Technical Position on Repository Design - Thermal Loads

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of High-Level Waste Management

John T. Buckley

INTERNAL DRAFT

ABSTRACT

This technical position is intended to provide the U.S. Department of Energy with a methodology acceptable to the NRC staff for demonstrating compliance with 10 CFR Part 60.133 (i). Section 3.0 presents the staffs positions and section 4.0 provides the corresponding discussions.

TABLE OF CONTENTS

List of Figures

1.0 INTRODUCTION

The purpose of this Technical Position (TP) is to provide guidance to the U.S. Department of Energy (DOE) on a methodology acceptable to the NRC Staff for demonstrating compliance with 10 CFR 60.133(i). The rule, 10 CFR 60.133(i) requires that DOE take into account the predicted thermal and thermomechanical response of the host rock, the surrounding strata and groundwater system in the design of the repository within the context of the performance objectives. An understanding of the thermal loads due to the emplacement of nuclear waste and corresponding thermomechanical response of the host rock and surrounding geologic setting is needed to design the underground structure. To design the underground facility, one must also understand the uncertainties associated with predicting the thermal loading and corresponding rock and groundwater responses. Many aspects of the design, including canister spacing, opening configurations and dimensions, and support requirements, depend on a thorough understanding of the effects of thermal load on the repository performance.

The underground structure design must allow the repository to meet the performance objectives of 10 CFR 60.111, 60.112 and 60.113. Further, the underground structure design must also comply with the design criteria of 10 CFR 60.130, 60.131 and 60.133.

As stated above, this TP provides a methodology acceptable to the NRC Staff for demonstrating compliance with the design criteria required out in 10 CFR 60.133(i). In addition, this TP includes a compliance determination methodology for reviewing analyses presented in the license application regarding 60.133(i).

This TP includes the following six sections: (1) Introduction, (2) Regulatory Background, (3) Technical Positions, (4) Discussion, (5) References, and (6) Bibliography. Section 2.0 identifies the specific regulations addressed by this TP. In addition, this section discusses other NRC guidance which may be applicable to the design of the underground structure considering the thermal loading and the thermomechanical response of the host rock to that loading.

Section 3.0 provides concise statements of the Staff's technical position on an acceptable methodology. An explanation and discussion of the position is provided in Section 4.0. Cited references are listed in Section 5.0. Uncited but related references are listed in the bibliography, Section 6.0.

Technical Positions are issued to describe and make available to the public criteria for methods acceptable to the NRC Staff for implementing specific parts of the Commission's regulations, or to provide guidance to the Department of Energy. Technical Positions are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the position will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

In the event that DOE chooses a methodology different from that identified by the NRC Staff in this TP and/or subsequent guidance, the NRC may require that DOE provide data and related information sufficient to allow the Staff to perform an independent analysis using a methodology (such as that presented in this TP) selected by the Staff. In addition, the Staff will review in detail the information provided by DOE in light of Standard Format and Content Guide(s) to be prepared by the Staff in preparation for license applications and such other guidance and regulatory documents (for example, those detailing Quality Assurance requirements) as may have been provided to the public and the DOE.

2.0 REGULATORY BACKGROUND

The regulatory requirements addressing thermal loads are identified in 10 CFR 60.133(i):

> "The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, groundwater system."

The performance objectives referred to in 60.133(i) are 60.111, 60.112 and 60.113(a)(1). These performance objectives are stated as follows:

60.111 Performance of the geologic repository operations area through permanent closure.

(a) Protection against radiation exposures and releases of radioactive material. The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency.

(b) Retrievability of waste. (1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program. (2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area prior to the end of the period of design for retrievability. (3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

60.112 Overall system performance objective for the geologic repository after permanent closure.

The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

60.113 Performance of particular barriers after permanent closure.

(a) General provisions - (1) Engineered barrier system. (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with groundwater of available void spaces in the underground facility shall be appropriately considered and analyzed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and (B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

The design of the underground facility must be such that the performance objectives of 60.111, 60.112 and 60.113 will be met. The thermal loading and the thermomechanical response of the host rock, surrounding strata, and groundwater system will, to a great extent, determine the ability of the geologic repository to comply with the performance objectives.

3.0 TECHNICAL POSITIONS

DOE must design the underground structure such that the performance objectives of 10 CFR 60.111, 60.112, and 60.113 (Section 2.0) will be met. In addition, the underground facility design must comply with the various design criteria as stated in 10 CFR 60.130, 60.131, and 60.133. The method presented below outlines the steps capable of evaluating the adequacy of the underground structure design as it is affected by the thermally induced responses in the host rock and surrounding strata. The adequacy of the underground structure design is evaluated specifically by comparing predicted thermally induced responses to performance-based design criteria, and then by testing the performance of the geologic repository system by using the predicted thermally induced responses as input to a performance assessment model. The NRC staff believes that compliance with 10 CFR 60.133(i) can be accomplished with the following methodology which is ultimately based on a fully coupled formulation of thermally induced phenomena but acknowledges the potential need for one-way coupling.

3.1 The following five step methodology, see Figure 1, can be used to demonstrate compliance with 10CFR Part 60.133(i):

3.1.1 Examine the thermally induced phenomena in the host rock and surrounding strata.

3.1.2 Develop performance based design criteria for the underground facility.

3.1.3 Obtain or develop predictive models for analyses.

3.1.4 Perform analyses with predictive models and compare results to performance based design criteria.

3.1.5 Input predicted results into performance assessment model to evaluate the performance objectives of 10CFR Parts 60.111. 60.112 and 60.113.

3.2 It is expected that a mechanistic understanding of the interactive behavior will be utilized to develop models to predict the thermal and thermomechanical response of the host rock, surrounding strata and groundwater system. These interactive models should be available at the time of license application. In the event a satisfactory understanding of the synergistic effects of thermal, mechanical, hydrological and chemical interactions cannot be gained prior to submittal of the license application, DOE should: (1) explain the current level of understanding and justify why an interactive model has not been developed, and (2) present plans and procedures to obtain a satisfactory level of knowledge during the performance confirmation program. Until predictive models can be developed through a mechanistic understanding of the interactive behavior, the staff finds the methodology outlined in Section 3.3 to be a reasonable approach for demonstrating compliance with 10 CFR 60.133 (i) provided conservative data and assumptions are used to account for uncertainties.

3.3 As stated in Section 3.2 above, until predictive models can be developed through a mechanistic understanding of the interactive behavior, an iterative analytical process based on the one-way coupled formulation of thermally induced phenomena can be used to predict the response of the host rock, surrounding strata and groundwater systems as suggested by step 3.1.4 above. A detailed flow diagram of this process is presented in Figure 2.

4.0 DISCUSSION OF TECHNICAL POSITIONS

The steps outlined in Sections 3.1 through 3.3 represent a methodology acceptable to the NRC Staff for evaluating and determining compliance with 10 CFR 60.133(i). This systematic approach provides a means to evaluate, through predictive modeling, the effects of thermally induced phenomena (in the host rock, surrounding strata, and ground water) on the repository performance associated with an underground structure design. The method includes five fundamental steps, which describe associated activities. These steps are: (1) evaluation of thermally induced phenomena in the host rock and surrounding strata, (2) development of performance based design criteria for the underground structure (3) obtaining or developing predictive models, (4) application of the predictive models with comparison of results to performance based design criteria, and (5) evaluation of the predicted results by a performance assessment model(s) for compliance with pre- and post-closure performance objectives. These activities are shown schematically in Figure 1.

There are two points in the methodology where evaluations are made with respect to the acceptability of the underground structure design. The first evaluation point involves the comparison of the predicted responses with the response limits set by the performance based design criteria. If the predicted response should exceed design criteria response limits, the underground structure design should be changed, with subsequent model application and reevaluation of predicted responses. The second evaluation point, performance assessment evaluation, takes place only after all performance based design criteria have been satisfied. If upon completion of the performance assessment test, the underground structure should fail to comply with the pre- and post-closure performance objectives, a reassessment associated with each major step in the methodology should be conducted, before new responses are predicted and submitted to the performance assessment model for reevaluation. Several iterations may be required until the underground facility design is brought into compliance with 10 CFR 60.133(i).

4.1 Discussion of Five Step Methodology

4.1.1 Examination of Thermally Induced Phenomena

The underground structure host rock, and surrounding strata will respond to the heat associated with the disposal of the nuclear waste. It is likely that thermal loading may be one of the most important underground structure design parameters (DOE, 1988). Therefore, to properly design an underground structure to comply with the performance objectives of 10 CFR Part 60, it will be necessary to understand the transfer of heat as well as associated phenomena such as thermally induced mechanical, chemical, and groundwater response in the host rock and surrounding strata. The level of response may vary for different materials and different locations at different times, which may have an effect on the design of the underground structure. The position in Section 3.1, therefore, is based on the need to provide understanding of the occurrence of these phenomena in the host rock and surrounding strata.

4.1.2 Develop Performance-Based Design Criteria

Although the host rock and surrounding strata are expected to respond to the transfer of heat, the level of such response which is acceptable from the standpoint of the performance objectives must be established. Design criteria derived from performance-based response limits, can then be used in the development of an underground structure design which complies with the performance objectives.

4.1.3 Predictive Models

The thermal load expected to result from the emplacement of spent nuclear fuel and HLW will affect the host rock and surrounding strata for thousands of years. Thus, the thermal load has the potential to alter the normal thermal, hydrological, mechanical, and chemical processes within the geologic setting throughout all of the waste containment and much of the waste isolation period. The staff expects DOE to develop a fully interactive model based on an understanding of the synergistic effects of the coupled thermal, mechanical, chemical and hydrological interactions. The staff recognizes that acquiring the knowledge necessary to develop such a model may require information which will be obtained during the performance confirmation program. Provided it is not possible to develop the necessary model prior to submittal of license application, the staff believes a reasonable interim approach to analyze the system would entail obtaining/developing four independent predictive models: thermal, mechanical, chemical, and hydrological. The scope of the heat transfer problem associated with geologic waste disposal is of such extent (e.g., geometric complexities, volume of host rock, and extended time frames) that it is not practical, nor even feasible to conduct experiments that will reveal the heat transfer, and thermally induced mechanical, hydrologic, and chemical responses at all locations of the host rock and surrounding strata for thousands of years into the future. However, reasonable estimates of these responses must be provided to allow an evaluation of the underground structure design against the requirements expressed by the performance objectives of 10 CFR Part 60. The position in Section 3.1.3, therefore, is based on the need to make predictions for evaluative purposes; the only approach that can provide such predictions is the development and application of predictive models.

Because of the transient nature of the heat transfer associated with the disposal of nuclear waste, the thermally induced mechanical, hydrologic, and chemical response levels will also change with time. Phenomenological details which may be important to the prediction of the response early in the history of the repository and which may occur relatively close to individual waste containers (for example the occurrence of pore water boiling), may not necessarily occur later in the history of the repository and much farther from the vicinity of the waste containers. Thus, predictive models capable of analyzing canister scale, repository scale and regional scale problems are required to assure that appropriate phenomenological detail will be included in the analyses.

Assumptions must be made about host rock conditions and phenomenological details which will be reflected in the predictive models. To include great complexity in the characterization of material behavior, for example, does not necessarily provide more accurate predictions, because (even if the complex details can be characterized at the scales needed) a complex model is often more difficult to verify and validate, resulting in more uncertainty associated with its use. The ultimate test of a model is that it must be empirically adequate; if simplifications produce models that cannot preserve the empirical phenomena, they are, by definition, inadequate (see van Fraasen, 1980). These assumptions should be consistent with the understanding of heat transfer and thermally induced mechanical, hydrologic, and chemical responses as expressed in predictive models. The proposed methodology as presented in Figure 2 utilizes current knowledge of thermally induced responses. The iterative process allows for analyses as a one-way coupling process with a feedback loop (Tsang, 1987).

Since the purpose of the predictive models is to help evaluate the adequacy of the underground structure design, the models must provide the performance measures that enable such evaluations. For the heat transfer model this measure would be the transient temperatures in the host rock and surrounding strata. For the mechanical model the measure would be the components of stress, strain, and displacement. For the hydrologic model, this measure would be the specific discharge of fluid through the host rock and surrounding strata and the directional flow vectors. For the chemical model, this measure would be the activities of components in the aqueous phase, the composition and concentration of mineral components, the fugacity of gaseous components, and the porosity and intrinsic permeability of the geologic material.

The reliability of model predictions is also affected to a great extent by the reliability of the information upon which the predictions are derived. Input data to the predictive models for heat transfer and thermally induced mechanical, hydrologic, and chemical responses must be representative of the prevailing conditions at the repository site. Thus, the data must be supported by appropriate tests of sufficient number and duration, which allows for reliable estimates of spatial representativeness, as well as range and distribution of the data. In addition, every aspect of obtaining the necessary input data as well as analyzing the data (data reduction) must be conducted in strict accordance with quality assurance procedures. Adherence to quality assurance plans and procedures contributes to the assurance of data adequacy.

The predicted heat transfer and thermally induced mechanical, hydrologic, and chemical responses in the host rock and surrounding strata are expected to be subject to uncertainty. The uncertainties result from assumptions regarding constitutive behavior, from approximations in the models used to simulate the constitutive performance, and from uncertainties associated with the respective model input parameters (such as thermal conductivity, bulk modulus, permeability, initial conditions, etc.). To properly evaluate the underground structure design, the effect of uncertainty in the model input parameters on the predicted results must be established. This includes, for example, the effect of uncertainties in the predicted temperatures on the prediction of the thermally induced stresses, groundwater flow, and chemical response (because temperatures are used as input to the models predicting these responses). Thus, a thorough evaluation of the uncertainties must be provided with respect to the predicted results and be included in the evaluation of performance as it may relate to the design of the underground facility.

Finally, all predictive models used for licensing should be verified and validated. Verifying and validating the predictive models are imperative if heat transfer and thermally induced effects are to be predicted with sufficient reliability to assure compliance of the underground structure design with the repository performance objectives. Without rigorous verification and validation against laboratory and field experiments, the reliability of a model cannot be known, and its application in the context of performance assessment would be of little value. NRC has provided guidance for model verification in NUREG-0856.

4.1.4 Design Evaluation with Individual Criteria

The performance based design criteria which may relate response limits (such as maximum rock temperature, displacements, stresses, flow rates, and mineral dissolution and precipitation rates) to the performance objectives, serve as the initial gauge by which the underground structure design should be tested. This means that the predicted results (including the uncertainties) of heat transfer, thermally induced mechanical, hydrologic, and chemical response associated with a particular underground structure design must be available and compared to the design criteria. An example of such comparisons associated with heat transfer predictions can be found in NUREG/CR-5428. Meeting all of the performance based design criteria will provide confidence that the underground structure design has a higher likelihood of meeting the performance objectives.

4.1.5 Design Evaluation for Performance Objectives

Although it may be possible to show that the underground facility design meets individual, performance based design criteria, the final evaluation of the underground structure design must be a test of its effect on the performance objectives of 60.111, 60.112 and 60.113. It is expected that models for the evaluation of performance objectives will be available, and will accept the predicted heat transfer, thermally induced mechanical, hydrologic, and chemical responses, including uncertainties, as input for analyses. A satisfactory evaluation by the performance assessment models, in addition to having met all the performance based design criteria, would demonstrate compliance with 10 CFR 60.133(i). An unsatisfactory evaluation by the performance assessment model would require a reassessment of the physical phenomena involved, the performance based design criteria, the predictive models, and the underground structure design. This reassessment would be required before any changes are made, which could be associated with the examination of the physical phenomena, performance based design criteria, predictive models, or the design. On the basis of any changes in design or evaluation approach, a reevaluation of the design is necessary against all the performance based design criteria and the performance assessment models.

4.2 Demonstrating Compliance With 10 CFR Part 60.133(i)

The licensing process requires the DOE to demonstrate that the regulations encompassed in 10 CFR 60 have been met. However, as stated in 10 CFR 60.101 (a)(2), "... it is not expected that complete assurance that they will be met can be presented. A reasonable assurance, on the basis of the record before the Commission, that the objectives and criteria will be met is the general standard that is required." The Commission must therefore make a finding that issuance of a license will not constitute an unreasonable risk to the health and safety of the public. Further, this finding must be made on the basis of the information presented in the license application. Part 60.24 of the rule requires that the application be as complete as possible at the time of docketing and, further, that DOE update its application as additional information becomes available.

In demonstrating compliance with design criteria of 10 CFR 60.133 (i), it is expected that a mechanistic understanding of the interactive behavior will be utilized to predict the thermal and thermomechanical response of the host rock, surrounding strata and groundwater system. The staff realizes however, that it may not be possible to obtain sufficient information, by license application submittal, to fully understand the phenomena. Therefore, the staff would find the iterative approach outlined in Section 3.3 to be a reasonable interim approach to demonstrate compliance with 60.133 (i) provided conservative data and assumptions are used to account for the uncertainties.

4.3 Iterative Thermal/Mechanical/Hydrologic/Chemical Analysis

Predictions of the heat transfer and thermally induced mechanical, hydrologic, and chemical response of the underground structure host rock and surrounding strata must be part of the basis upon which the underground structure is designed. Analyses will be required, as stated in Section 3.1.4, which collectively would provide a perspective of the transient rock temperatures and associated rock stresses and deformations, groundwater flow, and chemical response such as the dissolution and precipitation of mineral species in the host rock and surrounding strata.

Based on the assumed one-way coupling processes (i.e., thermal/mechanical/hydrologic/chemical), it is necessary to perform the analyses by iterations (see Figure 2). Figure 2 shows a detailed flowchart of the iterative process which can be used to perform the analyses described in Section 3.1.4 and 4.1.4. This would involve an initial set of predictions of heat transfer, thermally induced mechanical, hydrologic, and chemical responses, with subsequent changes to the thermal properties consistent with the predictions of dissolution and precipitation of mineral species in the rock (i.e., from the chemical model), and re-analysis producing a second set of predictions of heat transfer, thermally induced mechanical, hydrologic, and chemical responses. The iterative process would continue until changes in the prediction of the respective phenomena reach some acceptable level. The position in Section 3.3, therefore, is based on the need to not only provide predictions about the heat transfer and thermally induced effects in the host rock and surrounding strata, but to provide it in a manner which allows an evaluation of the assumption of uncoupled processes.

5.0 REFERENCES

Cook, N.G.W., Coupled Processes in Geomechanics in C.F. Tsang, Coupled Processes Associated with Nuclear Waste Repositories. Academic Press, Inc., 1987.

Code of Federal Regulations (CFR), Title 10, "Energy", U. S. Government Printing Office, Washington, D.C., revised annually. U.S. Nuclear Regulatory Commission.

de Marsily, G., An Overview of Coupled Processes with Emphasis on Geohydrology in C.F. Tsang, Coupled Processes Associated with Nuclear Waste Repositories. Academic Press, Inc., 1987.

Langmuir, D., Overview of Coupled Processes with Emphasis in Geochemistry in C.F. Tsang, Coupled Processes Associated with Nuclear Waste Repositories. Academic Press, Inc., 1987.

Silling, S., "Final Technical Position on Documentation of Computer Codes for High-Level Waste Management", NUREG-0856, U.S. Nuclear Regulatory Commission, Washington, D.C., 1983.

Tsang, C.F., Ed., Coupled Processes Associated with Nuclear Waste Repositories. Academic Press, Inc., 1987.

U.S. Department of Energy (DOE), Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0199, 1988.

U.S. Nuclear Regulatory Commission (NRC), "Modeling Analysis for NRC High Level Waste NMSS/RES Staff for Model Validation, Progress Report 1, Modeling Exercise," Geosciences System Performance Branch, 1989.

Van Fraasen, B.C., The Scientific Image. Oxford, The Clarendon Press, 1980.

6.0 BIBLIOGRAPHY

Avdonin, N.A., "Some formulas for Calculating the Temperature Field of a Formation During Thermal Injection." Neft I Gax, v. 7, p. 37-41, 1964.

Bauer, S.J., Costin, L.S., Holland, J.F., "Preliminary Analyses in Support of In Situ Thermomechanical Investigations", SAND88-2785, Sandia National Laboratories, 1988.

Bear, J., Dynamics of Fluids in Porous Media. American Elsevier, 1972.

Bear, J. and Braester, C.V., "On the Flow of Two Immiscible Fluids in Fractured Porous Media", p. 177-202 in Developments in Soil Science, v. 2, Fundamentals of Transport Phenomena in Porous Media. Elsevier, 1972.

Brandshaug, T., "Stability of Disposal Rooms During Waste Retrieval", NUREG/CR-5335, Itasca Consulting Group, Inc., 1989.

Carslaw, H.S. and Jaeger, J.C., Conduction of Heat in Solids, 2nd edition. Oxford, The Clarendon Press, 1959.

Costin, L.S., Chen, E.P., "An Analysis of the G-Tunnel Heated Block Thermomechanical Response Using a Compliant - Joint Rock Mass Model", SAND87-2699, Sandia National Laboratories, 1988.

Deutsch, W.L., "Geochemical Modeling of the Nuclear Waste Repository System - A Status Report", PNL-3518, Pacific Northwest Laboratory, Richland, Washington, 1980.

Helgeson, H.C., "Evaluation of Irreversible Reactions in Geochemical processes Involving Minerals and Aqueous Solutions - I. Thermodynamic Relations". Geochimica et Cosmochimica Acta, V. 32, p. 455-481, 1968.

Helgeson, H.C., Garrels, R.M., and MacKenzie, F.T., "Evaluation of Irreversible Reactions in Geochemical processes Involving Minerals and Aqueous Solutions - II. Applications". Geochimica et Cosmochimica Acta, v. 33, p. 455-481, 1969.

Huyakorn, P.S. and Pinder, G.F., Computational Models in Subsurface Flow. New York, Academic Press. 1983

Lorig, L.J., Dasgupta, B., "Analysis of Emplacement Borehole Rock and Liner Behavior for a Repository at Yucca Mountain", NUREG/CR-5427, Itasca Consulting Group, Inc. 1989.

Mack, M.G., Brandshaug, T., Brady, B.H., "Rock Mass Modification Around a Nuclear Waste Repository in Welded Tuff," NUREG/CR-5390, Itasca Consulting Group, Inc., 1989.

Mercer, J.W. and Faust, C.R., "Geothermal Reservoir Simulation: 3. Application of Liquid- and Vapor-Dominated Hydrothermal Modeling Techniques to Wairakei, New Zealand", Water Resources Research, v. 15, 1979.

Moore, D.E., Morrow, C.A., and Byerlee, J.D., "Chemical Reactions Accompanying Fluid Flow Through Granite Held in a Temperature Gradient." Geochimica et Cosmochimica Acta, v. 47, p. 445-453, 1983.

Reeves, M. and Cranwell, R.M., "User's manual for the Sandia Waste Isolation Flow and Transport Model (SWIFT) 4.81", NUREG/CR-2324, SAND81-2516, 1981.

Reeves, M., Ward, D.S., Johns, N.D., and Cranwell, R.M., "Theory and Implementation for SWIFT II, the Sandia Waste Isolation Flow and Transport Model, 4.84". NUREG/CR-3328, SAND83-1159, 1986.

Rimstidt, J.D. and Barnes, H.L., "The kinetics of silica-water reactions." Geochimica et Cosmochimica Acta, v. 44, p. 1683-1699, 1980.

Wolery, T. J., "EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: User's Guide and Documentation," UCRL-53414, Lawrence Livermore National Laboratory, Livermore, California, 1983.

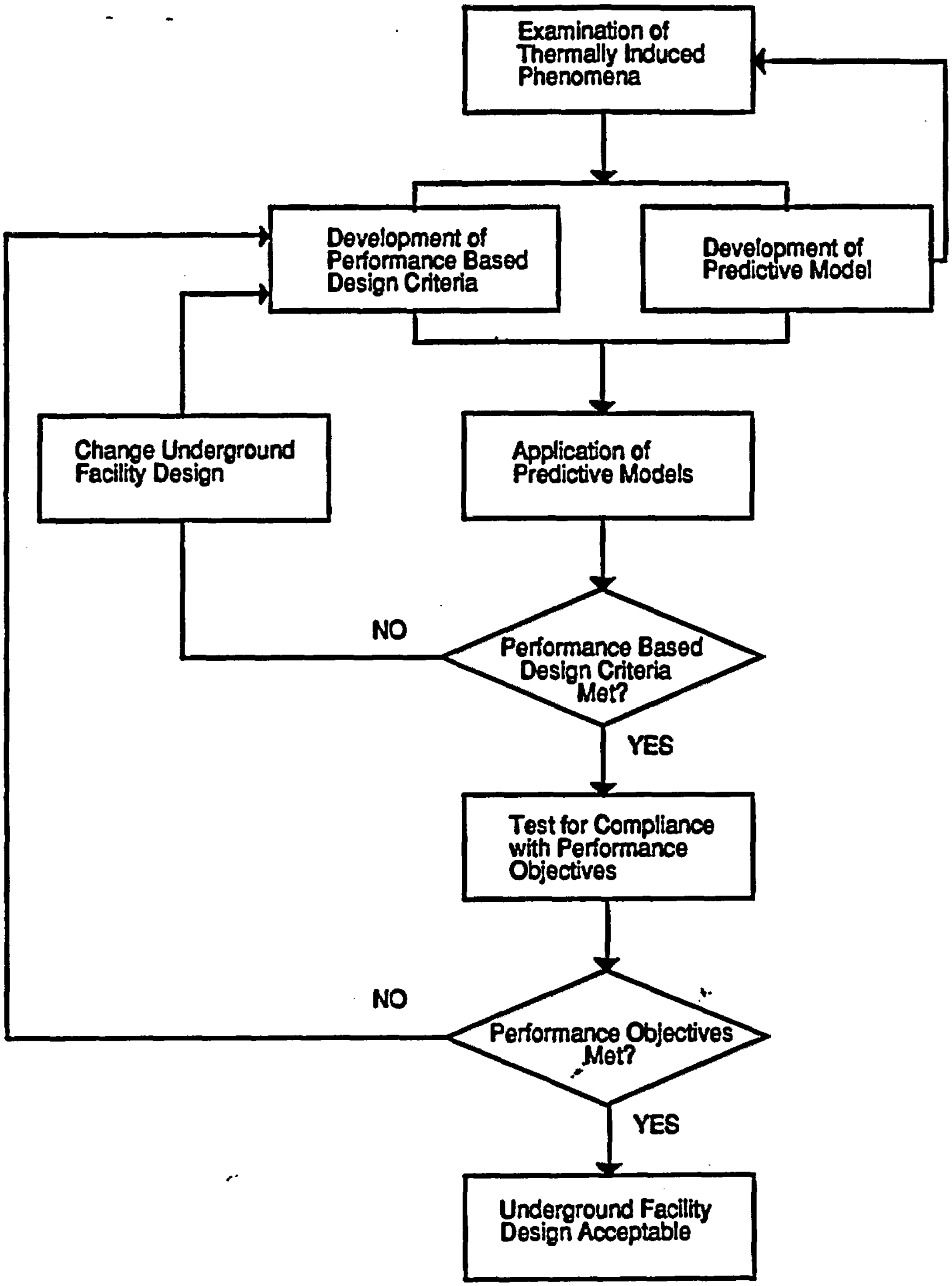

Figure 1. Steps for Compliance Demonstration and Compliance Determination

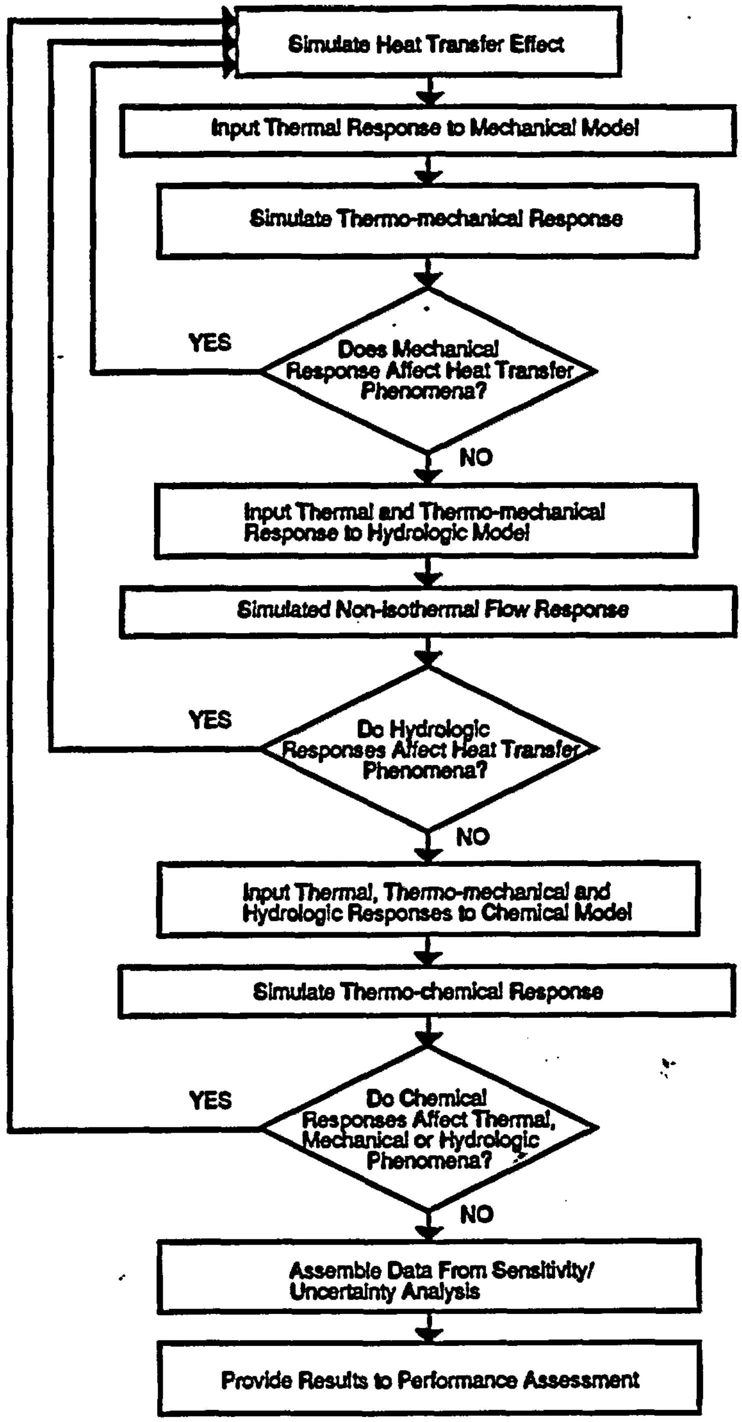

Figure 2. Iterative Process of Analyses

APPENDIX A - GLOSSARY

Geologic Repository - a system which is intended to be used for, or may be used for, the disposal of radioactive wastes in excavated geologic media. A geologic repository includes: (1) The geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste.

Geologic Repository Operations Area - a high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas, where waste handling activities are conducted.

Geologic Setting - the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located.

Host Rock - the geologic medium in which the waste is emplaced.

Retrieval - the act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.

Underground Facility - the underground structure, including openings and backfill materials, but excluding shafts, boreholes and their seals.

Underground Structure - means the underground facility and the shafts, boreholes and their seals.

Validation - assurance that a model as embodied in a computer code is a correct representation of the process or system for which it is intended.

Verification - assurance that a computer code correctly performs the operations specified in a numerical model.

APPENDIX A

TECHNICAL POSITION REVIEW CRITERIA

In reviewing the internal draft of a Technical Position (TP), the responsible staff members should review the TP from the perspective of the U. S. Department of Energy (DOE) and other potential interested parties to be sure that intent is clear. Questions that should be considered include:

- Does the TP have clarity?

  1. Is it readable?
  2. Is the logic clear?
  3. Is the relationship to the regulations clear?
  4. What is the main message?

- Will DOE be able to understand what we are expecting from it?

- Are the staff's positions consolidated in one place in the TP as opposed to being spread out over many different sections so that what we are asking can easily be determined.

- Is the organization of the TP adequate for meeting the standard for TPs and in keeping with its purpose?

  1. Background and Purpose
  2. Technical Position
  3. Rationale

- Is the TP explicitly organized in this way or if not, does it effectively communicate these items?

- Are the staff's positions reasonable, practicable, supportable, comprehensive, sufficient?

- If the staff's position sets forth a detailed description of a compliance demonstration method, does it have adequate justification?

- Is the use of should, could, and must appropriate and accurate?

- Are links with related issues and requirements clearly identified?

- Is the style of the TP acceptable?

  Tone   Is the choice of language objective?

  Clarity   Is the TP succinct and clear?

Coherence Are the main points clear and logically connected? Do they hang together?

Emphasis Are the main points identifiable? Do the structure and format aid clarity (i.e., is it easy to read)?

Unity Is the discussion focused?