconsolidation characteristics of crushed salt versus consolidation pressure, temperature, time, moisture content, particle size distribution, and composition ('salt' can contain significant impurities)."

Subissue 4.1.2

4.1.2.1. The information/data needs are insufficient. Also, the different categories of information/data needs are not logically related to the word descriptions. Selecting the most appropriate excavation method involves considering (1) the desired excavation characteristics (e.g., size, shape, and excavation rate); (2) the physical characteristics of the site (e.g., stratigraphic data and rock mass characteristics); and (3) working environment characteristics (e.g., ambient temperature of the rock and strata gases). Other important considerations include (1) whether explosives will be allowed; (2) whether the excavation will be completed before waste emplacement begins or whether it will proceed simultaneously; (3) if excavation proceeds simultaneously, how close the excavation process will be to emplaced waste; and (4) what haulage method will be used (if conveyor belts are contemplated, will an underground crusher be used?).

4.1.2.1.A.2. These discontinuities are probably not relevant to salt or to selection of an excavation method.

4.1.2.1.A.3. Add "(rock quality designation, rock mass rating, and NGI quality index)."

4.1.2.1.B.1,2,3,4,5,6,9,10,11,12. Delete. They are irrelevant to selection of an excavation method.

4.1.2.1.B.13. Add "Tensile strength of intact rock samples."

4.1.2.1.B.14. Add "Abrasive-ness."

4.1.2.1.C.2,3,4. Delete. They are irrelevant to selection of an excavation method.

4.1.2.1.D.5. Delete. It is irrelevant to selection of an excavation method.

4.1.2.1.E. Delete. It is irrelevant to selection of an excavation method.

4.1.2.1.F. Add "Excavation requirements."

4.1.2.1.F.1. Add "Size and shape of openings."

4.1.2.1.F.2. Add "Desired excavation rate."

4.1.2.1.F.3. Add "Mining methods."

4.1.2.1.F.4. Add "Muck haulage methods and size distribution of muck."

4.1.2.1.F.5. Add "Dust generation and control."

4.1.2.1.F.6.a,b. Add "Water control, a. Mining process water, and b. Groundwater inflow."

4.1.2.1.G. Add "Expected underground working environment."

4.1.2.1.G.1. Add "Potential for 'heat stress' in workers."

4.1.2.1.G.2. Add "Potential for repository to be classified as a 'gassy mine'."

4.1.2.1.G.3. Add "Allowable dust."

4.1.2.1.G.4. Add "Allowable radon working level."

4.1.2.1,2,3,4,5,6,7,8,10. Those subsections having items entitled "discontinuities" or "mechanical properties of rock mass" should be modified as indicated below:

Discontinuities

- a. Clay seams, pockets, and inclusions
- b. Partings
- c. Structural discontinuities (i.e., slides)
- d. Sharp lithological boundaries
- e. Anomalies in crystal size
- f. Sedimentary anomalies (i.e., channels)
- g. Collapsed structures
- h. Fractures and sheared zones related to geometry of rooms
- i. Extrusions

Mechanical properties of rock mass

- 1. Delete "In situ modulus of deformation."
- 2. Delete "Joint stiffness."
- 3. Delete "Joint roughness coefficient."
- 4. Delete "Shear modulus."
- 5. Delete "Poisson's ratio."
- 6. Delete "Modulus of elasticity."

7. Add "Yield limit."
8. Add "Angle of internal yield friction versus temperature and stress."
9. Add "Confined compressive strength versus stress."

4.1.2.2-6. The lists are very redundant. Many data sets are duplicated. A complete list could be placed under the heading "Effect of site characteristics on repository design."

4.1.2.2.A.6. Delete. Trafficability is not relevant to ground control.

4.1.2.2.B. See the comment for subsection 1.1.1.1.B. In particular, subsection 4.1.2.2.B.8 (Rock hardness versus temperature) does not seem to be relevant to ground control.

4.1.2.2.D.8. Reword to read: "Ground support design and expected behavior of ground control system at elevated temperature."

4.1.2.2.D.9. Add "Rock bolt anchorage capacity versus time."

4.1.2.2.E.3. Add "Expected water inflow."

4.1.2.3. It is not clear whether this information/data need refers to the layout and orientation of surface or underground facilities. Subsection 4.1.2.3.A seems to be appropriate for surface facilities but is incomplete because meteorological data are not included. Subsections 4.1.2.3.B-F pertain to underground facilities.

4.1.2.3.A. Delete. Topographic characteristics pertain to surface facilities. This item does not seem relevant to underground layout, with the possible exception of repository flooding caused by surface floodwaters entering shafts.

4.1.2.3.B.1.g. Add "Orientation."

4.1.2.3.C. Either indicate that these properties apply to nonsalt rocks or delete.

4.1.2.3.D.3. Add "Thermal conductivity."

4.1.2.3.D.4. Add "Areal thermal loading."

4.1.2.3.D.5. Add "Geometry of waste emplacement scheme."

4.1.2.4.A.2.g. Add "Orientation." This discontinuity information would pertain primarily to nonsalt rocks.

4.1.2.4.A.3. Add "(rock quality designation, rock mass rating, NGI quality index)."

4.1.2.5. The information/data needs are insufficient. Uncertainty in each category of characteristics and properties should be reported to assess the "ability to predict repository room closure." Spatial inhomogeneities should also be noted in each

characteristic and property. Finally, stratigraphic data may influence the ability to predict.

4.1.2.5.B. It is not clear why shear wave and longitudinal wave velocities are not needed here but are needed in subsection 4.1.2.2.B. If the intent is to back into elastic constants, this approach would be irrelevant for salt.

4.1.2.5.D.2,3,4,5. These items relate to deformations and predicting deformations, whereas this subsection relates to the "ability to predict repository room closure." The logic is not clear. Because the behavior of salt is poorly understood, it is very difficult if not impossible to extrapolate from one set of conditions to another. The only satisfactory tests must be carried out in a full-scale prototype under actual repository temperature and stress conditions.

4.1.2.6. The question of "stability of pillars" is probably irrelevant for a repository in salt, provided that the width-to-height ratio is greater than two (preferably four) and a low (<25%) extraction ratio is used.

4.1.2.6.A.2.g. Add "Orientation," and note that subsection 4.1.2.6.A.1 applies primarily to nonsalt rocks.

4.1.2.6.A.3. Add "(rock quality designation, rock mass rating, NGI quality index)."

4.1.2.6.B.12. Add "Influence of size (volume) on rock strength."

4.1.2.7. The uncertainties and inhomogeneities associated with each property and characteristic should be added. Also add the temperature dependence of all properties. Uncertainties in characteristics and properties are the key for this subsection.

4.1.2.7.A.2.g. Add "Orientation."

4.1.2.8. Delete all information/data needs except those under "C." Earthquakes have little influence on underground workings, unless the mine or repository is sited very near the epicenter. Away from the epicenter, the dominant seismic energy is near the surface. The response of the surface facilities should be controlling as far as an acceptable seismic design.

4.1.2.8.B.1,2. This list is incomplete. Shear and longitudinal velocities and density should be added. The list should be similar to that under subsection 4.1.2.6.B, as revised. If the lists under these two subsections were combined, the list would be complete.

4.1.2.8.C.9. Add "Frequency-magnitude data for site."

4.1.2.9.B. Delete. This item (Rock stress and displacements) seems to be irrelevant to trafficability.

4.1.2.9.D.5. Add "Brine migration."

4.1.2.9.D.6. Add "Humidity of ventilation air." Salt will take water from the air when the relative humidity exceeds 75%.

4.1.2.10. The key things relevant to large-scale ground movements (uplift or subsidence) are (1) depth and lateral extent of the repository, (2) extraction ratio, (3) time elapsed before backfilling, (4) area thermal loading, and (5) percentage of extraction. None of these appears to be listed. Thermally induced uplift may be more of a problem than subsidence.

4.1.2.10.A. Delete. This item (Soil characteristics and properties) does not seem relevant to subsidence caused by underground excavation.

4.1.2.10.B.2.g. Add "Orientation," and note that subsection 4.1.2.10.B.2 applies to nonsalt rocks.

4.1.2.10.C. Except for item 10, this subsection applies primarily to nonsalt rocks in the overlying strata. The inhomogeneities in all properties and characteristics should be required, as should the temperature dependence of properties.

4.1.2.10.F. Add "backfill" after "crushed salt."

Subissue 4.1.3

4.1.3.1.A.1.h. Add "Discontinuities."

4.1.3.1.A.3. It is not obvious what is meant by rock quality, but the condition of the rock surface should be characterized. A significant layer of contamination will build up on the walls of the excavation from diesel fumes, ventilation air, and dust.

4.1.3.1.A.5 or E.7. Substitute the following wording for A.5 or add as E.7: "Expected natural repository resaturation characteristics (e.g., from seeps and efflorescence)." Such resaturation is different than that related to "brine pockets."

4.1.3.1.A.5. Delete. This item is included in subsections "E" and "G."

4.1.3.1.G. Reword to read: "Reconsolidation characteristics of the crushed salt as a function of consolidation pressure, temperature, time, moisture content, particle size distribution, and composition."

Subissue 4.1.6

The ambient air in the repository during the operating period will be vented to the atmosphere unless its radioactive content exceeds a specified level, in which case it will pass through high-efficiency particulate air filters before being vented. To establish the "specified level," aboveground dispersion will probably have to be considered.

4.1.6.1.B.5. Add "Hygroscopicity."

4.1.6.1.C.2.3. The thermal conductivity called for under subsection 4.1.6.1.C.2 addresses quasi-steady-state calculations. Once the specific heat is called for (subsection 4.1.6.1.C.3), a transient calculation is suggested. For that, density is also required.

4.1.6.1.C.4. Change to "Surface roughness of subsurface excavations." Several rock-to-air heat transfer coefficients will be required, depending on the operating mode of a specific passage. Also, the air flow will be fixed for the different operating modes. If the roughness were known, the heat transfer coefficient could be calculated.

4.1.6.1.C.4. Add "Geothermal gradient."

4.1.6.1.C.5. Add "Density of salt, crushed salt, and nonsalt rocks."

4.1.6.1.E.3. Add "Wind and related data for exhaust dispersion calculations."

Subissue 4.1.7

Add "Hygroscopicity" to subsection 4.1.7.1.B.

Subissue 4.1.8

4.1.8.1.C. Proper repository design requires information on the variation in thermal properties over distances that are multiples of, say, the diameter of the waste container. The design should not be concerned with small volumes of media, that is, volumes measured in a few cubic inches, especially where the thermal properties are very different. However, it will be necessary to consider extremes of average values for media between, say, different waste packages. The information/data needs say nothing about measuring variations in physical properties.

Density values (mean and variation) are needed, along with heat capacity and thermal conductivity, to analyze transient behavior.

4.1.8.1.C.2. Add "(mean and variation)" after "thermal conductivity."

4.1.8.1.C.3. Add "(mean and variation)" after "specific heat."

4.1.8.1.C.5 Change to "Surface roughness of subsurface excavations." Several rock-to-air heat transfer coefficients will be required, depending on the operating mode of a specific passage. Also, the air flow will be fixed for the different operating modes. If the roughness were known, the heat transfer coefficient could be calculated.

Subissue 4.1.9

See Sec. 3.2.1.

4.1.9.1.H. If backfilling is to occur, add "Experimental verification that a shifted waste package in thermally hot media can be located and retrieved at a rate comparable

to emplacement." If the rooms are to be kept open, add "Calculations and design criteria for slashing back emplacement rooms to keep them open throughout the retrieval period."

Subissue 4.1.10

See Sec. 3.2.2. The subissue should be reworded to read: "Are the site characteristics such that surface facilities can be constructed and kept operational throughout the emplacement period of _ years and the observational period of _ years?"

4.1.10.1(also 2,3,4,5,6,7,9,10).A.3. Change to "Terrain."

4.1.10.1(also 2,5,7,9,10).B.6. Add "Waterways and ports."

4.1.10.1(also 2,5,7,9,10).B.7. Add "Airports."

4.1.10.1.C. A more logical list would be: 1. Soil description and classification; 2. Soil stratigraphy; 3. Standard penetration value (blow count); 4. Hydrologic characteristics (for rock mass and soil); 5. Depth to "top of rock"; 6. Index tests (a-d), except use "Atterberg limits" instead of "plasticity"; 7. Undisturbed shear strength; 8. In situ shear strength; 9. Compaction properties; 10. Expansibility, swell index; and 11. Relative density and cyclic mobility for sand. The changes suggested for this list will apply to subsequent parallel sections in subissue 4.1.10, as indicated.

4.1.10.1.D. If the changes suggested in the subsections of "D" below are adopted, a more logical ordering would be: 1. Permeability, 2. Transmissivity, 3. Storativity, 4. Piezometric surface, 5. Hydraulic gradients, 6. Chemical composition of water, and 7. Differentiation between surface water and groundwater.

4.1.10.1.D.1. Substitute "Piezometric surface."

4.1.10.1.D.2. Substitute "Permeability."

4.1.10.1.D.7. Add "Differentiation between surface water and groundwater."

4.1.10.1.E.5. Reword to read: "Expected tornado characteristics."

4.1.10.2.C. Delete items 9, 11, and 12. The outstanding unresolved issue here is the inclusion of dynamic property data when there does not seem to be a need for such in the design of surface facilities. However, it is important that, in the event of a design earthquake, entrance/egress capability for shaft operation be retained. This performance capability needs to be more fully developed.

4.1.10.2.C.13. Add "Soil stratigraphy."

4.1.10.2.C.14. Add "Depth to 'top of rock'."

4.1.10.2.C.15. Add "Undisturbed shear strength."

4.1.10.2.E. Same changes as suggested for subsection 4.1.10.1.D.

4.1.10.2.E.2. It is not clear how "pore pressure" will be used.

4.1.10.2.E.7. Add "Identification of aquifers." All of the hydrologic characteristics of this subsection should be related to separately identified aquifers.

4.1.10.2.F.1.b. Change to "Corresponding effective peak acceleration."

4.1.10.2.F.3. Add "Site-amplification factors related to site geotechnical conditions."

4.1.10.2.F.4. Add "Liquefaction potential."

***4.1.10.3.A.1.** "Wet lands" should be "wetlands."

4.1.10.3.B.1. Add "(Unified Soil Classification System)."

4.1.10.3.B.3. Reword to read: "Depth to 'top of rock'."

4.1.10.3.C.1.a. Reword to read: "Depth to 'top of rock'."

4.1.10.3.C.1.f. Delete. Grain size distribution affects only the rock name and really cannot be obtained without crushing the rock.

4.1.10.3.C.3. Reword to read: "Rock quality designation and core recovery percent." Include under subsection 4.1.10.3.D as item 3.

4.1.10.3.E. Same changes as suggested for subsection 4.1.10.1.D. Also, hydrologic characteristics must relate to specific aquifer units.

4.1.10.3.F. Comment is the same as that for subsection 4.1.10.2.F.1.b and F.3,4.

4.1.10.3.G.4. Add "Temperature ranges."

4.1.10.4,5.D. Same changes as suggested for subsection 4.1.10.1.D.

4.1.10.5.E.5. Add "Air temperature and humidity" (see the comment for subsection 4.1.10.4.E.1).

4.1.10.6.C.2. Reword to read: "Uniform Building Code earthquake zone or other seismic risk zonation." The Uniform Building Code earthquake zone may not always be appropriate.

4.1.10.6.C.3. If this subsection is retained, it should read "Potential for tsunami effect," but the potential would be zero for the Paradox and Permian Basin sites and most probably for the salt dome sites as well.

4.1.10.6.D.4. Add "Air temperature and humidity" (see the comment for subsection 4.1.10.4.E.1).

4.1.10.7.E.6. Reword to read: "Uniform Building Code earthquake zone or other seismic risk zonation." The Uniform Building Code earthquake zone may not always be appropriate.

4.1.10.9.E.3. Add "Temperature ranges."

4.1.10.10.F.5. Add "Temperature ranges."

Subissue 4.1.11

Reword to read: "What characteristics of the site require long-term monitoring?"

4.1.11.1.A. A list of parameters of interest should be developed, because the parameters will directly determine the information/data needs required to resolve the subissue. The list should include, for example, fluid composition, flux, temperature, room convergence, and tunnel convergence.

4.1.11.1.B. A list should also be provided of the instrumentation required. Instrumentation availability and durability should also be considered. Indeed, subsections 4.1.11.1.A and B could be subdivided, and subsection 4.1.11.2 could be eliminated.

Another point of view is that the "instrumentation required" needs no elaboration in a site characterization plan.

4.1.11.2. See Sec. 3.2.3.

4.1.11.2.A.1.f. Delete. Grain size distribution probably has no value, except as an index of permeability. Void ratio might be a better index.

4.1.11.2.A.2. Faults and fractures are not distinguished. In fact, faults are totally ignored. Because faults provide the single largest and most readily available path for transport of radionuclides to the accessible environment, this subsection should include them. Further, movement along faults should be included in any long-term monitoring program.

4.1.11.2.B.7. Add "Quality factors for P and S wave transmission." The quality factor (Q) for propagation of P and S waves may be a better measure of the state of a rock mass than P and S wave propagation velocities. Therefore, it should be measured, in conjunction with the wave velocities, as a matter of routine.

4.1.11.2.D. Reword to read "Premining in situ direction and magnitude of principal stresses." Delete items 2-7, which are parameters to be measured during performance monitoring; that is, they belong under subsection 4.1.11.1.A, not under site characteristics.

4.1.11.2.G. Delete. This item is not a site characteristic. However, also refer to commentary for subsection 4.1.11.1.2.

4.2.2 Issue 4.2

Subissue 4.2.1

4.2.1.A.6. Add "Distance of closest approach to planned repository site."

4.2.1.B. It is not clear whether hazardous features can be neutralized (e.g., by drilling to relieve gas pressure or by removing brine).

4.2.1.B.5. Add "Distance of closest approach to planned repository site."

4.2.1.C. Sufficient reliable statistical data on which to base a probabilistic estimate are not available.

4.2.1.D. Add "Estimates of, and the bounds on, the occurrence of tensile fractures within the repository horizon." Subsections should include: 1. Location and spacing, 2. Horizontal and vertical extent, 3. Aperture and filling, and 4. Orientation.

4.2.1.E. Add "estimates of the nature and extent of bedding planes that could intersect the repository." Subsections should include: 1. Nature of lithologies marking bedding planes, 2. Permeability of contact, and 3. Lateral extent of bedding planes.

Subissue 4.2.2

4.2.2.B.5. Add "Support and reinforcement procedures."

4.2.2.B.6. Add "Ventilation practices."

4.2.2.B.7. Add "Water and gas drainage practices."

4.2.2.C.5. Add "Alternatives to access, service, and emplacement excavation design."

4.2.2.C.6. Add "Alternative ventilation practices."

4.2.2.C.7. Add "Alternative drainage practices for water and gas."

Subissue 4.2.3

Emplacement and retrieval temperature conditions should be mentioned, as should special provisions for high-temperature operation and ventilation requirements. Also, the headings for subsections 4.2.3.A and B should read "definition of" instead of "define."

4.2.3.A.1. The subsections should read: "a. Excavation of main headings and storage rooms, b. Drilling of storage holes, c. Transport of waste within underground

facility and shaft, d. Emplacement of container within storage room, and e. Packing of storage hole and backfilling of room."

4.2.3.A.6. Add "Reaction of salt or rock to waste loadings."

Subissue 4.2.4

The design of individual seals and the criteria for selecting seal and bulkhead locations are not mentioned. Also, the conditions expected in the storage room at the time of backfilling are not mentioned.

4.2.4.A. The heading should read "definition of" rather than "define." Also, the information/data needs appear to be a shopping list, and the relevance of listed items is not always obvious.

4.2.3 Issue 4.3

Subissue 4.3.1

4.3.1.B.7. Add "Shaft condensate and bleeds." This item could be considered to some degree to be part of the ventilation requirements, but water rings, pumps, pipelines, pumping stations, and bleeders or distilling chambers will need to be considered.

Subissue 4.3.2

4.3.2.A.6. Add "and their physical properties," after "materials."

4.3.2.A.7. Add "and fabrication tolerances" after "geometry."

Subissue 4.3.3

Costs are mentioned, but it is not indicated how they would be compiled.

4.3.3.A,B. The headings of subsections 4.3.3.A and B should read "definition of" rather than "define." The sequence of steps in subsection 4.3.3.A.1 should be expanded (see the comment for subsection 4.2.3.A.1).

4.3.3.C.6. The phrase "mean time between failures" is unclear and should be replaced by "average downtime for each class of equipment," if that is what the authors are trying to address.

Subissue 4.3.4

It almost seems as if some of the information/data needs lists were borrowed from other waste isolation projects because many of the items are pertinent for "hard" rocks but are irrelevant for salt. For example, salt does not behave elastically, which means that certain of the rock mechanics requirements are superfluous for performance assessment of the host rock.

***4.3.4.A.** The heading should read "definition of" rather than "define."

4.3.4.A.8. Add "Availability of acceptable seal materials."

4.3.4.B.1. Delete. Salt does not fracture, except within a narrow range of loading conditions.

4.3.4.B.2. Delete. Rock strength and cohesion are meaningless in salt.

4.3.4.B.3. Delete. Because salt is virtually impermeable, measuring changes in conductivities would be very difficult, if not impossible.

4.3.4.B.5. Add "Condition of excavation walls (i.e., with respect to contamination)."

4.3.4.C. Reword to read: "Performance characteristics of seal systems." The performance of the seals is not the sum of the rock and seal performance. The interface is typically the most troublesome area. Further, seal performance strongly depends on the host rock environment (e.g., rock type and stress state). Insert the following three information/data needs ahead of items C.1-C.5: "1. Seal location (rock mass characteristics and properties), 2. Seal material, and 3. Seal system mechanical properties."

4.3.4.D.3,6,7. The authors should make clear what "liner" is being referred to.

4.3.4.D.4. The meaning of "vibrational environment" is unclear. If "seismic environment" is meant, this information need is somewhat superfluous as regards underground structures.

4.3.4.D.9. Add "Existence and condition of boreholes drilled from excavation (e.g., gas-relief holes)."

4.2.4 Issue 4.4

Subissue 4.4.1

The information/data needs are basically a shopping list, and it is not obvious how the various subparts of the subissue are related.

4.4.1.B.1.a. It is not clear what is meant by contamination levels.

4.4.1.B.1.d. Add "Age of waste, type of waste (i.e., spent fuel from boiling water reactors or pressurized water reactors, commercial high-level waste, and defense high-level waste), and the radionuclide source term."

4.4.1.B.2.d Add "Waste container heat load."

4.4.1.C. The relevance of off-site operations and facilities to the issue as stated should be clarified. Also, it seems doubtful that such concerns will be under the purview of the Civilian Radioactive Waste Management Program.

4.4.1.C.3. The traffic patterns off site, as they relate to the possibility of accidents if wastes are transported by truck, are outside of the purview of the Civilian Radioactive Waste Management Program.

5 SUGGESTIONS TO IMPROVE PRESENTATION

5.1 INTRODUCTORY MATERIAL

The Salt Repository Project Office has requested suggestions regarding background material that would be useful in an introduction to the issues hierarchy document (see App. A). The peer review panel suggests that the starting point and approach used to develop the issues hierarchy be described, as well as the criteria used to select the information and data needs. Also, the introduction should indicate that the information and data needs are generalized and that more detailed needs will be specified in subsequent documents, such as the SCP and the underground test plan. If the authors of the document intend to distinguish clearly between "information needs" and "data needs," such distinction should be evident, not only in the introduction but also in the format of the hierarchy.

Additional suggestions for material to be included in the introduction are:

1. Information on the origin of DOE's draft Mission Plan and the four performance objectives (key issues) that must be addressed in the SCP.
2. A discussion of the relationship of the present document to the Hierarchy of Information Needs in Volume II of the draft Mission Plan.
3. A brief summary of the NRC and EPA regulations and guidelines for a geological repository that serve as the basis for many of the issues, including issues 1.1, 1.2, and 1.3.
4. A list of the intended uses of the document (e.g., as a guide in developing site-specific issues and site-specific information and data needs required for the SCP).
5. A description of the format of the hierarchy, including an explanation of the different levels and their interrelationship. This description is particularly important because the proposed hierarchy does not have a simple branching structure. (It seems acceptable that information and data needs to resolve some subissues can come from the results of resolving other subissues or from the information and data needs under subissues elsewhere in the hierarchy.)
6. An indication of the criteria used to judge the completeness of the lists of information and data needs. This item may be difficult because of the generic nature of the document and because the specific data needs will depend on the needs of the performance assessment tools (models) that are being developed.

7. A reference to an appended glossary of terms intended to have meanings specific to the SRP. Technical terms that are generally used in the fields of geology, geologic engineering, hydrology, and geochemistry need not be included. Terms that probably should be included are:

- accessible environment
- engineered barrier system
- controlled area
- geological setting
- data need
- host formation
- disturbed zone
- information need
- drilling scenario
- significant source of groundwater

5.2 HIERARCHICAL STRUCTURE

The structure of the issues hierarchy must be consistent. As written, issues 4.2-4.5 are not structured in a manner consistent with the preceding portions of the document. For example, the authors changed the hierarchical structure for issues 4.2-4.5 by deleting the use of subissues at the three-digit level and by substituting information/data needs at that level. Alternatively, it could be that the information/data needs labels have been misplaced and that the three-digit statements under subissues 4.2-4.5 have erroneously been stated as declaratory sentences rather than as questions.

The issues hierarchy refers to key issues, issues, and subissues as "issues." If the distinction between these hierarchical levels is still current, the authors could improve the structure of the issues document by keeping the hierarchy -- key issues, issues, subissues, information needs, and data needs -- firmly in mind during the revision process.

5.3 ISSUE AND SUBISSUE DESCRIPTIONS

Issue and subissue descriptions should be edited for grammar and spelling, revised where necessary to improve clarity, checked for completeness, and put into a format that is consistently maintained throughout the document (see Sec. 5.2). An example of a revision designed to achieve most of these goals is given below:

Current version:

- 4.4.1 Evaluation of the requirements and associated costs for measures which must be implemented to protect the health and safety of repository workers during construction, operation, and closure.

Suggested revision, based on the suggestions in this report, including those in this paragraph:

- 4.4.1 What measures must be taken to protect the health and safety of repository workers during construction, operation, closure, and decommissioning?**

REFERENCES

U.S. Department of Energy, April 1984, *Mission Plan for the Civilian Radioactive Waste Management Program, Vol. I: Overview and Current Program Plans, Vol. II: Information Required by the Nuclear Waste Policy Act of 1982*, DOE/RW-0005 DRAFT.

U.S. Department of Energy, 1983, *Nuclear Waste Policy Act of 1982: Proposed General Guidelines for Recommendation of Sites for Nuclear Waste Repositories; Proposed Rule*, Code of Federal Regulations, 10 CFR 960.

U.S. Environmental Protection Agency, 1985, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, Working Draft No. 5, Final 40 CFR 191.

U.S. Mining Safety and Health Administration, Jan. 1, 1984, *Safety and Health Standards -- Metal and Nonmetal Underground Mines*, Code of Federal Regulations, 30 CFR, Chapter I, Subchapters D, E, and N.

U.S. Nuclear Regulatory Commission, Jan. 1, 1984, *Disposal of High-Level Radioactive Wastes in Geologic Repositories*, Code of Federal Regulations, 10 CFR Part 60.

U.S. Nuclear Regulatory Commission, July 1982, *Standard Format and Content of Site Characterization Reports for High-Level-Waste Geologic Repositories*, Regulatory Guide 4.17.

APPENDIX A

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

Department of Energy
Chicago Operations Office
Salt Repository Project Office
505 King Avenue
Columbus, Ohio 43201-2693
Commercial (614) 424-5916
F.T.S. 976-5916

March 15, 1985

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

Dear Dr. Harrison:

SUBJECT: PEER REVIEW OF PRELIMINARY ISSUES HIERARCHY AND DATA NEEDS FOR SITE CHARACTERIZATION, FEBRUARY, 1985

You are asked to provide an independent peer review of the attached issues hierarchy and statement of data needs for site characterization. "Issues" are defined as questions related to the performance of a repository, and its component elements, that must be answered prior to receiving a construction authorization from the NRC. Issues for site characterization are derived from four performance objectives (Key Issues) defined in the Mission Plan (DOE/RW-0005). These Key Issues relate to:

1. Postclosure repository performance
2. Preclosure repository performance
3. Environmental Impact
4. Engineering cost and feasibility

In developing these broad performance objectives, the DOE was guided by applicable regulations and standards (e.g., 10 CFR 60, 40 CFR 191, 10 CFR 960), environmental legislation, and DOE's own internal orders. The SCP deals primarily with the Key Issues related to Postclosure Performance and Engineering Cost and Feasibility; the scope of the attached report is similarly restricted.

In developing its issues hierarchy, ONWI has utilized an "objectives tree" logic in which broad issues are broken down into more manageable sub-issues, and eventually to specific data needed to resolve an issue. These data needs then drive the preparation of test plans and procedures for site characterization (see Attachment 1 for an illustration of the logic behind the issues hierarchy).

Your review should consider the following:

- 1) the logical development of issues/sub-issues within the hierarchy,
- 2) the completeness of the issues list relative to the stated performance objectives. (If other issues can be developed, these should be identified).

W. Harrison
Page 2

- 3) the appropriateness of the way each issue is worded (i.e., Are the questions presented in such a way as to be answerable?), and
- 4) the completeness of the listings of information and data needs in order to resolve the questions asked.

In addition, we would appreciate suggestions which the reviewers might have regarding background information which would be useful in an Introduction when this report is released to the public.

It must be emphasized that this report is a preliminary statement of data needs relative to identified issues. The report is being used currently in the preparation of surface-based characterization plans and in-situ test plans; however, significant revision is anticipated prior to public release. Your review will provide useful insight into the completeness of our issues breakdown. Additionally, this review exercise will serve as an introduction for the review panelists to the scope of the forthcoming SCP. SRPO requests that a written technical review be completed and organized as follows:

- a) Summary Statement of Review, providing the reviewers overall impressions of the document;
- b) General Comments; and,
- c) Specific Comments, including a citation of the page and paragraph which they relate to.

SRPO would appreciate it if the reviewer(s) would indicate which comments appear to require resolution before publication approval.

Within one week of receiving this instruction, please provide T. Baillieul of my staff with a schedule for your review and a list of the review panelists you have selected.

Sincerely,

R. C. Wunderlich
Deputy Project Manager
Salt Repository Project Office

SRPO:TAB:max:6330B

Enclosures:

- 1) Presentation on issues development
- 2) QA review checklist and reporting forms (QAP 7.1 Appendices A & B)
- 3) Report, "Issues Hierarchy and Data Needs for Site Characterization"

APPENDIX B
CONCURRENCE SHEET

APPENDIX B

CONCURRENCE SHEET

I concur that the Argonne National Laboratory review of ONWI's preliminary draft entitled *Salt Repository Project Issues Hierarchy and Data Needs for Site Characterization* fairly represents my comments, where incorporated, to the peer review panel.

Donald L. Baars

Douglas G. Brookins

Gregory B. Baecher

Joseph S. Busch

Victor E. Baker

John D. Ditmars

Richard M. Bateman

Charles H. Dowding

Barry H.G. Brady

Terry Engelder

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APPENDIX C**ACTION TO BE TAKEN ON THE ARGONNE PEER REVIEW
PANEL'S COMMENTS AND RECOMMENDATIONS**

APPENDIX C

ACTION TO BE TAKEN ON THE ARGONNE PEER REVIEW PANEL'S COMMENTS AND RECOMMENDATIONS

The final draft of ANL's peer review report was submitted to SRPO on July 3, 1985. Since then, ONWI has continued to update the issues hierarchy document. A microfiche copy of the most recent version (Office of Nuclear Waste Isolation, July 1986) is attached to the inside back cover of this report. Modification will continue until the issues hierarchy document is incorporated into the SCP for the Deaf Smith County site.

By agreement with SRPO, ANL is conducting its peer review in two phases. The first phase, which ends with the publication of this report, includes documenting the interim resolution of the 38 Argonne comments and recommendations on pages 1-5, either by reference to ONWI's July 1986 revision or to the issues hierarchy published by DOE (Sept. 1986), or through action statements. Phase two will take place when ANL conducts the peer review of Sec. 8.2 (Issues to Be Resolved and Information Required during Site Characterization) of the SCP. At that time, ANL will determine whether ONWI has appropriately incorporated the content of the following action statements into Sec. 8.2. As part of this second phase, ANL also will examine ONWI's responses to the detailed comments and recommendations on pages 7-67 of this report, as reflected in Sec. 8.2.

<u>Comment or Recom- mendation</u>	<u>Action Statement</u>
1, 6, 7, 10-14	At the time the reviewed report was prepared, revisions to the issues hierarchy in the draft Mission Plan (U.S. Department of Energy, April 1984) were being considered. The issues hierarchy in the reviewed report was one of the proposed revisions. The revised Mission Plan (U.S. Department of Energy, June 1985) retained the issues hierarchy of the draft. Subsequent to the ANL peer review, ONWI (July 1986) drafted a new issues hierarchy document, using the issues hierarchy in the final Mission Plan as a starting point. Recently, the three repository project offices have been asked by DOE's Office of Geologic Repositories (OGR) to adopt a common issues hierarchy (U.S. Department of Energy, Sept. 1986). All earlier issues hierarchies have now been superseded. The issues hierarchies in the ONWI July 1986 and the DOE Sept. 1986 documents address all NRC and EPA regulations. Section 8.2 of the SCP will also address all such regulations.

With respect to ANL's proposed recasting of the issues, the following table shows where the issues suggested by ANL are included in the ONWI July 1986 and the DOE Sept. 1986 documents.

ANL Item Number	ANL Issue Number	ONWI (7/86) Issue Number	DOE (9/86) Issue Number
10	1.1	1.9(1)	1.4
11	1.2	1.9(2)	1.5
12	1.3	1.10	1.6
13	1.4	1.13	1.3
14	1.5	1.11	1.1 and 1.2

2, 8

The hierarchical structure refers mostly to the breakdown of each key issue into issues and then into information needs; however, a loose hierarchical structure among the issues exists in later versions. For example, in the "drilling scenario" situation mentioned by ANL, Issue 1.8 of the ONWI July 1986 document characterizes the likelihood and extent of future human interference, and Issue 1.11 uses the characterization data to assess the effect of inadvertent human intrusion on overall system performance. Issue 1.11 can be considered to be "above" Issue 1.8 because it requires information from Issue 1.8. In the DOE Sept. 1986 report, the issues are broken down into performance, design, and characterization issues. Their inter-relationships are depicted in Fig. 1 (page 4) of that document.

The DOE Sept. 1986 report develops a hierarchical structure under Key Issues 1, 2, and 4, as suggested by ANL. Key Issue 3, which is still under development, is expected to have a hierarchical structure. In the ONWI July 1986 document, the inter-relationships among issues are illustrated by the influence diagrams developed for each issue. Also, the strategy sections for each issue help to resolve the questions raised by ANL. ONWI will ensure that ANL concerns are addressed in Sec. 8.2 of the SCP.

3, 9, 20-26

The reviewed report contains a list of information needs for each subissue, but strategies are not described. The ONWI July 1986 document has a separate strategy section for each issue, thereby showing the connection between the issue and the associated information needs. Section 8.2 of the SCP will retain such strategy sections.

With regard to a step-by-step process for developing information and data needs, the relevant steps are presented in the strategy sections of the ONWI July 1986 document. Section 2.3.3 presents issue-resolution steps that closely parallel those suggested by ANL, as can be seen in the following table.

ANL Step-by-Step Approach		ONWI (7/86) Issue-Resolution Steps	
20.	Define governing factors	1.	Describe issue
21.	Establish resolution method	2.	Select resolution approach
22.	Develop conceptual models	3.	Document conceptual understanding
23.	Identify processes or events	4.	Specify resolution criteria
24.	Develop mathematical models	5.	Identify appropriate information needs
25.	Identify site-specific parameters	6.	Identify and collect data
26.	Apply models to estimate quantities	7.	Perform analyses
		8.	Compare results to resolution criteria
		9.	Document issue resolution

Figure 5 of the DOE Sept. 1986 report summarizes the uniform approach to issues resolution developed by OGR. All of the steps proposed by ANL and presented in the ONWI July 1986 document are implicitly included in that approach and will be included in Sec. 8.2 of the SCP.

4 Although the ONWI July 1986 document does not always emphasize the iterations between steps in the strategy sections for the individual issues, it discusses such iteration in Sec. 2.3.3 (Issue Resolution Steps). Section 8.2 of the SCP will emphasize the iterative nature of the process.

5, 15-19 The final Mission Plan addresses costs using a structure that is different from the one proposed by ANL. The ONWI July 1986 report addresses costs associated with construction, operation, closure, and decommissioning, using the structure in the Mission Plan. In particular, Issue 4.1 considers the cost effectiveness of waste-package

operations; Issue 4.2 considers the cost effectiveness of the surface design as adapted to the surface characteristics at the site; Issue 4.3 considers the cost effectiveness of the underground operations as adapted to the underground characteristics at the site; Issue 4.4 considers the cost effectiveness of operations based on hydrologic conditions; Issue 4.5 considers the effects of certain natural events expected to occur at the site on the cost effectiveness of all operations (construction through closure); Issue 4.6 considers the cost effectiveness of all operations with respect to protecting the health and safety of workers; and Issue 4.7 considers the cost effectiveness of closure. Issue 4.8, which concerns retrievability, is the only issue that does not specifically address cost effectiveness.

Cost effectiveness is adequately addressed in the final Mission Plan under Key Issue 4. The DOE Sept. 1986 report refers less explicitly to cost or availability of technology. However, satisfaction of the preclosure system guideline [10 CFR 960.5-1(a)(3)] requires that these considerations be addressed in the resolution strategy developed for the DOE Sept. 1986 report, which will be summarized in Sec. 8.2 of the SCP.

With respect to recasting the issues, the set of issues in the final Mission Plan, as reflected in the ONWI July 1986 and the DOE Sept. 1986 documents, encompasses those suggested by ANL, as shown in the following table.

ANL Item Number	ANL Issue Number	ONWI (7/86) Issue Number	DOE (9/86) Issue Number
15	4.1	4.2, 4.3, 4.4, 4.5	4.1
16	4.2	4.3	4.2, 4.4
17	4.3	4.1, 4.3, 4.7	4.4
18	4.4	4.6	4.2
19	4.5	4.1-4.7	4.1-4.5

27, 28, 30

Revisions of the ONWI July 1986 document to accommodate the DOE Sept. 1986 report will address the problems raised by ANL. In particular, ONWI will ensure that the terms used are consistent with those in other program documents.

29

Revisions of the ONWI July 1986 document will address subissue concerns and information and data needs with respect to characterization of the Deaf Smith County site.

- 31 The ONWI July 1986 document identifies information needs, but does not attempt to estimate values for those informational elements. Where required, such quantification will be included in the performance allocations being specified in the SCP.
- 32 In the ONWI July 1986 document, the discussion section for Issue 1.9 includes a definition of the containment period as the period during which containment is substantially complete. This definition will be retained in Sec. 8.2 of the SCP. A confidence level was not included because it will be part of the performance allocation exercise in the SCP.
- 33 In the ONWI July 1986 document, the discussion section for Issue 1.9 includes a statement of the purpose of the containment period and presents an approach to defining loss of containment. Section 8.2 of the SCP will retain both items.
- 34 The ONWI July 1986 document does not include the referenced subissue. However, the information and data needs for resolving issues concerning waste-package performance (Issue 1.9) address the probabilities of forces causing mechanical failures and the expected frequencies of occurrence of defects in the waste package that could contribute to such failures. ONWI will ensure that the ANL concerns are addressed in Sec. 8.2 of the SCP.
- 35 The ONWI July 1986 document includes Issue 4.8, which deals specifically with retrieval. Retrieval is also considered in Issue 2.4 (radiological worker safety). In the DOE Sept. 1986 report, retrieval is addressed in Issue 2.4. Section 8.2 of the SCP will include retrieval as an issue.
- 36 Issue 4.2 in the revised Mission Plan most closely corresponds to subissue 4.1.10 in the reviewed report. The breakdown of information needs for Issue 4.2 is adequate. In the ONWI July 1986 document, the strategy section for Issue 4.2 lists the steps that logically give rise to the information needs and then correlates them to the specific information needs. ONWI will ensure that the ANL concerns are addressed in Sec. 8.2 of the SCP.
- 37 The term "long-term monitoring" has its basis in 40 CFR 191.14(b). The proposed revisions to 10 CFR 60 to implement EPA standards (U.S. Nuclear Regulatory Commission, 1986) require that DOE develop a monitoring program for after permanent closure (60.144 proposed). The ONWI July 1986 document does not explicitly address long-term monitoring, and the DOE Sept. 1986 report explicitly addresses monitoring only during the performance confirmation period (Issue 1.7). Section 8.2 of the SCP will address long-term monitoring to the extent required by NRC regulations, as it is the implementing agency for regulations dealing with long-term monitoring.

38

Issue 4.5 does not appear in the ONWI July 1986 document and will not appear in Sec. 8.2 of the SCP.

REFERENCES FOR APPENDIX C

Office of Nuclear Waste Isolation, July 1986, *Issues Hierarchy, Resolution Strategy, and Information Needs for Site Characterization and Environmental/Socioeconomic Evaluation*, draft report.

U.S. Department of Energy, Sept. 1986, *Issues Hierarchy for a Mined Geologic Disposal System*, DOE/RW-0101.

U.S. Department of Energy, June 1985, *Mission Plan for the Civilian Radioactive Waste Management Program, Vol. I: Part I, Overview and Current Program Plans, and Part II, Information Required by the Nuclear Waste Policy Act of 1982*, DOE/RW-0005.

U.S. Department of Energy, April 1984, *Mission Plan for the Civilian Radioactive Waste Management Program, Vol. I: Overview and Current Program Plans, Vol. II: Information Required by the Nuclear Waste Policy Act of 1982*, DOE/RW-0005 draft.

U.S. Nuclear Regulatory Commission, June 19, 1986, *Disposal of High-Level Radioactive Wastes in Geologic Repositories: Conforming Amendments, Code of Federal Regulations, 10 CFR Part 60, Proposed Rule, Federal Register, 15(118):22288-22301.*

CONCURRENCES

I concur with the introduction and action statements of App. C, which are in response to the recommendations and comments of Argonne's review report entitled *Radioactive Waste Isolation in Salt: Peer Review of the Office of Nuclear Waste Isolations's Draft Report on an Issues Hierarchy and Data Needs for Site Characterization.*

T. Baillieul, Salt Repository Project Office

W. Harrison, Argonne National Laboratory

T.I. McSweeney, Office of Nuclear Waste Isolation

APPENDIX D
CREDENTIALS OF PEER REVIEW PANEL MEMBERS

Donald L. Baars

University of Utah: B.S., Geology (1952)

University of Colorado: Ph.D., Geology (1965)

Dr. Baars is a consulting geologist for numerous petroleum and energy-related companies. His area of expertise is the geology of the southwestern United States, with emphasis on the Colorado Plateau. Prior to becoming a full-time consultant in 1980, Dr. Baars was a professor of geology and a part-time petroleum consultant. After having taught at Washington State University from 1965 to 1968, he became full professor at Fort Lewis College in 1969. At the college, Dr. Baars's research focused on the tectonic development of the Ancestral Rockies and Paradox Basin, and the petrography of Colorado Plateau limestones.

Since 1980, Dr. Baars has been a visiting professor at several western and midwestern universities. For example, he became adjunct professor at the Colorado School of Mines in 1982. He has also been very active in professional organizations, becoming associate editor of the *American Association of Petroleum Geologists Bulletin* (1971-1977), the Rocky Mountain Association of Geologists' *The Mountain Geologist* (1969-1981), and the *Geological Society of America Bulletin* (1983-1986).

Dr. Baars is author and coauthor of 46 major publications, including a book published in 1982 on the geologic history of the Colorado Plateau. He is a member of seven professional societies and is past president of the Four Corners Geological Society.

Gregory B. Baecher

University of California, Berkeley: B.S.C.E., Civil Engineering (1968)

Massachusetts Institute of Technology, S.M., Civil Engineering (1970)

Massachusetts Institute of Technology, Ph.D., Civil Engineering (1972)

Dr. Baecher is Associate Professor of Civil Engineering and Head of the Construction Facilities Division at the Massachusetts Institute of Technology. His principal field of interest is engineering geology and rock mechanics, with emphasis on statistical site characterization and engineering risk assessment. Since 1974, he has served as a consultant for numerous geotechnical engineering firms and U.S. government agencies. In 1978-1979, he served on an independent review panel concerning nuclear waste disposal for the Office of Science and Technology Policy and has since been an expert consultant to other U.S. government committees. Before 1974, Dr. Baecher worked at the International Institute for Applied Systems Analysis and served with the U.S. Army Corps of Engineers.

Dr. Baecher has taught numerous courses in geotechnical engineering and reliability, soil mechanics, and prediction and risk in rock engineering. He has published more than 65 papers on such topics as safety and uncertainty in soil engineering, methods of estimating soil properties, and statistical methods in engineering geology.

As an invited lecturer at several American and European universities, Dr. Baecher has spoken on the uncertainty of models in geotechnical prediction and on the probabilistic geotechnical analysis of waste repositories. Dr. Baecher is a member of seven civil engineering and mathematical societies.

Victor R. Baker

Rensselaer Polytechnic Institute: B.S., Geology (1967)

University of Colorado: Ph.D., Geology (1971)

Dr. Baker has been Professor of Geosciences at the University of Arizona since 1981. From 1982 to the present, he has held a joint appointment at that university as Professor of Planetary Sciences/Lunar and Planetary Laboratory. From 1971 to 1981, Dr. Baker served as Assistant and then as Associate Professor in the Department of Geological Sciences at the University of Texas at Austin. In 1979-1980, he was a Fulbright-Hays Senior Research Scholar at Australian National University. Prior to 1971, he was City Geologist for Boulder, Colo., and Geophysicist and Geophysicist-Hydrologist for the U.S. Geological Survey.

Dr. Baker has served on numerous technical and advisory committees, study groups, and panels. Author of approximately 80 research papers, plus numerous reports, reviews, abstracts, and encyclopedia articles, he is a member of 11 professional societies and has been active on their committees. He has served as a consultant to governmental agencies and private firms on problems related to flood hydrology, river erosion, engineering geology, and geoarchaeology.

Richard M. Bateman

Oxford University (Lincoln College): B.A., Physics (1962)

Oxford University (Lincoln College): M.A., Physics (1967)

Since 1982, Mr. Bateman has been President of Vizilog, Inc., a consulting service to major oil companies in the fields of petrophysics and formation evaluation. As President of Petrophysical Data Consultants from 1980 to 1983, he directed a team of engineers and geologists that was writing log analysis software and installing log analysis systems for oil companies. Mr. Bateman spent five years at Amoco International (1975-1980), where his expertise was established in reserve estimation, equity negotiation, quality control of field logging, log interpretation, and formation evaluation by computer. As an engineer for Schlumberger (1964-1975), Mr. Bateman worked in both South and North America on logging projects and carried out research projects at the Schlumberger Doll Research Center in Ridgefield, Conn. His work included interpretation of well logs using statistical methods, permafrost studies, design and programming of well-log interpretation routines, dipmeter studies, nuclear tool responses, and accuracy studies for quality control. Mr. Bateman has been actively engaged in teaching formation evaluation to engineers and geologists, both domestically and overseas, through his association with the International Human Resource Development Corporation.

Mr. Bateman acquired a patent on a neutron well-logging technique for gas detection in 1977. Since then he has published many papers on log analysis and formation evaluation, and has written books on control of log quality and monitoring of reservoir performance. He is a member of four professional societies.

Barry H.G. Brady

University of Queensland: B.Sc. (1963)

University of Queensland: M.Sc. (1967)

University of London (Imperial College): M.Sc., Engineering and Rock Mechanics (1977)

University of London (Imperial College): Ph.D., Mining and Geo-Engineering (1979)

As Chief of CSIRO's Division of Geomechanics in Melbourne, Australia, Dr. Brady directs a group of 80 scientists, engineers, and support staff in basic and applied research in geomechanics. From 1979 to 1983, he was a professor at the University of Minnesota, where his research focused on numerical methods of stress analysis and their application to design of radioactive waste repositories and mining excavations. While at the Royal School of Mines, Imperial College, London (1975-1979), he researched boundary element methods of stress analysis and their application to mine design and underground excavation. Before that time, he acquired experience in rock mechanics at Mount Isa Mines, Ltd. (1967-1975).

Over the last six years, Dr. Brady has been a principal investigator supported by research grants from the Australian Mineral Industries Research Association, Ltd., Battelle's Office of Nuclear Waste Isolation, Rockwell International, and the National Science Foundation. He is principal author of a book on rock mechanics for underground mining and has authored or coauthored more than 50 journal articles, conference and symposium papers, keynote addresses, and major consulting reports for corporations and government agencies in Australia, the United Kingdom, the United States, Canada, and Finland.

Dr. Brady was a member of the DOE Research Assistance Task Force in 1981, which was a group of 30 specialists who were to advise on research needs in radioactive waste isolation. He is an active member of 10 international professional societies and has been an invited speaker at several international symposia. Dr. Brady received the U.S. National Rock Mechanics Committee Award in 1980 for significant original contributions to research in rock mechanics.

Lawrence W. Braile

University of Washington: B.S., Geology (1969)

University of Washington: M.S., Geology (1970)

University of Utah: Ph.D., Geology (1973)

Dr. Braile has been a professor in the Department of Geosciences at Purdue University since 1973. His research interests include crustal seismic studies, applications of quantitative analysis methods in geology and geophysics, and seismotectonics of midcontinental North America. In 1978, Dr. Braile was codirector of an international cooperative seismic profiling experiment in the Yellowstone-Snake River Plain. As part of a research team from Purdue University, the University of Texas at El Paso, and the University of Pittsburgh, Dr. Braile has been actively involved for the past six years in geological and geophysical studies of the midcontinent area of eastern North America. These studies have been aimed at evaluating earthquake hazards and understanding midcontinent seismicity.

Additional research interests of Dr. Braile include developing quantitative linear inversion methods for modeling geophysical data and applying digital processing techniques to one- and two-dimensional filtering of gravity, magnetic, and seismic data. Since 1976, Dr. Braile has served as a consultant to petroleum companies on geophysical methods of exploration and to several of the national laboratories.

Dr. Braile has published more than 60 papers on seismic research and the application of analytical methods in geophysical studies. He has presented approximately 80 papers at national and international meetings over the past 10 years. He is a member of four professional geological societies and is an associate editor of the *Journal of Geophysical Research*. In 1983 he was appointed to the Committee on Seismology of the National Research Council, National Academy of Sciences.

Michael S. Bronzini

Stanford University: B.S., Civil Engineering (1967)

Pennsylvania State University: M.S., Civil Engineering, Transportation (1969)

Pennsylvania State University: Ph.D., Civil Engineering, Transportation (1973)

Registered Professional Engineer, PE-018277-E, State of Pennsylvania

Dr. Bronzini became Director of the Transportation Center and Professor of Civil Engineering at the University of Tennessee in 1983, after five years as Associate Director and Associate Professor. He has more than 17 years of experience in transportation research, including development of improved methods for predicting the operational, economic, energy-use, and environmental consequences of alternative cargo and passenger systems. His particular expertise is in the fields of project management, transportation system modeling, network analysis, simulation, computer software development, freight transportation, and inland waterways.

Dr. Bronzini's previous experience includes three years (1975-1978) serving as Senior Associate and Manager of the Transportation Analysis Group for CACI, Inc., and two years (1973-1975) teaching transportation engineering at the Georgia Institute of Technology. Among numerous major research projects, Dr. Bronzini has been involved with freight transportation contingency planning for Argonne National Laboratory and DOE, and a national energy transportation study for a joint U.S. Department of Transportation/DOE task force.

Dr. Bronzini has been a consultant to numerous state, national, and private organizations. He has produced more than 70 journal articles, research reports, reviews, conference papers, and presentations on transportation engineering and analysis. He is a member of nine professional organizations and in 1982 served as President of the Transportation Research Forum.

Douglas G. Brookins

Santa Rosa Junior College: A.A. (1956)

University of California, Berkeley: A.B., Geology (1958)

Massachusetts Institute of Technology: Ph.D., Geochemistry (1963)

Professor Brookins joined the faculty of the Department of Geology at the University of New Mexico, Albuquerque, in 1971 and served as Chairman from 1976 through 1979. He holds part-time positions with the geological surveys of Maine and the United States. Dr. Brookins has been an active participant in several symposia on the scientific basis for nuclear waste management and an active researcher on the Oklo natural reactor and natural analogs. He has served as a consultant to Sandia National Laboratories for geochemistry and geochronology at the Waste Isolation Pilot Plant site.

Prior to accepting the position at the University of New Mexico, Dr. Brookins served first as Assistant and then as Associate Professor of Geology at Kansas State University from 1963 to 1971. During that time he had a part-time appointment as a geochemist with the Kansas State Geological Survey. Professor Brookins had had prior experience at the Geochronology Laboratory at the Massachusetts Institute of Technology; ANCO Corporation, Wilmington, Mass.; California Co., Wy.; Cabot Spectrographic Laboratory at the Massachusetts Institute of Technology; and Bear Creek Mining Co.

Professor Brookins has published extensively in the fields of geochronology, trace-element studies, isotope geochemistry, uranium deposits, and radioactive waste disposal. His publications related to radioactive waste isolation are on such topics as isotope composition of halite and included brines, the Oklo natural reactor, shale as a repository host rock, thermodynamics of radionuclide migration, Rb-Sr systematics of the Salado Formation (Upper Permian), clay minerals suitable for overpack material, clay mineral-brine interaction during evaporite formation, long-term stability of evaporites, and near-field reactions in evaporites.

Professor Brookins is a member of 31 honorary and professional societies. He is a Fellow of the Geological Society of America and a member of the American Institute of Chemists, the Mineralogical Society of America, and the Explorers Club.

Joseph S. Busch

Northwestern University: B.S., Chemical Engineering (1949)

Johns Hopkins University: M.S., Chemical Engineering (1953)

Carnegie Mellon University: Ph.D., Chemical Engineering (1960)

Dr. Busch is Principal Engineer with Raymond Kaiser Engineers, Oakland, Calif. He has 32 years experience working on nuclear and chemical engineering projects for both government and industry. He has supervisory and design experience with solid-, liquid-, and gas-processing systems for nuclear and nonnuclear facilities. His nuclear experience includes work on both fast reactors and light-water reactors.

Dr. Busch participated in the National Waste Terminal Storage Program by working on a conceptual design for a mined repository in salt for highly radioactive waste. He was assistant project manager in charge of underground technology and also served as head of the thermal analysis group. As such he directed the work of mining, rock mechanics, heat transfer, and ventilation engineers and consultants, and coordinated the design of subsurface systems with that of surface facilities. Dr. Busch also served as manager of a preconceptual design of an incinerator facility to be constructed at Idaho National Engineering Laboratory. He has also participated in the Basalt Waste Isolation Project and the Nevada Nuclear Waste Storage Investigation.

A registered chemical engineer in Pennsylvania, Michigan, Mississippi, and New York, Dr. Busch has published numerous papers on heat transfer, nuclear systems, and pollution abatement.

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 Senior Engineer and leader of the Hydrologic and Geologic 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 affected 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 measuring and modeling 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 Vice Chairman of the Executive Committee of the Hydraulics Division of the American Society of Civil Engineers. He is also 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 the Massachusetts Institute of Technology. His teaching and research activities at those institutions 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.

Charles H. Dowding

University of Colorado at Boulder: B.S., Civil Engineering (1967)

University of Illinois at Urbana: M.S., Civil Engineering (1968)

University of Illinois at Urbana: Ph.D., Civil Engineering (1971)

Dr. Dowding is Associate Professor of Civil Engineering at Northwestern University, where he has taught since 1976. From 1972 to 1976, he was an Assistant Professor at the Massachusetts Institute of Technology. His principal field of research is in rock and soil mechanics, with special emphasis on blasting, dynamic response, jointed media, exploration decisions, and foundation engineering.

Dr. Dowding has been a consultant to numerous national engineering companies on projects related to nuclear power plant design, rock mechanics testing, earthquakes, blasting, and subsidence. He has been Cochairman of the National Research Council Committee for Rock Mechanics Research Requirements and is Chairman of the Rock Mechanics Committee of the Geotechnical Division of the American Society of Civil Engineers. Over the past 10 years, he has received numerous research grants, one of which was for calculating and characterizing the behavior of rocks under unusual conditions such as blasts and earthquakes.

In 1981, Dr. Dowding received the Outstanding Applied Research Award in Rock Mechanics from the U.S. National Committee for Rock Mechanics. He has published more than 40 papers and books, has edited proceedings on rock mechanics, and has presented more than 30 public talks on his research.

Terry Engelder

Pennsylvania State University: B.S., Geology (1968)

Yale University: M.S., Geology (1972)

Texas A&M University: Ph.D., Geology (1973)

Since 1973, Dr. Engelder has been associated with Lamont-Doherty Geological Observatory of Columbia University, most recently (1979 to the present) as a Senior Research Associate. From 1970 to 1973, he was a Research Assistant at the Center for Tectonophysics at Texas A&M University.

Dr. Engelder's laboratory research has focused on (1) frictional properties of rock, with emphasis on the effect of fault gouge; (2) dilatancy of rocks; (3) mechanical properties of rocks affecting strain relaxation; (4) fluid transport properties of rocks; (5) geochemistry of rock-water interactions; and (6) rock parameters affecting pressure solution. His field studies have dealt with fault zones, strain relaxation, in situ stress measurements, solution cleavage, in situ ultrasonic properties of rock, and propagation of joints.

A member of three professional societies and past associate editor of two journals, Dr. Engelder has been an author or coauthor of 50 scientific papers.

John B. Farr

University of California, Berkeley: A.B., Geophysics (1951)

University of California, Berkeley: M.A., Geophysics (1953)

University of California, Berkeley: Ph.D., Geophysics (1957)

University of Tulsa: J.D. (1971)

Dr. Farr is Chief Geophysicist at Western Geophysical Company, Litton Industries, where he is responsible for design and implementation of extensive seismic programs throughout the world. As Manager of Special Projects (1975-1979), Dr. Farr directed nuclear power plant siting programs in the United States and Puerto Rico, using high resolution seismic methods. He was responsible for developing a high-frequency seismic method having a resolution one order of magnitude greater than existing systems.

From 1957 to 1975, Dr. Farr worked for AMOCO, where he directed geophysical research on the seismic responses of various geological rock suites and on matrix and pore materials. He also developed new methods of subsurface imaging. During this period, he received 10 U.S. patents related to novel methods of acquiring and processing seismic data. His work from 1957 to 1965 was mainly related to geophysical exploration. During this period, he held positions as Seismograph Party Chief, District Geophysicist (Texas), Senior Staff Geologist (Oklahoma), and Supervisor of Geophysical Operations (Alaska).

Dr. Farr has written more than 16 publications on his work in resolution of seismic profiling, including earth holography as a seismic method. He is a member of eight professional societies, including two bar associations.

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 Roy F. Weston, Inc., in May 1985 as a Senior Geologist. Since that time, he has worked on U.S. Department of Energy environmental assessments and has been managing the Crystalline Repository Project Office (currently the Repository Technology Program) and the site characterization plan effort of the Salt Repository Project Office.

From 1982 to 1985, Mr. Fenster was a staff member of the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory. He was Technical Project Manager and member of the multidisciplinary core peer review staff, which reviews technical and programmatic documents for the Salt Repository Project Office of the Civilian Radioactive Waste Management Program. He also served as a technical reviewer for parts of Argonne's Lake Superior regional report related to siting a repository for high-level radioactive waste in crystalline rocks.

Before coming to Argonne, Mr. Fenster was 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 document concerning selecting sites for repositories in crystalline rocks for isolating high-level radioactive waste.

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 the siting of repositories for high-level radioactive waste, midcontinent tectonics, and structural geology in the Northeast, and has worked on more than 30 consulting reports. He is a member of five professional societies, including the Association of Engineering Geologists.

Serge Gonzales

D. University: A.B., Geology (1958)

Miami University: M.S., Geology (1960)

Cornell University: Ph.D., Stratigraphy (1963)

Certified Professional Geologist, No. 1914, American Institute of Professional Geologists

Registered Geologist, No. 110, State of Georgia

Since 1982, Dr. Gonzales has been a full-time consultant, serving as President of Earth Resource Associates, Inc. From 1978 through 1981, he was Associate Director of the Institute of Natural Resources at the University of Georgia, where he also was Associate Professor of Geology. From 1971 to 1978, he was Staff Geologist at the Institute of Community and Area Development, also at the University of Georgia, with joint appointment as Assistant Professor of Geology. While Assistant Professor for the Department of Geology at Miami University (Oxford, Ohio) from 1966 to 1971, Dr. Gonzales worked part time as a consulting geologist for Earth Science Laboratories, Inc. Working as a petroleum geologist for EXXON Company from 1963 to 1966, he specialized in offshore exploration and development geology.

Dr. Gonzales has had extensive experience in the areas of applied geology and mineral resources. In particular, he has expertise in mined-land reclamation, subsurface storage of hydrocarbons, and subsurface disposal of hazardous and radioactive waste. He has assessed various evaporite deposits as sources of salt and other minerals, and as sites for waste disposal, with particular emphasis on natural dissolution phenomena.

Dr. Gonzales is a member of six professional societies and has published more than 100 articles and reports, many of which relate to the geologic disposal of radioactive waste and related regional and rock-type assessments.

Douglas F. Hambley

Queen's University at Kingston: B.Sc., Mining Engineering (1972)

Lewis University: MBA (1986)

Registered Professional Engineer, No. 18026014, Province of Ontario, and
No. 062-039201, State of Illinois

Mr. Hambley has more than 10 years experience in mining, tunneling, and underground construction. He joined the staff of the Geoscience and Engineering Group of the Energy and Environmental Systems Division of Argonne National Laboratory in 1984. Prior to working at Argonne, Mr. Hambley was employed as a Senior Mining Engineer for nearly four years by Engineers International, Inc., a mining/tunneling consulting firm located in Westmont, Ill. In addition to designing several large tunnels for various purposes, he spent more than two years as Project Engineer on U.S. Nuclear Regulatory Commission contracts to assess retrievability from repositories for high-level radioactive waste and to provide technical assistance for repository design reviews.

Between 1972 and 1980, Mr. Hambley held various technical positions with major Canadian mining companies, including Denison Mines Ltd. and Falconbridge Nickel Mines Ltd. During his employment at Denison (1977-1980), he was responsible for several major projects, including (1) a tripartite (Denison/Rio Algom/CANMET) regional stability study; (2) investigation, specification preparation, and tender evaluation for Stanrock Mine dewatering and shaft rehabilitation; (3) design of the backfill system for a pillar recovery scheme; and (4) design of the underground garage and supply station for diesel fuel at No. 1 shaft.

Mr. Hambley has published on retrievability of high-level nuclear waste, design of shafts and tunnels, computer modeling of mine openings, and raise boring cost estimation. He is active in several technical societies.

Timothy R. Harper

University of Southampton, B.Sc., Geology (1965)
University of London (Imperial College): M.Sc., D.I.C.,
Structural Geology and Rock Mechanics (1970)
University of London (Imperial College): Ph.D.,
Engineering, Rock Mechanics (1973)

Dr. Harper is a research associate concerned with hydraulic fracturing and fluid-rock interactive processes. Fifteen of his 20 years of experience have been primarily devoted to geomechanical problems. In many cases, the projects have related to the safety of nuclear installations and to waste disposal. His experience encompasses both surface workings and deep exploration.

From 1975 to 1981, he was with Dames & Moore, where his consulting work included evaluation of fault stability, development of potential movement criteria for nuclear power plant design, evaluation of the mechanical aspects of the genesis of a series of geological structural episodes, and evaluation of rock mechanics. Clients included power companies, oil companies, and governments. Before 1975, Dr. Harper taught geotechnics in the Department of Engineering at the University of Aberdeen, Scotland.

Consulting services relating to nuclear facility safety have been provided by Dr. Harper to a variety of organizations, including British Nuclear Fuels Limited, the governments of the United Kingdom and Sweden, and to a major utility in the United States. These services ranged from the site specific (e.g., the Windscale reprocessing plant in the United Kingdom and the Nine Mile Point plant in New York State) to the generic (e.g., shaft sealing and backfilling, and overall research requirements for intermediate-level waste disposal). A significant percentage of his consulting work has involved evaluation of stress state and the implications for engineering projects. Approaches used have included numerical modeling and laboratory and field testing of the mechanical response of both porous and fractured media to fluid injection and withdrawal.

Dr. Harper has published more than 15 papers dealing with mechanical aspects of geological materials, the mechanics of geological processes, and nuclear waste disposal. He is a member of six professional societies.

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, and No. 487, State of Virginia

Dr. Harrison is Associate Director for Geoscience and Engineering for 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 design and deployment of energy technologies, and (3) development of physical and mathematical models of geophysical and geotechnical systems.

Dr. Harrison's group recently completed comprehensive surveys of geoscience data pertaining to 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. He and his group were the first to apply formal decision analysis for determining the relative favorability of specific crystalline rock areas for such repositories. Dr. Harrison has conducted numerous other geotechnical projects at Argonne, ranging from field studies of the feasibility of using dredged material to reclaim abandoned mined lands to projecting future Soviet oil output by assessing the development of its giant fields.

From 1971 to 1975, Dr. Harrison was Professor of Geography (Associate Department Chairman) at the University of Toronto, where he specialized in studies of slope stability in sedimentary terrains and the siting of supertanker ports. Before 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 College of William and Mary. 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. Earlier he was on the faculty of Dartmouth College's Department of Geology and geologist with the Indiana Geological Survey.

An author of more than 125 papers, reports, reviews, and books, Dr. Harrison was made Senior Scientist at Argonne in 1976.

Allen W. Hatheway

University of California at Los Angeles: A.B., Geology (1961)

University of Arizona: M.S., Geological Engineering (1966)

University of Arizona: Ph.D., Geological Engineering (1971)

University of Arizona: Professional Degree, Geological Engineering (1982)

Professional Registration:

Geological Engineer, No. 9025, State of Arizona

Geologist, No. 1439, State of California, and No. 153, State of Maine

Engineering Geologist, No. 941, State of California

Civil Engineer, No. C-22654, State of California, and No. 28417, State of Massachusetts

Presently a Professor of Geological Engineering at the University of Missouri at Rolla, Dr. Hatheway specializes in waste management, seismic risk assessment, hazards mitigation, rock engineering and underground construction, and critical facility siting. From 1976 to 1981, he was Vice President and Chief Geologist of Haley and Aldrich, Inc., where he directed a professional geologic staff in waste disposal siting, rock structure evaluation, and seismic risk assessment. From 1961 to 1976, he worked for geological and geotechnical consulting firms in California and as an exploration geologist in Arizona and Washington.

As a member of the U.S. Army Reserve, Colonel Hatheway is Mobilization Designee, and Deputy Division Engineer, U.S. Army Engineer Division, Missouri River, Omaha. He was Adjunct Assistant Professor of Civil Engineering at the University of Southern California from 1971 to 1974 and Adjunct Associate Professor of Geology at Boston University from 1979 to 1981.

Dr. Hatheway's main field of interest and experience has been the development of site- and area-specific geologic assessments in terms of hydrogeology, engineering properties, rock structure, and hazards. He has applied his expertise to a wide variety of projects, including solid, special, and hazardous waste disposal.

Dr. Hatheway is author of more than 50 technical papers and editor of three books encompassing material on engineering geology, environmental geology, hydrogeology, geotechnical engineering, rock mechanics, seismic risk, nuclear facility siting, and professional practice. He belongs to 12 professional societies and is active on several committees. For example, he is a member of the Environmental Concerns Committee and serves as the elected secretary (1984-1989) of the Management of Hazardous Waste Committee of the American Society of Civil Engineers.

Amy B. Hull

Iowa State University, B.S., Biochemistry/Chemistry (1980)

Northwestern University, M.S., Geology (1984)

Northwestern University, Ph.D., Geochemistry (1987)

Ms. Hull is a Geochemist in Argonne National Laboratory's Energy and Environmental Systems Division. Her research focuses on theoretical and experimental analysis of the geochemistry of brines in rock salt as a function of the thermal profile and gamma radiation field. She is modeling the dissolution behavior of rock salt by studying a multicomponent electrolyte system (Na-K-Mg-Ca-SO₄-Cl-H₂O) at elevated temperatures and varying gamma radiation exposures. The purpose of these studies is to illuminate the phenomena that could accelerate brine migration in a repository environment.

Since 1983, as a graduate research assistant, Ms. Hull has been studying the problems of toxic versus essential environmental concentrations of micronutrients and has been modeling the geochemical cycles of these trace elements. In 1982 she conducted experimental studies on the high-temperature solubilities of clay minerals. Before attending Northwestern University, Ms. Hull worked for Nalco Chemical Company (1981) as a Chemist and Project Leader, researching the formation and removal of sulfur oxides from flue gases. From 1979 to 1981, she was a research associate in chemical sedimentology at Iowa State University.

Ms. Hull is author and co-author of numerous publications dealing with (1) the morphology, growth, thermodynamic stability, and dissolution of evaporitic minerals under various sedimentological conditions; (2) the global geochemical cycles of micronutrients; and (3) her studies of SO₂/SO₃ at Nalco. She is a member of four professional and honorary chemical and geological societies.

Charles H. Jacoby

Missouri School of Mines and Metallurgy: B.S., Mining Engineering (1941)

Mr. Jacoby has extensive experience in conducting exploration and feasibility studies related to salt domes. He is presently Consulting Engineer for Jacoby and Company Inc., and consults on various problems related to salt exploration, evaluation, recovery, and storage capacity. From 1953 to 1977, he was Director of Development for International Salt Company, where he gained extensive experience in the directed development of salt mines all over the world. His work included evaluating and studying the emplacement of hazardous and toxic materials in salt deposits. Before 1953, Mr. Jacoby worked in manganese exploration and evaluation for several corporations and U.S. government offices.

Some of Mr. Jacoby's recent consulting activities have included (1) economic evaluation of salt reserves, (2) creation of propane storage cavities in bedded salt, (3) design of deep well disposal systems in salt to combat and prevent pollution, and (4) establishment of design criteria for creating cavities in salt for Battelle's Office of Nuclear Waste Isolation.

Mr. Jacoby holds 22 U.S. patents dealing with salt mining, brine field revival, hydraulic fracturing, and geothermal systems. He has published more than 30 papers in his areas of expertise and is a member of 12 professional societies.

G. R. Keller

Texas Tech University: B.S., Mathematics (1968)

Texas Tech University: M.S., Geophysics (1969)

Texas Tech University: Ph.D., Geophysics (1973)

Dr. Keller is Chairman and Professor of Geophysics at the University of Texas at El Paso. He is also Director of the J.W. Miller Memorial Geophysical Laboratory and consultant to Los Alamos National Laboratory. From 1976 to 1982, Dr. Keller was Director of the University of Texas at El Paso Seismological Observatory. He was Assistant Professor at the University of Kentucky from 1973 to 1976 and at the University of Utah for the academic year 1972-1973.

Dr. Keller's research interests include seismic studies of crustal structure and plate tectonics. Some of his most recent work involves the seismicity of the midcontinental United States, specifically the Mississippi embayment and New Madrid fault zone.

Dr. Keller has been professionally active as Associate Editor for the *Journal of the Society of Exploration Geophysicists*, the *Geological Society of America Bulletin*, and a special volume on rifting published by *Tectonophysics*. He is a member of 12 professional societies and has served on four committees. He has authored and coauthored more than 70 papers, maps, and reports on seismology, regional geophysics, and tectonics.

Jerome Kruger

Georgia Institute of Technology: B.S., Chemistry (1948)

Georgia Institute of Technology: M.S., Chemistry (1950)

University of Virginia: Ph.D., Physical Chemistry (1953)

Dr. Kruger is Professor of Materials Science and Engineering, and Chemical Engineering, at Johns Hopkins University. After being with the National Bureau of Standards Corrosion Division since 1955, he spent 1983-1984 as a Lady Davis Fellow in Materials Engineering at the Technion-Israel Institute of Technology. From 1952 to 1955, Dr. Kruger was a chemist for the Naval Research Laboratory.

Dr. Kruger is an expert on corrosion. His research has covered such topics as corrosion electrochemistry, localized corrosion, and stress corrosion cracking. He has also conducted ellipsometric studies of the oxidation and preservation of metal surfaces. He has taught several extension courses on these topics at universities across the United States and has been an invited lecturer at more than 60 universities and conferences around the world. In November 1984, Dr. Kruger served on an ad hoc corrosion panel of the National Materials Advisory Board. Before that he had served as a member of a working group organized by the Office of Nuclear Waste Isolation. Both of these bodies were concerned with corrosion testing of alloys for use in repositories for nuclear waste. He was also a member of a National Academy of Sciences panel established to evaluate the Swedish plan KSB-2 for nuclear waste burial.

Dr. Kruger has published more than 90 papers and has been the editor of five books on corrosion. He is active in several professional societies, including having served as Chairman of the Corrosion Division of the Electrochemical Society; as President of the Federation of Materials Societies; as National Treasurer of the Electrochemical Society; and on the Board of Directors of the National Association of Corrosion Engineering. In 1978 he served as the U.S. delegate to the International Corrosion Council and was elected First Vice President in 1984 (succeeding to the presidency in 1987).

Darrell I. Leap

Marshall University: B.S., Geology (1960)

Indiana University: M.A., Geology (1966)

The Pennsylvania State University: Ph.D., Geology (1974)

Certified Professional Geologist, No. 518, State of Indiana

Registered Professional Hydrogeologist, American Institute of Hydrology

Dr. Leap has been Associate Professor of hydrogeology at Purdue University since 1980, teaching courses in general hydrogeology, groundwater modeling, and well-testing methods. From 1974 to 1980, Dr. Leap was employed as a hydrologist with the U.S. Geological Survey, serving as Project Chief of a groundwater tracer project and as Principal Investigator for Hydrology for the Nevada Nuclear Waste Storage Investigations under contract to DOE. In the latter position, he was responsible for managing six research projects supporting waste-repository siting at the Nevada Test Site. He was also responsible for starting the Survey's groundwater modeling project for the Nevada Test Site and environs.

From 1966 to 1971, Dr. Leap worked as a Geologist/Hydrologist for the South Dakota State Geological Survey and was Project Chief for three different projects involving countywide geologic mapping and hydrologic analysis of surface-water and groundwater supplies in eastern South Dakota. He also taught in the Department of Geology at the University of South Dakota.

Dr. Leap's present research involves groundwater tracer studies, groundwater modeling, groundwater resource assessment, and regional hydrogeology. He has been a consultant on groundwater use and pollution for various companies. He has participated in more than 40 symposia and conferences, lecturing or coauthoring papers in more than 30. Topics covered include the geologic disposal of high-level nuclear waste and quality assurance for nuclear waste isolation studies.

Dr. Leap is the author of 15 technical reports and refereed papers, as well as numerous abstracts on groundwater analysis and nuclear waste disposal. He is a member of five professional societies and served as President of the Indiana Water Resources Association in 1982.

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. Before 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 the 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 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.

Digby D. Macdonald

University of Auckland, New Zealand: B.Sc., Chemistry (1964)

University of Auckland, New Zealand: M.Sc., Chemistry (1966)

University of Calgary, Canada: Ph.D., Chemistry (1969)

As Director of the Chemistry Laboratory, Physical Sciences Division, SRI, Dr. Macdonald specializes in electrochemistry, corrosion science, and mathematical modeling of physical systems. His research on the corrosion of metals has involved fundamental studies on metal dissolution, stress corrosion cracking, corrosion fatigue, localized corrosion, activity transport in nuclear reactors, and thermodynamic and electrochemical phenomena in aqueous systems.

Dr. Macdonald has also served as Director and Professor at the Fontana Corrosion Center, Ohio State University, and Honorary Associate Professor of Chemistry at the University of Calgary. He was also Senior Research Associate for Alberta Sulfur Research, Ltd., and Assistant Research Officer for Atomic Energy of Canada, Ltd.

Dr. Macdonald has published more than 150 papers in scientific journals, books, and conference proceedings. He is also author of a book on transient techniques in electrochemistry, approximately 50 technical reports, and three patents and numerous patent disclosures. He has delivered more than 100 presentations on his research topics. He belongs to three professional societies and has served on two National Academy of Sciences committees.

Joseph D. Martinez

Louisiana State University: B.S., Electrical Engineering (1937)

Louisiana State University: M.S., Geology (1952)

Louisiana State University: Ph.D., Geology (1959)

Registered Professional Electrical Engineer (EE), No. 01981, State of Louisiana

Certified Professional Geological Scientist, No. 2050

Dr. Martinez is currently active as a consultant. In that capacity, he has recently been involved in litigation associated with mine problems in Louisiana salt domes. He is Professor Emeritus of Petroleum Engineering at Louisiana State University, having taught in that field from 1965 to 1968 and 1981 to 1982. As Director of the Institute for Environmental Studies (1968-1981), his research dealt with salt dome utilization and environmental considerations, salt dome geology, salt mine hydrology, and the origin of salt dome caprock. Also, as Director of the Institute for Saline Studies (1965-1968), Dr. Martinez researched groundwater problems, evaporite diapirism, petrology of diapiric gypsum and anhydrite, and use of solution cavities in salt domes for power storage.

Dr. Martinez has taught a wide variety of geology courses at the University of Wisconsin (1964-1965), Northern Illinois University (1961-1964), and Rice University (1957-1958), and was Senior Research Geophysicist for Humble Oil Company (1952-1961). As a consultant, he has applied his knowledge and experience in the preparation of environmental impact statements for the proposed use of salt domes for crude oil storage and for the reconnaissance of deep mine hydrology in metamorphic and igneous rocks for possible isolation of high-level radioactive wastes.

Dr. Martinez holds three U.S. patents relating to coring apparatus. He is a member of six professional societies and has published more than 60 papers on his research, the most recent of which have dealt with models for salt dome stability and hazardous waste disposal.

Dennis Z. Mraz

University of Ostrava, Czechoslovakia: M.Sc., Mining Engineering and Construction (1962)

University of Ostrava, Czechoslovakia: completed one year of a Ph.D program
Mine Managers Certification, No. 523, Province of Alberta

Mr. Mraz is most recently President of Mraz Project Consultants, Ltd., Saskatoon, Saskatchewan. From 1981 to 1984, he was with Denison Mines, Ltd., as Vice President of Operations for Dentherm Resources, Ltd.; with Quintette Coal, Ltd., as Vice President and General Manager-Operations; and with Potacan Potash Company as an internal consultant. As General Manager for Luscar-Sterco, Ltd. (1978-1981), Mr. Mraz was responsible for operating a surface- mining operation and designing the underground mining operation. From 1969 to 1978, he was Engineering Manager for International Minerals and Chemical Corp. (Canada) Ltd., where he was, among other things, directly responsible for engineering research and development for underground mining operations.

His consulting activities have included studying rock mechanics, designing mining methods, preparing guidelines for safety pillars in shafts and exploration holes, and spacing solution caverns in deep salt formations. Since 1982, Mr. Mraz has been advisor to the Department of Earth Sciences, University of Waterloo, on studies associated with testing salt rocks.

Mr. Mraz is a member of five professional organizations and has written seven papers dealing with plasticity and flow of salt and how they affect design of mining methods.

Schlomo P. Neuman

Hebrew University, Jerusalem, Israel: B.S., Geology (1963)

University of California, Berkeley: M.S., Engineering Science (1966)

University of California, Berkeley: Ph.D., Engineering Science (1968)

Dr. Neuman has been a Professor of Hydrology at the University of Arizona since 1975. Previously, he had taught at the University of California, Berkeley (1974-1975 and 1968-1970) and had conducted research at the Institute of Soil and Water, Agricultural Research Organization, Bet-Dagen, Israel (1970-1974).

Dr. Neuman has many years of wide-ranging experience in hydrology and hydrogeology acquired through academic research, consulting work for government and industry, and graduate teaching. His main areas of research and expertise include well hydraulics, design and analysis of pumping tests, computer modeling of groundwater flow and subsurface contaminant transport, fractured-rock hydrology, flow in unsaturated soils, and use of statistics in hydrology. Much of his recent research and consulting activities have been in the area of high-level radioactive waste disposal in geologic environments.

Dr. Neuman has received numerous awards for distinguished contributions to the field of hydrogeology. He is a fellow of the American Geophysical Union and has published more than 80 research papers.

Robert A. Paddock

Washington and Lee University: B.S., Physics (1964)

Michigan State University: M.S., Physics (1966)

Michigan State University: Ph.D., Physics (1969)

Dr. Paddock is a geophysicist in the Hydrologic and Geologic Engineering Section of the Geoscience and Engineering Group of the Energy and Environmental Systems Division at Argonne National Laboratory. For more than 12 years, he has served as project leader or team member investigating physical transport of substances in the hydrosphere by way of natural processes and man-made conveyances in the context of energy resources, wastes, and technology development. Dr. Paddock's primary activities have included definition of data requirements, acquisition techniques, and processing schemes; model applications; and data interpretation for model evaluation.

Before joining Argonne as a full-time staff member in 1975, Dr. Paddock was Assistant Professor of Physics at Ripon College. While on the faculty, Dr. Paddock spent several semesters as a Resident Research Associate at Argonne working in the area of physical transport in the hydrosphere.

Dr. Paddock has authored more than 30 scientific and technical publications and has served as a reviewer of technical papers for the Hydraulics Division of the American Society of Civil Engineers.

Robert E. Reilinger

Villanova University: B.S., Physics (1969)

Cornell University: M.S., Physics (1972)

Cornell University: Ph.D., Geophysics (1979)

Dr. Reilinger is a research scientist in the Department of Earth, Atmosphere, and Planetary Sciences at the Massachusetts Institute of Technology. He was Research Associate in the Department of Geological Sciences at Cornell University from 1979 to 1983. During that time, he served as Project Director for the U.S. Geodynamics Project entitled "Recent Crustal Movements in the United States." From 1972 to 1974, he was a physicist for the Naval Strategic Systems Navigation Facility.

Dr. Reilinger's current research interests are measurement and interpretation of vertical movements in the earth's crust, global tectonics, methods of earthquake prediction, and interpretation of deep seismic reflection data (COCORP) as they relate to the evolution and structure of the continental crust. His research has been funded by the National Science Foundation, U.S. Geological Survey, U.S. Nuclear Regulatory Commission, National Oceanic and Atmospheric Administration/National Geodetic Survey, and National Aeronautics and Space Administration.

Author of more than 25 papers in his field, Dr. Reilinger is also a member and officer of the International Association of Geodesy Working Group on Geodetic Application for Earthquake Prediction. He belongs to four professional and honorary societies.

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 member of the Geoscience and Engineering Group, Energy and Environmental Systems Division, Argonne National Laboratory, where he serves as a core peer review panelist. During the past two years, he has reviewed numerous models proposed by DOE contractors for use in performance assessment of waste package and repository designs. He has also reviewed several technical reports concerning the corrosion testing of waste package materials and the mathematical methods used to analyze accelerated life test data. Concurrently, he has served as a member of the laboratory director's task force for developing and applying electromagnetic technology to the continuous casting of sheet steel. As part of that group, he has been responsible for the conceptual design of both bench-scale and full-scale systems for handling and electromagnetically shaping molten metals.

During Dr. Rote's time at Argonne, his research efforts have shifted more toward applied research problems. He has served as principal investigator on numerous research and assessment programs concerned with developing, verifying, validating, and documenting models used for air pollution assessment. Sponsors have included the U.S. Environmental Protection Agency, U.S. Air Force, and Federal Aviation Administration. He has also directed field programs requiring the acquisition, analysis, and interpretation of air-quality, meteorological, and source data. Dr. Rote has concurrently served as an advisor to the above agencies on model validation, model application, monitoring, and data-analysis techniques. As leader of the Air Resources Section from 1976 to 1983, he was Director of the Atmospheric Impact Assessment Study of the proposed DOE Satellite Power System. Chemical and electromagnetic interactions in the ionosphere and magnetosphere were studied.

Dr. Rote began his career as a professional physicist before leaving graduate school by serving as a part-time employee and consultant to Clevite Research Center, where he conducted experimental studies of the electromagnetic properties of PZT ceramics. After completing his graduate education, he first served as a postdoctoral fellow and later as an assistant professor in the Physics Department of the University of Illinois at Chicago. During that same period, he served as a consultant to the Physics Division of Argonne National Laboratory, where he conducted basic research in nuclear physics. In 1970, he became a full-time staff member of Argonne.

Dr. Rote is an author or coauthor of 70 reports, book chapters, and 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 aspects of rock mechanics. Much of his research has related to mining, underground construction, and underground storage, with special emphasis on 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 serves as a rock mechanics consultant to ONWI and Oak Ridge National Laboratory; as a resource consultant for rock mechanics to the Overview Committee for the Basalt Waste Isolation Project; as a coinvestigator of an ONWI-sponsored project at Texas A&M University to develop constitutive equations for salt; and as a 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's Nevada Nuclear Waste Storage Investigations.

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 1972 to 1976, he was Vice President and Resident Consultant at RE/SPEC, Inc. 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.

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 radioactive waste disposal are to investigate interactions of materials proposed to be used in disposing of radioactive 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 organic compounds in mobilizing heavy metals and on the movement of phenol compounds through water-bearing rock.

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

Before coming to Argonne, Dr. Seitz was 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 more than 60 papers in scientific journals, primarily on geochemical topics.

John C. Stormont

University of Wisconsin, Madison: B.S., Mining Engineering (1980)

University of Arizona: M.S., Mining Engineering (1983)

Mr. Stormont is a member of the technical staff at Sandia National Laboratories, where he conducts experimental programs related to mining, rock engineering, and radioactive waste disposal. He is responsible for development of plugs and seals for the Waste Isolation Pilot Plant (WIPP) project.

Before joining Sandia, Mr. Stormont was a Research Assistant at the University of Arizona, where he studied the sealing of rock masses as related to disposal of radioactive waste. His thesis research focused on the mechanical strength of borehole plugs. While at the University of Arizona, Mr. Stormont also taught geomechanics.

After obtaining his Bachelor's degree in 1980, Mr. Stormont worked as a field assistant. His duties included logging drill core and measuring in situ stresses using the hydraulic fracturing method. He also worked summers as a Junior Engineer with Climax Molybdenum Co. (1979) and as Assistant City Engineer for Monroe, Wis. (1978).

In 1982 Mr. Stormont received the Sulger Memorial Scholarship from the University of Arizona; in 1980 he received the Kerwin-Patterson Award from the University of Wisconsin. Mr. Stormont has published several reports on borehole plugs and seals for geologic repositories, including the program plan for the WIPP plugging and sealing program, and on stress measurement techniques in salt.

Robert R. Unterberger

Syracuse University: B.S., Physics (1943)

Harvard and Massachusetts Institute of Technology: Radar School (1944)

Duke University: Ph.D., Physics (1950)

Dr. Unterberger has been a Professor of Geophysics at Texas A&M since 1968. From 1950 to 1968, he was Senior Research Associate for Chevron Oil Field Research Company, where he applied geophysical methods to well logging and petroleum exploration.

Specializing in exploration geophysics, Dr. Unterberger is an expert in borehole geophysics and radar and sonar penetration of rocks. He has received more than 21 major grants to study electromagnetic and ultrasonic wave propagation in rocks, electron paramagnetic resonance, and optical pumping. In addition to his research and teaching, Dr. Unterberger is consultant to more than 20 petroleum and mineral companies.

Dr. Unterberger's most recent work has involved probing salt domes with radar, sonar, and nonlinear sonar. He has published 40 papers related to these techniques. Dr. Unterberger holds 10 U.S. patents concerning geophysical methods of mapping formations and numerous foreign patents. He is a member of eight professional societies.

Gary S. Was

University of Michigan: B.S., Nuclear Engineering (1975)

Massachusetts Institute of Technology: S.M., Nuclear Engineering (1977)

Massachusetts Institute of Technology: Sc.D., Nuclear Materials Engineering (1980)

After a year of postdoctoral research at the Massachusetts Institute of Technology, Dr. Was became Assistant Professor in the Department of Nuclear Engineering at the University of Michigan. From 1978-1980, he was Staff Scientist for Entropy, Ltd., where he helped develop a fuel performance and reliability computer code system. He also spent a summer (1974) working for the U.S. Environmental Protection Agency on developing a model for radiation transport through effluent pathways.

Dr. Was researches the effects of impurities on the susceptibility of austenitic alloys to intergranular cracking at both high and low temperatures in aqueous environments and on the effect of ion beam mixing on the physical and mechanical properties of alloy surfaces. His achievements have included significant advances in understanding chromium depletion in nickel-base alloys, characterizing quantitatively the electrochemical behavior of chromium-depleted zones in austenitic alloys, and developing models to measure the performance of stainless steel fuel cladding in light-water nuclear reactors.

Dr. Was is author and coauthor of more than 18 publications and has presented his research at 12 conferences. He is a member of nine professional and honorary societies.

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 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 analyzing measured net radiation values in Canada and reconstructing 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.

Bryan E. Wilde

Royal Institute of Chemistry, London: B.S. (1959)

Royal Institute of Chemistry, London: M.S. (1961)

Royal Institute of Chemistry, London: Ph.D., Physical Chemistry (1963)

Rennsalaer Polytechnical Institute: Ph.D., *Materials Engineering* (1965)

Dr. Wilde is Professor of Metallurgical Engineering and Director of the Fontana Corrosion Center at Ohio State University. From 1979 to 1984, he was Research Consultant and Supervisor of the Corrosion Behavior and Failure Analysis Section at U.S. Steel Research. From 1968 to 1979, he supervised the Corrosion Kinetics Section at USS Research.

While at USS Research, Dr. Wilde developed electrochemical methods for predicting localized corrosion performance of materials. He supervised 26 scientists involved in analyzing environmentally and mechanically induced failures in materials and in designing new materials. Dr. Wilde's recent research involves evaluating the corrosion performance of various materials, including aluminum, coated steel, and nickel; characterizing the cavitation and erosion of materials; and discerning the mechanisms of environmental crack growth under static and impact loading. He has also studied hydrogen-induced fracture of ferrous and nickel-base alloys.

Dr. Wilde is author of more than 65 publications dealing with corrosion of materials and electrochemical reactions under various environmental conditions.