JUL 10 1991

Mr. Dwight E. Shelor
Associate Director for Systems
and Compliance
Office of Civilian Radioactive Waste
Management
U.S. Department of Energy RW-30
Washington, D.C. 20585

Dear Mr. Shelor:

SUBJECT: AVAILABILITY OF DRAFT STAFF TECHNICAL POSITION ON "GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS"

The purpose of this letter is to provide a copy of the draft staff technical position (STP) on "Geologic Repository Operations Area (GROA) Underground Facility Design -- Thermal Loads" to the U.S. Department of Energy (DOE), the State of Nevada, and the affected-units-of-local-government. A notice of availability of the draft STP is now being published in the Federal Register, with a public comment period of 90 days. I am providing you with a copy concurrently with the publication of the Federal Register notice.

The U.S. Nuclear Regulatory Commission's (NRC's) Division of High-Level Waste Mangement is issuing the draft STP to provide guidance to DOE on a methodology acceptable to the staff for demonstrating compliance with 10 CFR 60.133(i). The NRC staff's position is that DOE should develop and use a defensible methodology to demonstrate the acceptability of a GROA underground facility design. The staff currently anticipates that this methodology will require development of fully coupled models to account for the thermal, mechanical, hydrological, and chemical processes that are induced by the thermal load. The GROA underground facility design: (1) should satisfy design goals/criteria initially selected by considering the performance objectives; and (2) must satisfy the performance objectives 10 CFR 60.111, 60.112, and 60.113. The methodology in the STP suggests an iterative approach suitable for the underground facility design at the time of a license application.

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If you have any questions or desire additional information about this STP, please contact the STP's project manager, Michael P. Lee, at 301/492-0421 or FTS 492-0421.

Sincerely,

(Original Signed by Joseph J. Holonich

for

John J. Linehan, Acting Director
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As Stated

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STAFF TECHNICAL POSITION ON GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS

Public Comment Draft Manuscript Completed: June, 1991

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ABSTRACT

The purpose of this draft staff technical position (STP) is to provide the U.S. Department of Energy (DOE) with a methodology acceptable to the U.S. Nuclear Regulatory Commission (NRC) staff for demonstrating compliance with 10 CFR 60.133(i). The NRC staff's position is that DOE should develop and use a defensible methodology to demonstrate the acceptability of a geologic repository operations area (GROA) underground facility design. The staff currently anticipates that this methodology will require development of fully coupled models to account for the thermal, mechanical, hydrological, and chemical processes that are induced by the thermal load. The GROA underground facility design: (1) should satisfy design goals/criteria initially selected by considering the performance objectives; and (2) must satisfy the performance objectives 10 CFR 60.111, 60.112, and 60.113. The methodology in this STP suggests an iterative approach suitable for the underground facility design at the time of a license application.

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ACKNOWLEDGMENTS

This staff technical position was prepared under the technical direction of Joseph O. Bunting, formerly of the Division of High-Level Waste Management (HLWM). The authors acknowledge the substantial contributions made by other HLWM management and staff including James R. Wolf, Office of the General Counsel, and Michael P. Lee, HLWM. Special thanks also to Loren J. Lorig of the Itasca Consulting Group, Mark J. Logsdon and Barbara Basse of Adrian Brown Consultants, and to Asadul H. Chowdhury, Simon Hsuing, William M. Murphy, Budhi Sagar, and Wesley C. Patrick of the Center for Nuclear Waste Regulatory Analyses.

DRAFT STAFF TECHNICAL POSITION ON

GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND

FACILITY DESIGN -- THERMAL LOADS

1.0 INTRODUCTION

This draft staff technical position (STP) emphasizes that the U.S. Nuclear Regulatory Commission (NRC) staff expects that the U.S. Department of Energy (DOE) will demonstrate a comprehensive, systematic, and logical understanding of the coupled thermal-mechanical-hydrological-chemical (T-M-H-C) responses associated with a particular geologic repository operations area (GROA) underground facility design. This demonstration is expected to be based primarily on a mechanistic understanding of the coupled processes. However, at the time of construction authorization, DOE may need to base its demonstration on empirical data from short-term tests and analyses based on partially coupled or multiple one-way-coupled predictive models.

The license application submitted before construction of the GROA must be updated before issuance of a license to receive, possess, and emplace waste, and, again, updated upon DOE's application to permanently close the repository. The NRC staff understands that with DOE's pursuit of appropriate technical programs of site characterization and performance confirmation, DOE's level of understanding and demonstration can evolve and improve significantly over the long time frame associated with the repository program.

The staff has included an approach that, based on our understanding today, is acceptable for demonstrating compliance with 10 CFR 60.133(i) at the time of construction authorization. However, the staff does not believe that it is necessarily the "best" or "optimum" approach for all time. The staff expects that, through the pursuit of appropriate technical programs, DOE would develop information that would enhance considerably the approach in this document. Therefore, the staff anticipates updating this STP as the development of significant information and insights from site characterization and performance confirmation programs, as well as any other technical activities, may warrant.

In this STP, the NRC staff assumes that performance assessment models will exist for evaluating compliance with 10 CFR Part 60 performance objectives. The STP also assumes that these models will incorporate the predicted T-M-H-C responses associated with a specific GROA underground facility design. However, elaboration on the specifics of performance assessments, with respect to the individual 10 CFR Part 60 performance objectives, is outside the scope of this STP.

1.1 Background

Section 60.133(i) requires that the underground facility for the GROA be designed so that the performance objectives will be met, taking into account the predicted thermal and thermomechanical response of the host rock, surrounding strata, and groundwater system. The performance objectives are those in 10 CFR 60.111, 60.112, and 60.113. They deal, generally, with the maintenance of safe operating conditions, the ability to retrieve emplaced wastes for a specified period, and the containment and isolation of the wastes after the geologic repository is permanently closed. Further, the underground facility design for the GROA must also comply with the design criteria of 10 CFR 60.130, 60.131, and 60.133.

The rule thus recognizes that 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 essential to the design of the underground facility. One must also understand the uncertainties associated with predicting the thermal loading and corresponding rock and groundwater responses so that these uncertainties can be accommodated by the design. Many aspects of the design, including canister spacing, opening configurations and dimensions, and support requirements, depend on predictions (using predictive models) of heat transfer, and thermally induced responses such as rock deformations, groundwater flow, and the dissolution and precipitation of mineral species.

The impact of thermal loads on repository performance can be a very complex technical issue, depending on many factors, including the magnitude of the thermal loads themselves. For those repository-generated thermal regimes that are within the range of engineering experiences, the use of existing predictive models to scope the possible effects of thermal loads on repository performance may be a reasonable approach to demonstrate compliance with 10 CFR Part 60 regulatory requirements.

On the other hand, repository-generated thermal regimes that are beyond the range of current engineering experiences pose significantly more complex problems. Such thermal regimes, acting over the long time frame of repository performance, produce effects that involve prediction considerations that are well beyond current engineering practice. For such situations, the use of an existing model, as a first step, to predict the likely repository effects of such loads, would not be satisfactory. This is because it is not known whether the model is appropriate. From a regulatory perspective, the first step is to confirm the programmatic need for evaluation of such thermal loads, giving due consideration to the attendant technical uncertainties and their effects on demonstrating compliance with regulatory requirements in a licensing proceeding.

For those situations where DOE makes programmatic decisions that produce repository-generated thermal regimes well beyond those for which engineering experience is available, it is expected that DOE will assume the burden to advance the state-of-the-art to predict the attendant coupled T-M-H-C effects on repository performance taking into account the impacts to containment, release, and transport of radionuclides.

The guidance in this STP focuses on the prediction of repository-generated thermal regimes beyond the range of current engineering experience. If, at any time, reliable information is gathered to convincingly demonstrate that further development of predictive models and codes would be unwarranted, nothing in this STP should be interpreted to suggest that the staff would expect that additional unnecessary steps would, nevertheless, be performed.

1.2 The Use of Models in Thermal-Response Predictions

The development of defensible predictive models requires a thorough understanding of the thermal loads due to emplacement of nuclear waste and corresponding thermally induced responses in the host rock and the surrounding geologic setting. An initial understanding is expected to be gained from site characterization testing and simplified analyses. Based on the current understanding of thermally induced responses in rock, the NRC staff finds that predictive models based on approximations of coupled formulations of T-M-H-C responses may have to be used for demonstrating compliance with 10 CFR 60.133(i) at the construction authorization stage of the repository licensing process. However, the staff expects model development/refinement to continue as a greater understanding of the thermally induced phenomena is gained during the period of repository construction and performance confirmation testing. This could result in more comprehensive models (for example, fully coupled models) by the time of application for a license to receive, possess, and emplace waste (source, special nuclear, or byproduct material) and, subsequently, an application for license amendment for permanent closure.

The models that are used at the time of construction authorization must be sufficiently robust for the Commission, with reasonable assurance, to make the safety findings set out in 10 CFR 60.31. But this by no means calls for the models to be the most sophisticated that can be developed. On the contrary, they must be sufficient to meet the standard of 10 CFR 60.24(a) in that the application is to be "... as complete as possible in the light of information that is reasonably available at the time of docketing." If the models are those that are "reasonably available," they can be used for purposes of analysis and decisionmaking. Of course, the judgment whether there is "reasonable assurance" of safety must take into account the uncertainty associated with the lack of more complete models; but that can be accomplished by appropriate conservatism.

The ongoing nature of model development is reflected at a number of places in 10 CFR Part 60. For example, for engineered and natural barriers important to waste isolation, DOE's license application is to provide "... a detailed description of the programs designed to resolve safety questions...." (10 CFR 60.21(c)(14)) If there is an unresolved safety question relating to model validation, this could be described in the application and need not stand in the way of the issuance of a construction authorization (so long as there is reasonable assurance of safety). Moreover, after a construction authorization is issued, DOE will have a continuing obligation to report to NRC on the "... results of research and development programs being conducted to resolve safety questions" (10 CFR 60.32(b)(4)); this too is addressed, among other things, to the progress in model development. The information will be reflected in DOE's updated application before NRC issuance of a license (10 CFR 60.24(b)). And, as part of the performance confirmation program during construction, DOE's measurements and observations are to be compared with the original design bases and assumptions (including those pertaining to the correctness of models), and if significant differences are noted, the need for modifications to the design or construction methods is to be determined (10 CFR 60.141(d)). This recognizes that the program must be a dynamic one, and it must allow for changes that reflect the steady accumulation of more information and insight.

1.3 Document Scope

This STP includes the following five sections: 1.0 -- Introduction; 2.0 -- Regulatory Framework; 3.0 -- Staff Technical Positions; 4.0 -- Discussion; and 5.0 -- References. Section 2.0 identifies the specific regulations addressed by this STP. Section 3.0 states the staff's technical positions on an acceptable approach to achieve compliance with 10 CFR 60.133(i). An explanation and discussion for the position statements are provided in Section 4.0. Cited references are listed in Section 5.0.

STPs are issued to describe and make available to the public methods acceptable to the NRC staff for implementing specific parts of the Commission's regulations, or to provide guidance to DOE. Moreover, STPs are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the STP will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a construction authorization or license by the Commission. Therefore, the objective of providing guidance to DOE on thermal-load design during the pre-licensing phase is to identify, at an early time, the potential for significant future problems, so that they can be avoided.

By cooperating on the use of informal methods such as the submission of reports, technical meetings, the opportunity for onsite visits, or quality assurance (QA) audits, DOE can assist the staff in its review when and if DOE submits a license application. The Commission recognizes and has stated in this regard, it "... cannot direct the Department to comply with the provisions for involving it during site characterization activities" (44 FR 70409). Although the Commission cannot direct the Department to comply with the provisions for involving it during site characterization activities, the Commission also noted that "... any failure to do so is likely to result in imprudent expenditures and subsequent delays, and ultimately could result in the denial of the application for the proposed site" (44 FR 70409).

If DOE chooses a methodology different from that identified by the NRC staff in this STP and/or in subsequent guidance, the staff may request 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 STP) selected by the staff.

2.0 REGULATORY FRAMEWORK

The regulatory requirement that forms the principal basis to address thermal load design requirements for the underground facility is set forth in 10 CFR 60.133(i):

> "§60.133(i) Thermal Loads. 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 (sic) surrounding strata, [and] groundwater system."

The performance objectives referenced in 10 CFR 60.133(i) are 10 CFR 60.111, 60.112, and 60.113 (NRC, 1990). A related regulatory requirement that provides an additional basis for the consideration of the effects of thermal loads is also found in 10 CFR 60.21(c)(1)(i)(F). The text of these and other applicable regulations are provided in Appendix B of this document. For the texts of other applicable 10 CFR Part 60 requirements, refer to U.S. Code of Federal Regulations, Title 10, "Energy."

Information contained in NUREG 1373 (Gupta and Buckley, 1989) is also relative to this STP.

3.0 STAFF TECHNICAL POSITIONS

The staff technical position on an acceptable methodology for demonstrating compliance with 10 CFR 60.133(i) is outlined in the following sections. The approach described in Sections 3.1 and 3.2 is based on an expected understanding of the fully coupled effects of thermally induced phenomena. However, the staff technical position described in Section 3.3 acknowledges the potential use of partial and/or multiple one-way coupled formulations of these phenomena.

3.1 Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)

DOE should develop a defensible approach that can be used to demonstrate the acceptability of the underground facility design. An example of an acceptable approach is described next and is illustrated in Figure 1.

Step No. 1 -- Preliminary Evaluation to Determine Sensitivity of the Performance Objectives to Thermal Loading

Make an evaluation to determine if the performance objectives (taking one at a time) are insensitive to thermal loading, based on current scientific understanding and/or engineering experience. If such an evaluation results in a positive answer, as indicated in Step No. 1A of Figure 1, then the underground facility design would be considered independent of thermal loading.

Step No. 2 -- Determination of the Existence of Predictive Models to Quantify the Effects of Thermal Loading

If the underground facility design cannot be established to be independent of thermal loading, determine if reliable predictive models exist to quantify the sensitivity of the design to thermal loading. If such models exist, use them to show compliance with 10 CFR 60.133(i), as indicated in Step No. 2A. In this case, the process is continued with the development of design goals/criteria in Step No. 4, and since reliable models already exist, Step No. 5 is omitted.

Step No. 3 -- Examination of the Thermally Induced Phenomena

If defensible models do not exist, examine the thermally induced phenomena in the host rock, surrounding strata, and groundwater system, to develop predictive models, to use in the design of the underground facility.

Step No. 4 -- Development of Design Goals/Criteria

Develop initial design goals/criteria for the underground facility, based on performance objectives, using simplified analyses.

Step No. 5 -- Development of Detailed Predictive Models

Develop predictive models for detailed analyses. Several iterations may be necessary between Step Nos. 5 and 3 (in Figure 1) before a satisfactory set of predictive models can be developed.

Step No. 6 -- Application of Predictive Models to the Underground Facility Design

Perform detailed analyses on the underground facility design with predictive models.

Step No. 7 -- Iterative Predictions to Check if Design Goals/Criteria are Met

Compare results of predictive models to initial design goals/criteria for the underground facility. If necessary, modify the underground facility design (Step No. 7A in Figure 1) until it complies with the design goals/criteria.

Step No. 8 -- Incorporation of Predicted Results in Pre- and Postclosure Performance Assessment Models

Incorporate the predicted results in performance assessment models, to evaluate compliance with the individual performance objectives of 10 CFR 60.111, 60.112, and 60.113.

If 10 CFR Part 60 performance objectives are not met, determine whether noncompliance with performance objectives results from deficiencies in the underground facility design, as shown in Step No. 8A (see bottom of Figure 1). If initial design iterations result in noncompliance with the performance objectives, reexamination of the design process should be considered beginning with either Step No. 3 or Step No. 4.

If, after numerous design iterations, noncompliance with 10 CFR Part 60 performance objectives persists, examination of other criteria not related to the underground facility design should be considered (Step No. 8B).

Step No. 9 -- Acceptability of Underground Facility Design

The underground facility design would be considered acceptable if 10 CFR Part 60 performance objectives are met.

3.2 Development of Detailed Predictive Models

To the extent practical, DOE should develop models to predict the thermal and thermomechanical response of the host rock, surrounding strata, and groundwater system, based on a mechanistic understanding of fully coupled T-M-H-C behavior.

3.3 Alternative Predictive Models

If a detailed understanding of the synergistic effects of T-M-H-C interactions cannot be gained before submittal of an application for construction authorization, DOE should:

(a) develop models that approximate fully coupled behavior in a manner that is not likely to adversely affect the performance objectives 10 CFR 60.111, 60.112, and 60.113; and

(b) present such plans for in-situ and laboratory monitoring and testing, and for additional model development, as may be appropriate to confirm the adequacy of the analytical methods used to support the application for construction authorization.

4.0 DISCUSSION

The following discussions parallel the list of staff technical positions given in Section 3.0. The technical positions outlined in Sections 3.1 through 3.3 represent an acceptable methodology for demonstrating 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 groundwater system) on the repository performance associated with an underground facility design. Also, the methodology takes into account the performance objectives of 10 CFR 60.111, 60.112, and 60.113, all of which must be satisfied by any design.

4.1 Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)

There are five decision points in the example approach shown in Figure 1 (see Step Nos. 1, 2, 7, 8, and 8A). The first two steps in the example approach are programmatic decision points. In Step No. 1, a decision will be made if the thermal loads have significant impacts on the performance of the geologic repository. In Step No. 2, a decision will be made on whether a need exists for the development of detailed predictive models.

In the next two decision points in the example approach (see Step Nos. 7 and 8) evaluations are made of the acceptability of the underground facility design. The evaluation point in Step No. 7 involves the comparison of the predicted responses with the response limits set by the design goals/criteria for the underground facility; those, in turn, are derived by considering the three 10 CFR Part 60 performance objectives. If the predicted response fails to meet the design goals/criteria for the underground facility, the underground facility design should be changed, with subsequent model application and reevaluation of predicted responses.

The fourth evaluation point, performance assessment evaluation (Step No. 8 of Figure 1), takes place only after all the underground facility design goals/criteria have been satisfied. If, on completion of the performance assessment evaluation, the underground facility design fails to comply with 10 CFR Part 60 pre- or postclosure performance objectives, or has a potential for adversely affecting the performance objectives, a reassessment associated with each step (or at least some of the steps) in the methodology should be conducted, before new responses are predicted and incorporated into the performance assessment models for reevaluation. Several iterations may be required before it can be determined that the underground facility design complies with 10 CFR 60.133(i).

The fifth and last decision point (Step No. 8A) determines if noncompliance with 10 CFR Part 60 performance objectives arises from underground facility design-related problems, or is the result of other design and/or site-related problems.

As illustrated in Figure No. 1, the process may be terminated at different decision points, depending on the state of the knowledge and complexity of the information needs.

The following discussions are a further amplification of Step Nos. 1 through 9, discussed in Section 3.1.

Step No. 1 -- Preliminary Evaluation to Determine Sensitivity of the Performance Objectives to Thermal Loading

Upon emplacement of spent nuclear fuel and high-level radioactive waste (HLW) in the underground facility, the host rock, surrounding strata, and groundwater system will respond to thermal loading generated by the waste. This response will depend on many factors, such as the T-M-H-C characteristics of the host rock, and those of the surrounding strata; hydrological and geochemical environment, the age of the waste and its thermal decay characteristics; and the designs of the underground facility and the waste package. Such a response will likely affect the preclosure performance objective 10 CFR 60.111, as well as the postclosure performance objectives in 10 CFR 60.113 and 60.112.

Therefore, a logical starting point for a strategy for compliance with 10 CFR 60.133(i) would consist of an evaluation to determine the sensitivity of the performance objectives (taking one at a time) to thermal loading. This is Step No. 1 in Figure 1. If it is determined on the basis of scientific understanding and/or engineering experience that the underground facility design is insensitive to thermal loading, then the design of the underground facility could proceed without further developmental work to show compliance with 10 CFR 60.133(i), as indicated in Step No. 1A. The design in this case is shown to be independent of the thermal loading.

Step No. 2 -- Determination of the Existence of Predictive Models to Quantify the Effects of Thermal Loading

If it is determined from Step No. 1 that the performance objective(s) is (are) sensitive to thermal loading, then it will be necessary to establish whether reliable predictive models exist to quantify the degree of sensitivity. If predictive models exist that can reasonably represent the T-M-H-C interactions, then there is no need to develop new models. Instead, existing models can be used to carry out the design analyses to show compliance with 10 CFR 60.133(i), as shown in Step No. 2A. Subsequently, Step Nos. 3 and 5 in Figure 1 may be skipped and the process continued with the development of design goals/criteria (Step No. 4). If reliable predictive models do not exist, the process continues to Step No. 3.

Step No. 3 -- Examination of the Thermally Induced Phenomena

It is likely that repository-induced thermal loading of the host rock, surrounding strata, and groundwater system may be one of the most important underground facility design parameters (DOE, 1988, p. 8.3.2.2-70). The level of response may vary among different geologic materials and in different locations in the geologic repository at different times, which could have an effect on the design of the underground facility. Therefore, to ensure that the design of the underground facility complies with the design criterion stated in 10 CFR 60.133(i), it will be necessary to understand the transfer of heat and the associated phenomena such as the thermally induced mechanical, chemical, and hydrologic response of the host rock, surrounding strata, and groundwater system. This understanding would include an assessment of the level of phenomenological coupling that may be necessary to reasonably characterize the phenomena and predict the responses.

Predictive capabilities of thermally induced phenomena would require characterization of the heat-transfer properties of the host rock, surrounding strata, and groundwater system. Essential information to obtain in this area would be the basic host rock thermal properties, such as thermal conductivity, density, and heat capacity. In addition, information about the host rock mineralogy, porosity, degree of saturation, and permeability would contribute to the understanding of the heat-transfer environment and heat-induced flow of liquids and gases. Information that would support such characterization of the heat transfer properties would initially come from site characterization activities and subsequently from performance confirmation testing.

Field and laboratory experiments would be necessary to provide evidence of the dominant modes of heat transfer that can be expected, including the degree to which these modes of heat transfer are affected by coupled T-M-H-C processes. The dominant modes of heat transfer may be functions of geometric scale and time. For instance, radiant heat transfer may only be of importance in openings around waste containers, disposal rooms, and access drifts that are not backfilled, whereas heat transfer associated with the vaporization of pore water and transfer of the vapor phase (i.e., convection/diffusion) may have to be considered on larger scales, perhaps tens to hundreds of meters from the underground facility, depending on the presence of water and the amount of waste to be stored per unit area (i.e., the thermal load). In addition, the identification and analyses of natural analogues could lend support to repository-related field and laboratory experiments.

Step No. 3 results from the need to bring about an understanding of the occurrence of heat transfer and thermally induced effects in the host rock, surrounding strata, and groundwater system, as the basis for developing or qualifying adequate predictive models of thermally induced responses.

Step No. 4 -- Development of Design Goals/Criteria

Although the host rock, surrounding strata, and groundwater system are expected to respond to the transfer of heat, the level of such response, which is acceptable from the standpoint of the repository performance objectives, needs to be established. Underground facility design goals/criteria derived from T-M-H-C response limits correlated to the repository performance objectives are expected to be essential in the development of the underground facility design. The purpose of developing design goals/criteria that are derived by considering the 10 CFR Part 60 performance objectives is to contribute to the assurance that the design of the underground facility has the likelihood of meeting these performance objectives. The design goals/criteria are to be developed on the basis of the understanding of the thermally induced phenomena in the host rock, surrounding strata, and groundwater system, and the expected consequences to the waste isolation capability of a site associated with the presence of an underground facility, including the thermal load. Thus, an approach to developing performance-based design goals/criteria would be:

(a) identify processes and events that could result from thermally induced phenomena (e.g., rock fracturing, groundwater flow, or mineral dissolution and precipitation) that could be of consequence to the performance of the repository (as defined by 10 CFR Part 60 general and specific design criteria and by preclosure and postclosure performance objectives);

(b) determine quantitatively and/or qualitatively in what way and to what extent these processes and events affect (or potentially affect) the performance of the repository; and

(c) determine the degree to which the processes and events are acceptable, to limit any response that may be of significance to the performance objectives.

To establish response limits expressed by the design goals/criteria, it is likely that simplified predictive T-M-H-C analyses of conceptual underground facility designs would be conducted. Because the phenomenological responses to be considered are "thermally driven," it is conceivable that the design goals/criteria could be expressed in terms of a maximum rock temperature, temperature gradient, or flux. However, they could also be expressed in terms of limiting rock stresses and displacements, groundwater flow rates, and mineral dissolution and precipitation rates. All these analyses require a certain level of scientific understanding, experimental evidence, predictive techniques (albeit simplified) and professional judgment.

There are various levels of details regarding the evaluation of thermal effects on repository performance upon which the development of such criteria could be based. However, the criteria are expected to be developed based on the available information and understanding about the host rock, surrounding strata, and groundwater system. New understanding about potential T-M-H-C processes and events in the host rock, surrounding strata, and groundwater system could be gained during the period of site characterization and performance confirmation testing. To better guide the development of the underground facility design, it is reasonable that such understanding be reflected in new and/or revised design goals/criteria. However, a documented rationale would be expected with any changes to such goals/criteria.

Step No. 5 -- Development of Detailed Predictive Models

The discussion for Step No. 5 in Figure 1 is contained in Section 4.2, "Development of Predictive Models."

Step No. 6 -- Comparison of Results from Predictive Models with the Design Goals/Criteria

The design goals/criteria that 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 facility 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 facility design must be available and compared to the design goals/criteria. An example of such comparisons associated with heat-transfer predictions can be found in NUREG/CR-5428 (Brandshaug, 1989). Meeting all the design goals/criteria will provide confidence that the underground facility design has a higher likelihood of meeting and/or not adversely affecting 10 CFR Part 60 preclosure and postclosure performance objectives.

Step No. 7 -- Iterative Predictions to Check if Design Goals/Criteria Are Met

Step No. 7 is a decision point to determine whether the design goals/criteria for the underground facility have been met. If the design goals/criteria have not been met, then the underground facility design needs to be modified (Step No. 7A in Figure 1) and the design needs to be reevaluated in the manner described in Step No. 6. If the design goals/criteria have been met, then the process continues to the next decision point found in Step No. 8.

Step No. 8 -- Incorporation of Predicted Results in Performance Assessment Models

Although it may be possible to show that the underground facility design meets individual design goals/criteria, the final evaluation of the underground facility design must be a test of the effect of the design on the performance, as measured against the objectives 10 CFR 60.111, 60.112, and 60.113. It is expected that models for the evaluation of performance objectives will be available, and will incorporate the predicted heat transfer and thermally induced mechanical, hydrologic, and chemical responses, including uncertainties, as input for analyses. Compliance with 10 CFR 60.133(i) would be demonstrated by (1) a satisfactory evaluation by performance assessment models that shows compliance with the performance objectives and (2) meeting of the design goals/criteria.

An unsatisfactory performance assessment result would require a return to Step No. 4, to perform a reassessment of the design goals/criteria of the predictive models (Step No. 5), or of the underground facility design (Step No. 6). This reassessment would be required before any changes are made. On the basis of any changes in design or evaluation approach, a reevaluation of the design is necessary against the design goals/criteria and the performance objectives. If unacceptable results are encountered, it may become necessary to return to Step No. 3, from Step No. 8 (see Figure 1).

It is conceivable that a noncompliance determination is not necessarily related to a deficiency in the underground facility design (Step No. 8A). This would be evident if repeated examinations of the design process (e.g., Step Nos. 3 through 7 in Figure 1) fail to yield a satisfactory evaluation by the performance assessment model (Step No. 8). In this case, a decision would be made to look for problems related to waste package design, borehole and shaft seals design, and/or geologic setting concerns (Step No. 8B); however, discussions of such analyses are beyond the scope of this STP.

Step No. 9 -- Acceptability of Underground Facility Design

This is the final step in the design of the underground facility. It is only reached when the design goals/criteria as well as the performance objectives have been satisfied. As indicated in Step No. 8, several iterations may be required before it can be concluded that 10 CFR 60.133(i) requirements have been complied with.

4.2 Development of Detailed Predictive Models

The thermal load expected to result from the emplacement of spent nuclear fuel and HLW will affect the host rock, surrounding strata, and groundwater system for thousands of years. Thus, the thermal load has the potential to alter the normal T-M-H-C processes within the geologic setting throughout the entire waste containment period and much of the waste isolation period. Predictions of the heat transfer and thermally induced mechanical, hydrologic, and chemical response of the underground facility host rock, surrounding strata, and groundwater system must be part of the basis upon which the underground facility is designed. Analyses will be required which collectively would provide a perspective on 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. The staff expects DOE to pursue the development of fully coupled models based on an understanding of the synergistic effects of the coupled T-M-H-C interactions.

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 that may be important to the prediction of the response early in the history of the repository and that 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, room-scale, repository-scale, and regional-scale problems are required to ensure that appropriate phenomenological detail will be included in the analyses.

The staff recognizes that assumptions must be made about host rock conditions and phenomenological details that 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, validate, and use. The staff also recognizes, on the other hand, that oversimplification in modeling may obscure the understanding of those processes that might have significant impact on design goals/criteria and/or performance. The analyst should choose a model that strikes a balance between unworkable detail and oversimplification of the processes that are being modeled. Such a balance can reduce the model uncertainty to a degree. Nevertheless, there remains residual model uncertainty that results from the simplification and lack of knowledge of the phenomena being modeled.

Since the purpose of the predictive models is to assist in the evaluation of the adequacy of the underground facility design, the models must provide a measure of performance that enables such evaluations. Relationships need to be established between the response measures and the performance measures. For the heat-transfer model, this response 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 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 derived by appropriate tests of a sufficient number and duration, which allow for reliable estimates of spatial representativeness, as well as range and distribution of the data. In addition, the acquisition of the necessary input data as well as the analysis of the data (e.g., data reduction) must be conducted in accordance with QA procedures (see Subpart G to 10 CFR 60).

Determination of the heat transfer and thermally induced mechanical, hydrological, and chemical behavior in the host rock, surrounding strata, and groundwater system must give consideration to the effects of uncertainties associated with the values of the parameters used in the predictive model input. To properly evaluate the underground facility design, the effects of uncertainty in model input parameters must be established with respect to the predicted results. This includes assumptions upon which the models rely, which tend to idealize a problem into manageable proportions. Assumptions and uncertainties could be related to geometric aspects of a problem such as two-dimensional versus three-dimensional analysis, simplified representation of the geologic stratigraphy and/or topography, orientation and frequency of rock joints, initial conditions, environmental conditions resulting from a range of anticipated processes and events, and to idealizations in constitutive relationships of phenomena. From the standpoint of model reliability, it is essential that assessments be made of the effects of uncertainties associated with model assumptions on the predicted results. Thus, an 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. The effects of uncertainties related to material properties could be assessed by using the range or statistical distribution of the properties. Examination of the change in response with respect to a variation (e.g., one standard deviation) in model-specific parameters provides a useful perspective on the evaluation of the design of an underground facility. Such examination would:

(a) indicate whether significant additional accuracy in the prediction is attainable, given the current parameter ranges and sensitivities;

(b) indicate which parameters may be important in achieving more accurate predictions; and

(c) provide useful guidance aimed at the development of an underground facility design, that accommodates certain parameter ranges.

The effects of assumptions could be assessed relatively, by varying the model in terms of alternatives (e.g., using different constitutive relationships and initial conditions), or directly, by evaluating the model against physical experiments. The results of these activities provide confidence in the reliability of a model, which would need to be expressed in qualitative and quantitative terms. It is expected that a statistical approach is needed to provide a systematic evaluation of the response uncertainties and their probabilities of occurrence. The NRC staff expects that DOE will use statistical methods that are consistent with the quality and quantity of data available in its approach to dealing with data uncertainties.

The licensing process requires that DOE demonstrate that the regulations embodied within 10 CFR Part 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 the issuance of a license will not constitute an unreasonable risk to the health and the safety of the public. Further, this finding must be made on the basis of information presented in the license application. Section 10 CFR 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. To the extent that the information in the application may be incomplete, it must nevertheless be sufficient (taking into account plans for performance confirmation) to support the findings stated above.

Finally, all predictive models used for licensing are likely to require a certain degree of verification and validation. Rigorous model verification and validation against laboratory and field experiments are expected to test the reliability of the models and are imperative if heat transfer and thermally induced effects are to be predicted with sufficient reliability to ensure compliance of the underground facility design with the performance objectives. However, there may be different levels of model validation, because factors that constitute a rigorous validation depend on the information obtained from the laboratory and field experiments. For example, it is reasonable to expect that a more rigorous model validation could be achieved for short-term (e.g., less then 10 years) predictions than for long-term predictions. It is also reasonable to expect that a more rigorous model validation could be achieved for predictions of phenomenological response in the close vicinity of the underground facility, including the individual waste containers, than for predictions of responses at greater distances from the underground facility, simply because of the problems associated with physical access. (NRC has provided guidance on documentation of model verification in NUREG-0856 (Silling, 1983). However, model validation and verification are complex issues that deserve a more extensive discussion than can be provided in this STP.)

4.3 Alternative Predictive Models

In demonstrating compliance with design criteria of 10 CFR 60.133(i), it is expected that a mechanistic understanding of the fully coupled behavior will be used 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 sufficiently detailed understanding of the synergistic effects of T-M-H-C responses before DOE submittal of an application for construction authorization. It is possible, therefore, that models will be developed and applied, that are based on less detailed understanding of the synergistic effects of T-M-H-C behavior. As a consequence, the models may not account for fully coupled T-M-H-C processes, but rather, approximate such processes by the application of, for example, partially coupled model, or multiple one-way coupled models (see Appendix C). In the application of such models, conservative data and assumptions must be used to compensate for the uncertainties, since otherwise such uncertainties may preclude the staff from finding, with reasonable assurance, that the performance objectives will be met. In addition, analyses using these models must be conducted in a manner that allows an evaluation of the effects of the assumption of, for example, one-way coupling, on the predicted results.

5.0 REFERENCES

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U.S. Department of Energy, "Configuration of Underground Facilities (Postclosure)" in "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada", Vol. VI, Part B, Chapter 8, Section 8.3.2.2, DOE/RW-0199, December 1988.

U.S. Nuclear Regulatory Commission, "Definition of the Term 'Performance Objectives' as used in 10 CFR 60.133(i)," Office of Nuclear Material Safety and Safeguards, Staff Position 60-003, August 8, 1990.

U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Waste in Geologic Repositories, Proposed Licensing Procedures," Federal Register, Vol. 44, No. 236, December 6, 1979, pp. 70408-70421

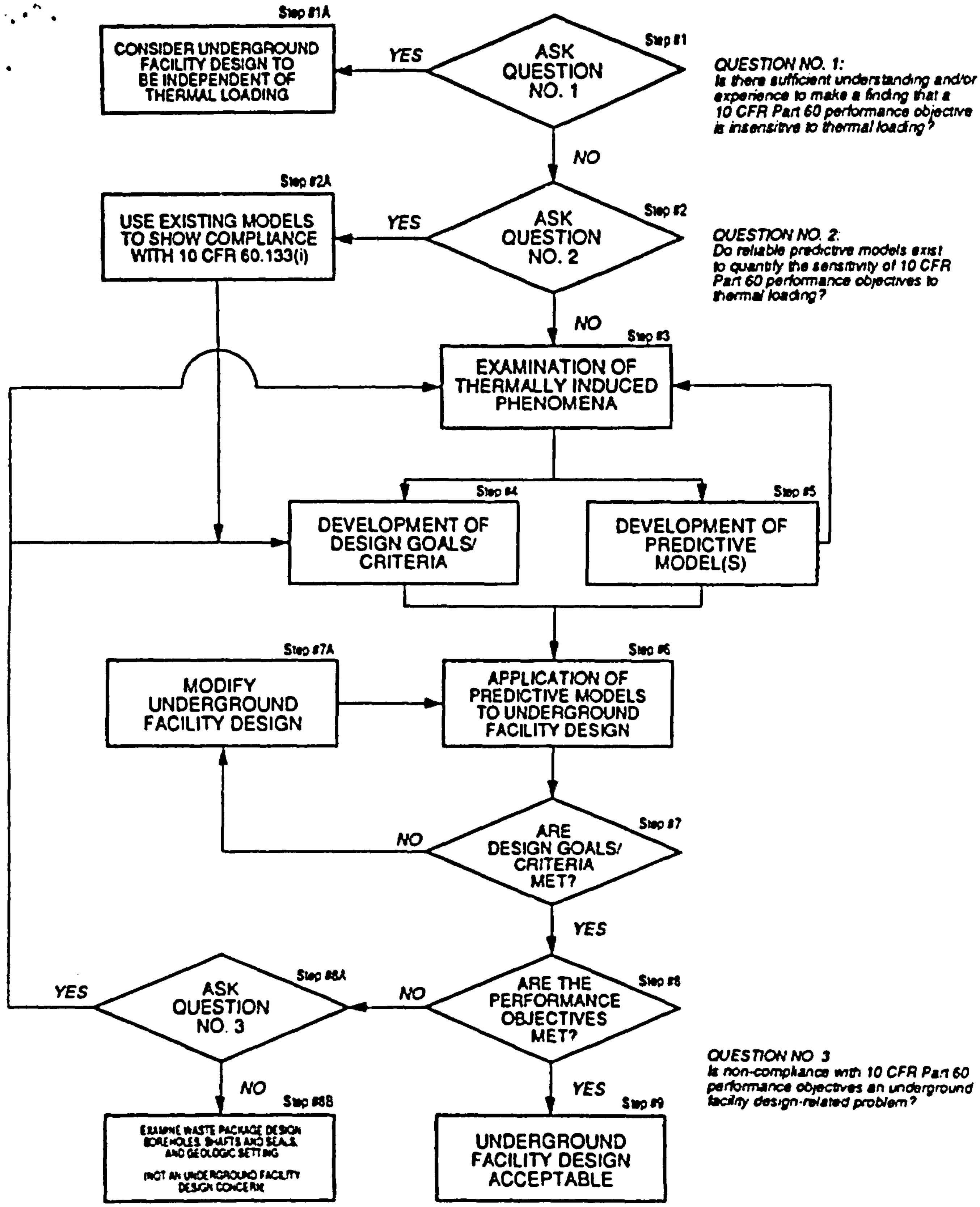

FIGURE 1 -- The Logic Flow for an Example of an Acceptable Methodology for Demonstrating Compliance with 10 CFR 60.133(i). The numbers next to the process blocks refer to the steps necessary to implement technical position 3.1. These steps are described in Sections 3.0 and 4.0 of the text.

APPENDIX A: GLOSSARY

As used in this guidance:

"Fully Coupled Model" is a model that incorporates in its formulation the interdependency of the four phenomena (thermal, hydrological, mechanical, chemical).

"Geologic Repository"* means 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"* means 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"* means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located.

"Host Rock*" is the the geologic medium in which the waste is emplaced.

"One-way Coupled Model" is a model that incorporates in <u>its</u> formulation the dependency of one process on another (e.g., Determination of rock stresses is dependent on temperature but determination of temperature is not dependent on stress).

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* Source: 10 CFR 60.2, "Definitions."

"Partially Coupled Model" is a model that incorporates in its formulation the interdependency of any two or three of the phenomena (thermal, hydrological, mechanical, chemical).

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

"Underground Facility"* means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals (Silling, 1983, p.3).

"Validation" means the 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" is the assurance that a computer code correctly performs the operations specified in a numerical model.

For definitions of other relevant terms, see 10 CFR 60.2.

REFERENCES

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

U.S. Code of Federal Regulations, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Part 60, Chapter I, Title 10, "Energy."

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* Source: 10 CFR 60.2, "Definitions."

APPENDIX B: APPLICABLE 10 CFR PART 60 REGULATIONS

§60.21(c)(1)(i)(F) Content of application.

[(c) The Safety Analysis Report shall include:
(1) A description and assessment of the site at which the proposed geologic repository operations area is to be located with appropriate attention to those features of the site that might affect geologic repository operations area design and performance. The description of the site shall identify the location of the geologic repository operations area with respect to the boundary of the accessible environment [including]....]

(F) The anticipated response of the geomechanical, hydrogeologic, and geochemical systems to the maximum design thermal loading, given the pattern of fractures and other discontinuities and the heat transfer properties of the rock mass and groundwater.

§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 before 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 ground water 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 10 CFR 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 percent 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.

(2) Geologic setting. The geologic repository shall be located so that pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement ground-water travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied. Among the factors that the Commission may take into account are:

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and ground water; and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

(c) Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events.

§§60.130 Scope of design criteria for the geologic repository operations area.

Sections 60.131 through 60.134 specify minimum criteria for the design of the geologic repository operations area. These design criteria are not intended to be exhaustive, however. Omissions in §§60.131 through 60.134 do not relieve DOE from any obligations to provide such safety features in a specific facility needed to achieve the performance objectives. All design bases must be consistent with the results of site characterization activities.

§§60.131 General design criteria for the geologic repository operations area.

(a) Radiological protection. The geologic repository operations area shall be designed to maintain radiation doses, levels, and concentrations of radioactive material in air in restricted areas within the limits specified in Part 20 of this chapter. Design shall include:

(1) Means to limit concentrations of radioactive material in air;

(2) Means to limit the time required to perform work in the vicinity of radioactive materials, including, as appropriate, designing equipment for ease of repair and replacement and providing adequate space for ease of operation;

(3) Suitable shielding;

(4) Means to monitor and control the dispersal of radioactive contamination;

(5) Means to control access to high radiation areas or airborne radioactivity areas; and

(6) A radiation alarm system to warn of significant increases in radiation levels, concentrations of radioactive material in air, and of increased radioactivity released in effluents. The alarm system shall be designed with provisions for calibration and for testing its operability.

(b) Structures, systems and components important to safety --

(1) Protection against natural phenomena and environmental conditions. The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.

(2) Protection against dynamic effects of equipment failure and similar events. The structures, systems, and components important to safety shall be designed to withstand dynamic effect such as missile impacts, that could result from equipment failure, and similar events and conditions that could lead to loss of their safety functions.

(3) Protection against fires and explosions. (i) The structures, systems and components important to safety shall be designed to perform their safety functions during and after credible fires or explosions in the geologic repository operations area.

(ii) To the extent practical, the geologic repository operations area shall be designed to incorporate the use of noncombustible and heat resistant materials.

(iii) The geologic repository operations area shall be designed to include explosion and fire detection alarm systems and appropriate suppression systems with sufficient capacity and capability to reduce the adverse effects of fires and explosions on structures, systems, and components important to safety.

(iv) The geologic repository operations area shall be designed to include means to protect systems, structures, and components important to safety against the adverse effects of either the operation or failure of the fire suppression systems.

(4) Emergency capability. (i) The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency.

(ii) The geologic repository operations area shall be designed to include onsite facilities and services that ensure a safe and timely response to emergency conditions and that facilitate the use of available offsite services (such as fire, police, medical and ambulance service) that may aid in recovery from emergencies.

(5) Utility services. (i) Each utility service system that is important to safety shall be designed so that essential safety functions can be performed under both normal and accident conditions.

(ii) The utility services important to safety shall include redundant systems to the extent necessary to maintain, with adequate capacity, the ability to perform their safety functions.

(iii) Provisions shall be made so that, if there is a loss of the primary electric power source or circuit, reliable and timely emergency power can be provided to instruments, utility service systems, and operating systems, important to safety.

(6) Inspection, testing, and maintenance. The structures, systems, and components important to safety shall be designed to permit periodic inspection, testing, and maintenance, as necessary, to ensure their continued functioning and readiness.

(7) Criticality control. All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.

(8) Instrumentation and control systems. The design shall include provisions for instrumentation and control systems to monitor and control the behavior of systems important to safety over anticipated ranges for normal operation and for accident conditions.

(9) Compliance with mining regulations. To the extent that DOE is not subject to the Federal Mine Safety and Health Act of 1977, as to the construction and operation of the geologic repository operations area, the design of the geologic repository operations area shall nevertheless include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR, Chapter I, Subchapters D, E, and N will give rise to a rebuttal presumption that this requirement has not been met.

(10) Shaft conveyances used in radioactive waste handling. (i) Hoists important to safety shall be designed to preclude cage free fall.

(ii) Hoists important to safety shall be designed with a reliable cage location system.

(iii) Loading and unloading systems for hoists important to safety shall be designed with a reliable system of interlocks that will fail safety upon malfunction.

(iv) Hoists important to safety shall be designed to include two independent indicators to indicate when waste packages are in place and ready for transfer.

§§60.133 Additional design criteria for the underground facility.

(a) General criteria for the underground facility. (1) The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides.

(2) The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires and explosions, will not spread through the facility.

(b) Flexibility of design. The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing or excavation.

(c) Retrieval of waste. The underground facility shall be designed to permit retrieval of waste in accordance with with the performance objectives of §60.111.

(d) Control of water and gas. The design of the underground facility shall provide for control of water or gas intrusion.

(e) Underground openings. (1) Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

(2) Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock.

(f) Rock excavation. The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment.

(g) Underground facility ventilation. The ventilation system shall be designed to:

(1) Control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of §60.111(a).

(2) Assure continued function during normal operations and under accident conditions; and

(3) Separate the ventilation of excavation and waste emplacement areas.

(h) Engineered barriers. Engineered barriers shall be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure.

(i) Thermal loads. 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 (sic) surrounding strata, [and] groundwater system.

APPENDIX C: ITERATIVE PROCESS FOR THE ANALYSIS OF THERMALLY-INDUCED PHENOMENA

Figure C1 shows an example of an analysis process to approximate fully coupled T-M-H-C responses, based on multiple one-way coupled predictive models. The process, however, could accommodate any level of coupling between any two or three of T-M-H-C phenomena (e.g., full coupling between heat transfer and hydrology, or between heat transfer and chemistry, or between heat transfer, hydrology, and mechanical behavior). The example analyses depicted in Figure C1 would initially involve a 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 mechanical, hydrologic, and chemical responses (e.g., changes in thermal properties due to dissolution and precipitation of mineral species in the host rock, as predicted by the chemical model). Subsequent analyses would produce a second, and third, etc. set of predictions of heat-transfer and thermally-induced mechanical, hydrological, and chemical responses. The iterative process would continue until changes in the prediction of the respective phenomena converge to some acceptable level.

The order in which the phenomena (e.g., thermal, mechanical, hydrological, or chemical) are analyzed in Figure C1 is shown only as an example. The responsibility to determine the most appropriate sequence of analysis rests with the licensee. The process depicted in Figure C1 is based on the need to not only provide predictions about the heat-transfer and thermally induced effects in the host rock, surrounding strata, and groundwater system, but to provide it in a manner that allows an evaluation of the assumption of uncoupled processes.

The licensee may chose to use approximate methods similar to that illustrated in Figure C1 for assessing the effects of thermal loads in the context of the underground facility design. However, regardless of the methods, assumptions, or approximations used in the design process, the licensee must demonstrate at the time of license application that the proposed underground facility design will conform to the performance objectives of 10 CFR 60.111, 60.112, and 60.113, as required by 10 CFR 60.133(i).

It is also important to note that not every design goal/criterion needs consideration of mechanical/chemical/hydrological changes resulting from thermal loading. For each performance objective, the scale of the problem (canister/room/repository/region) and duration of interest (0 to 100 years, 0 to 300/1000 years, 0 to 10,000 years) will be different. The analyses should consider the existing information such as laboratory and field test data, simplified model studies, and natural analogues, before embarking on any detailed analyses. For certain cases, it may be possible to terminate the analysis procedures in Figure C1 at the end of first or second stage.

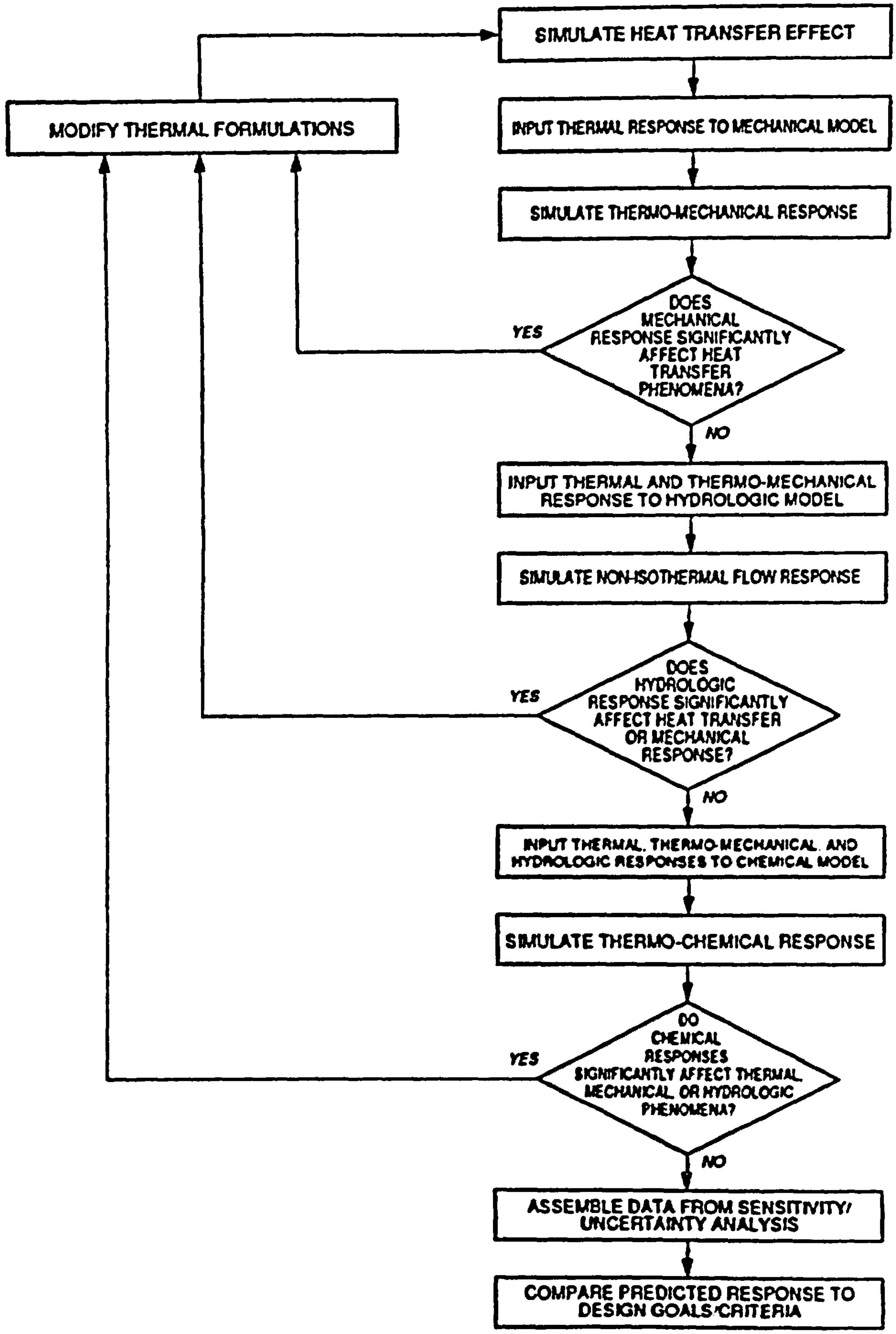

FIGURE C1 -- Example of an Iterative Process for the Analysis of Thermally Induced Phenomena Based on One-Way Coupling

APPENDIX D: DISPOSITION OF PUBLIC COMMENTS