JUL 6 1990

MEMORANDUM FOR: Joseph O. Bunting, Chief
Engineering Branch
Division of High-Level Waste Management

FROM: Ronald L. Ballard, Chief
Geosciences & Systems Performance Branch
Division of High-Level Waste Management

SUBJECT: REVIEW OF INTERNAL DRAFT TECHNICAL POSITION ON "REPOSITORY DESIGN - THERMAL LOADS"

We have reviewed the internal draft of the Technical Position (TP) on Repository Design - Thermal Loads as requested in your memorandum of May 31, 1990. Our review is based on the criteria provided in Appendix A of WM Policy #46 (Technical Position Review Criteria).

Attachment A contains our detailed comments. Attachment B provides a mark-up of the TP containing suggestions related to style and/or clarity. Our general comments with respect to the staff's internal draft position are as follows:

- The position is taken in the TP that, while the staff wants fully-coupled interactive models of thermal, mechanical, hydrological and chemical effects, we don't think DOE can do it for the license application. Consequently, the staff will settle for an interim, one-way coupled model in the license application, to be followed by development of the necessary fully-coupled mechanistic models by way of a performance confirmation program. This position seems to encourage a less-than-desired analysis for licensing purposes which may lead to hearing complications. An alternative (and preferred) approach would be to describe what is desired (fully-coupled models) and permit a lesser analysis if the state-of-the-art so dictates, but only if the analysis clearly demonstrates, with appropriate conservatism, that public health and safety can be achieved with reasonable assurance.

- While the general five-step methodology for demonstrating compliance with 10 CFR 60.133(i) appears to be acceptable, the lack of substantive technical discussion and implementation guidance for each step of the methodology reduces the significance of the methodology and the effectiveness of the TP to provide DOE with an understanding of how to demonstrate compliance with 10 CFR 60.133(i) by implementing the methodology in a manner acceptable to the NRC. This results from the detailed technical guidance in the TP being focused toward only one of the five steps of the methodology (how to perform analyses with predictive models as shown in Figure 2 of the TP). Although the TP stresses that compliance with 10 CFR 60.133(i) requires assurance that

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thermal effects have been adequately considered in the design of the underground structure such that the performance objectives are met, there is no guidance provided in establishing the link between the surrogate, performance based design criteria and response limits defined by this TP and the 10 CFR Part 60 design criteria and performance objectives.

Although not required by WM Policy #46, documentation assessing any regulatory or technical uncertainties identified through the Systematic Regulatory Analysis (SRA) of the subject regulatory requirement (60.133(i)) should accompany TPs during the internal review process. Such documentation would provide added assurance that we are not inadvertently introducing complications into the licensing process.

The staff who participated in this review remain available to discuss these comments. Any technical discussions necessary can be arranged through Jeffrey Pohle on extension 20545.

Ronald L. Ballard

Ronald L. Ballard, Chief
Geosciences & Systems Performance Branch
Division of High-Level Waste Management

Attachments: See Jacket
As stated

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° The described iterative analytical process based on a one-way coupled formulation, the proposed acceptable approach to performing analyses with predictive models, may be technically incorrect and/or unimplementable; clarification is needed to be sure.

° Although not required by WM Policy #46, documentation assessing any regulatory or technical uncertainties identified through the Systemmatic Regulatory Analysis (SRA) of the subject regulatory requirement (60.133(i)) should accompany ~~the~~ TP's during the internal review process. ~~If any regulatory uncertainties have been identified, the potential for impacts on the technical position being put forth at this time should be assessed~~. If any technical uncertainties have been identified, those that are being addressed by the TP should be identified.

The staff who participated in this review remain available to discuss these comments. Any technical discussions necessary can be arranged through Jeffrey Pohle on extension 20545.

Ronald L. Ballard, Chief
Geosciences & Systems Performance Branch
Division of High-Level Waste Management

Attachments:
As stated

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Received w/Ltr Dated 7/6/90

ATTACHMENT A

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH DETAILED COMMENTS ON INTERNAL DRAFT TP REPOSITORY DESIGN-THERMAL LOADS

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH
DETAILED COMMENTS ON INTERNAL DRAFT TP
REPOSITORY DESIGN-THERMAL LOADS

JUNE 29, 1990

1. Paragraph 3 of Section 1.0 (Introduction) states that "In addition, this TP includes a compliance determination methodology for reviewing analyses presented in the license application regarding 60.133(i)."

   This sentence overstates the content of the TP. With one exception (the acceptability of an iterative analytical process based on a one-way coupled formulation in implementing prescribed predictive modeling), the TP provides no acceptance criteria for staff use in determining the acceptability of DOE's implementation of each step of the proposed methodology. The final paragraph of Section 1.0 (page 2) only indicates that the NRC requires data and information sufficient to allow staff to perform an independent analysis using "a methodology (such as that presented in this TP)." Needed data and information are not identified (the Standard Format and Content Guide is not expected to cover this level of detail) nor is any commitment to a particular methodology implied. There is no specific section of the TP explicitly outlining the "NRC compliance determination methodology." The only other reference to such is in the caption of Figure 1.

   If the TP is to have utility as a compliance determination methodology for for NRC use in review of a license application, the TP will have to be expanded. Substantive, "acceptable" approaches for implementing all steps of the compliance demonstration methodology will be necessary (they should be included anyway, for guidance to DOE). The acceptance criteria for each step will be based on those "acceptable" approaches. The resultant product will then be suitable for direct incorporation into the standard review plan.

2. The last sentence on page 1 of Section 1.0 states that "In addition, this section [Section 2.0] 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."

   The sentence is ambiguous and it will be unclear to DOE whether the guidance is applicable or not. Either take a position on the applicability of the other NRC guidance and be prepared to defend the position or delete the reference to other guidance.

3. We note that in the Regulatory Background Section (Section 2.0) GWTT is not included as one of the performance objectives under consideration under 60.133(i). Could not the repository be designed such to limit the extent of the disturbed zone and enhance the likelihood of meeting the

GWTT performance objective? Further, wouldn't the approaches discussed as technically acceptable for predicting the mechanical, hydrological and chemical thermal response be applicable in determining the extent of the disturbed zone?

The basis for excluding GWTT from consideration in demonstrating compliance with 60.133(i) needs to be discussed and presented in the Regulatory background section.

4. It is stated in Section 3.2 that "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."

   This approach appears questionable because it puts the NRC in the position of granting a license for a nuclear facility based on a recognized inadequacy in the licensing information and based on a promise that certain analyses and data will be obtained. The position provides no stipulation that certain results regarding repository performance be derived from the promised data and analyses, only that such information be generated. The leeway provided to DOE by this TP appears to be at variance with the requirements for the content of the Safety Analysis Report of 10 CFR 60.21(c), especially, 60.21(c)(i)(F) and the characteristics of the assessment specified in 60.21(c)(ii).

   DOE should be required to show, at a minimum, that any alternative analysis provided for thermal loading underestimates the effects on repository performance. If a "satisfactory understanding of synergistic effects" cannot be obtained, then the bias inherent in a bounding analysis cannot be gaged, and a pessimistic performance assessment cannot be assured.

5. It is stated in Section 3.2 that "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."

   Unless DOE has a mechanistic understanding of the interactive behavior, the use of conservative data and assumptions, or even the definition of these, cannot be assured.

6. Step one of the five-step compliance demonstration methodology is to "examine the thermally induced phenomena in the host rock and surrounding strata." The technical discussion about step one provided in Section 4.1.1 primarily restates the need to provide an "understanding of the occurrence of these phenomena in the host rock and surrounding strata"

because "it is likely that thermal loading may be one of the most important underground structure design parameters."

It is not clear what we specifically want from DOE on this topic because the section does not provide any substantive technical discussion. For example, the discussion indicates that "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." We interpret this sentence to indicate that the NRC considers heterogeneity, anisotropy and temporal decay of the heat source important technical factors in understanding thermally induced phenomena on a site specific basis. While such site characteristics and conditions are important, there also are more fundamental aspects of thermally induced phenomena to be described and understood. For example, basic physical principles such as mass balance, balance of stresses, forces, and momentum, dynamic and inertial effects, dimensionality, etc. that serve as bases for the formulation of mathematical models (see CNWRA review of Szymanski letter report on conceptual considerations of the Yucca Mountain groundwater system with special emphasis on the adequacy of this system to accommodate a high-level nuclear waste repository, prepared by Rachid Ababou; an inadequate development of basic physical principals was a significant weakness in the Szymanski report resulting in models that did not represent truly coupled processes with reasonable feedback effects). The technical discussion gives no indication that these are important technical subjects.

We should provide more substantive technical guidance to DOE as to what an adequate examination of thermally induced phenomena would include.

7. Step two of the five-step compliance demonstration methodology is to "develop performance based design criteria for the underground facility" that are derived from "performance based response limits."

The discussion about step two provided in Section 4.1.1 provides little technical elaboration about what design criteria and response limits are, what data and information related to performance based design criteria and response limits the NRC needs or technical discussion about how this step can be implemented in an acceptable way.

We note that there are some examples of "response limits" provided in Section 4.1.4 ("such as maximum rock temperature, displacements, stresses, flow rates, and mineral dissolution and precipitation rates"), but this this is much later in the text and not in the area of "first use" of the terminology. In addition, there is a mention of "performance measures" in Section 4.1.3 (Predictive Models; page 10). It states that "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." It is not clear if these "performance measures" are examples of either "performance based design criteria" or "performance based response limits" (or neither). None of these terms appear in the glossary.

Finally, implementing the proposed methodology of using the "performance based design criteria" and "performance based response limits" will require that a strong link be established and demonstrated between these surrogates and the 10 CFR 60 design criteria and performance objectives. The TP stresses that compliance with 60.133(i) requires that DOE must design the underground structure such that the performance objectives are met, but the TP provides little guidance in this area. Unless the link between the performance objectives and the performance based design criteria and response limits can be demonstrated, it is doubtful that the use of the surrogate criteria would stand up in a licensing action.

We should provide more substantive technical guidance to DOE as to what performance based design criteria are, what data and information about their development we require and what an adequate methodology for their development entails. In particular, the TP should provide substantive guidance on how to establish the link between the surrogate, performance based design criteria and response limits and the 10 CFR 60 design criteria and performance objectives.

8. Step three of the five-step compliance demonstration methodology is to "obtain or develop predictive models for analyses." It is stated in the TP that "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" and that "these interactive models should be available at the time of license application." After stating that "it is expected" that interactive, mechanistic models will be used in predictive analyses and that these interactive models "should be available" at the time of license application, the TP takes the position that "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." This is the most significant position taken in the TP. However, the position is based solely on the condition "if interactive models are unavailable at the time of license application."

The need to postulate that interactive models will not be available at the time of licensing and the formulation of a technical position around that postulated condition is questionable. In fact, many interactive, coupled models are available and in use now, and in some cases have been for some time. A fully coupled thermal, mechanical, hydrological, and chemical interaction model may not now be available. However, coupled models exist for all six combinations of these four classes of phenomena taken two at a time. Coupled models exist for some of the combinations of these four classes of phenomena taken three at a time. Thus, interactive models will be available at the time of a license application just as the TP indicates they "should" or are "expected" to be. Why postulate otherwise?

9. Step four of the five-step compliance demonstration methodology is to "Perform analyses with predictive models and compare results to performance based design criteria." The TP takes the position that "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." The "iterative analytical process" based on the one-way coupled formulation of thermally induced phenomena is described in a "detailed flow diagram" presented in Figure 2. In Figure 2 the results of a preceding simulation are input to simulate various responses, respectively (thermomechanical, non-isothermal flow, and thermo-chemical responses). After each simulation is performed a decision is made regarding whether the simulated response affects the heat transfer phenomena.

Because the heat transfer response apparently is not simulated, how can such a decision be made? It is not clear what is intended. Perhaps what is intended is described in the last paragraph of Section 4.3 (page 14). Therein it is stated that "...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." However, the flow chart does not indicate that estimates of heat transfer and various responses are to be iterated until changes "reach some acceptable level." The decision boxes in Figure 2 more properly belong after the simulation of heat transfer, because the decision regards effects on the heat transfer phenomena. Just because the repeated iteration of the calculational chain reduces changes in predicted parameters, there is no guarantee that the solutions converged to are (1) the correct mathematical limit state because an analysis of the uniqueness of the convergence process has not been performed or (2) representative of the realistic values of the various responses, because a fully or better coupled model might yield a significantly different solution. Contrary to the statement in the text, no evaluation can be obtained through these exercises of the assumption that the processes are uncoupled, because the modeling assumes no coupling or one-way coupling through a limited set of parameters.

10. The flow chart in Figure 2 ends with "provide results to performance assessment." The step wherein there is a test for meeting the performance based design criteria is missing.

11. In taking the position that an "iterative analytical process based on the one-way coupled formulation of thermally induced phenomena" is acceptable "if interactive models are unavailable at the time of license application," the TP states in Section 4.1.3 (page 9) that 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."

    The performance confirmation period was intended to provide data that would validate or otherwise assure correct analysis of repository performance. The performance confirmation period was not intended to provide information essential to modeling repository performance. That essential information must be obtained prior to applying for construction authorization.

12. Additional citations to 10 CFR 60 should be provided. 10 CFR 60.21 should be cited as part of the regulatory basis for the TP. Also, because it plays such a large role in the internal draft TP, the regulations pertaining to the performance confirmation period, 10 CFR Subpart F, should also be cited. Perhaps the regulatory basis could be divided into primary and secondary citations.

13. It is stated in Section 4.0 (page 7) that "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)." It is suggested that "evaluating and determining" compliance be replaced by "demonstrating" compliance to be consistent with SRA terminology and the introduction on page 1.

14. It is stated in Section 4.1.3 (page 10) that "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."

    Although this is a good point about the need for predictive models on different scales, the sentence is ambiguous. Different scales must be modeled, but cannot different models be used for different scales (as long as they are consistent)? The sentence could be read as implying that a single model must cover all scales of interest, which may not be feasible.

15. The discussion in the second paragraph of page 10 begins to discuss the issue of model validity and the needed level of model accuracy. This is a complex, difficult issue deserving a more extensive, careful discussion than that provided.

16. The second sentence of the second paragraph on page 11 lists the different types of uncertainties in predicted heat transfer and thermally induced mechanical, hydrologic, and chemical responses in the host rock and surrounding strata. The discussion is incomplete. Uncertainties related to the environmental conditions experienced by the repository (alternatively this may be considered the range of anticipated scenarios for which the repository must be designed) should be acknowledged.

17. The second sentence of the last paragraph of page 11 states that "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."

    The use of the term "reliability" may be inappropriate in this context, because it is usually used to refer to a type of confidence for things other than predictive models. Use of the term "reasonable assurance" may be more appropriate.

18. The last sentence on page 13 states that "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."

    How can either DOE or NRC staff assure that the conservatisms introduced are (1) truly conservative and (2) sufficient to account for lack of knowledge about the modeling, if the nature of the modeling is not understood as postulated?

ATTACHMENT B

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH
MARK-UP OF INTERNAL DRAFT TP
REPOSITORY DESIGN-THERMAL LOADS

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

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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.

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.

REDUNDANT, ALREADY STATED IN FIRST SENTENCE

~~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). SPECIFICALLY WHERE?

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. OR NOT BE?

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.

EXPLANATION → EXPRESSES WHY WE CHOOSE TO DO A DIFFERENT ANALYSIS. (TO COMPARE)

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 a~~n~~ independent (COMPARATIVE) 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.

REDUNDANT. STATED TWICE ON PAGE 5, ONCE ON PAGE 1

~~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~~ THESE performance objectives.

3.0 TECHNICAL POSITIONS

REDUNDANT, AGAIN

? ~~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 methodOLOGY presented ~~below~~ outlines the steps ~~capable of~~ NECESSARY TO evaluatE ~~ing~~ the adequacy of the underground structure design as it is affected by the thermally induced responses in the host rock, ~~and~~ surrounding strata AND GROUNDWATER SYSTEM. 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] ASSESSING ? 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] AWKWARD 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.

Combined?

PRIOR TO SUBMITTAL OF A LICENSE APPLICATION

3.3 ~~As stated in Section 3.2 above,~~ IF ~~until~~ predictive models NOT can be developed BASED ON A ~~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.

READS AS IF FOR ALL TIME.

4.0 DISCUSSION OF TECHNICAL POSITIONS

The steps outlined in Sections 3.1 through 3.3 DEMONSTRATING represent a methodology acceptable to the NRC Staff for ~~evaluating and determining~~ compliance with 10 CFR 60.133(i). This METHODOLOGY ~~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 methodOLOGY 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~~ THAT may be important to the prediction of the response early in the history of the repository and ~~which~~ 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, 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~~ 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 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~~ CHANGES THAT 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~~ THAT 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.

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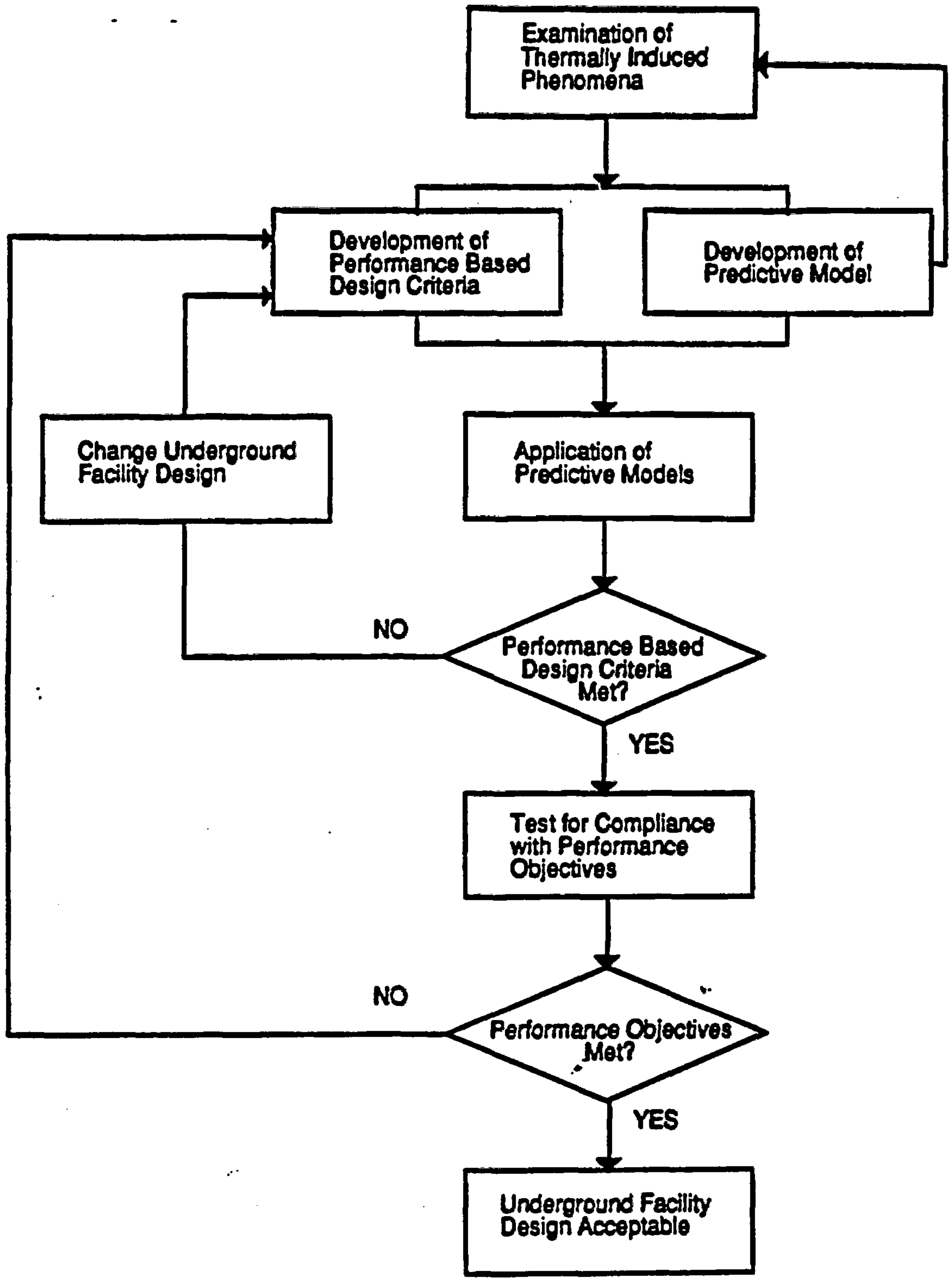

Figure 1. Steps for Compliance Demonstration and Compliance Determination

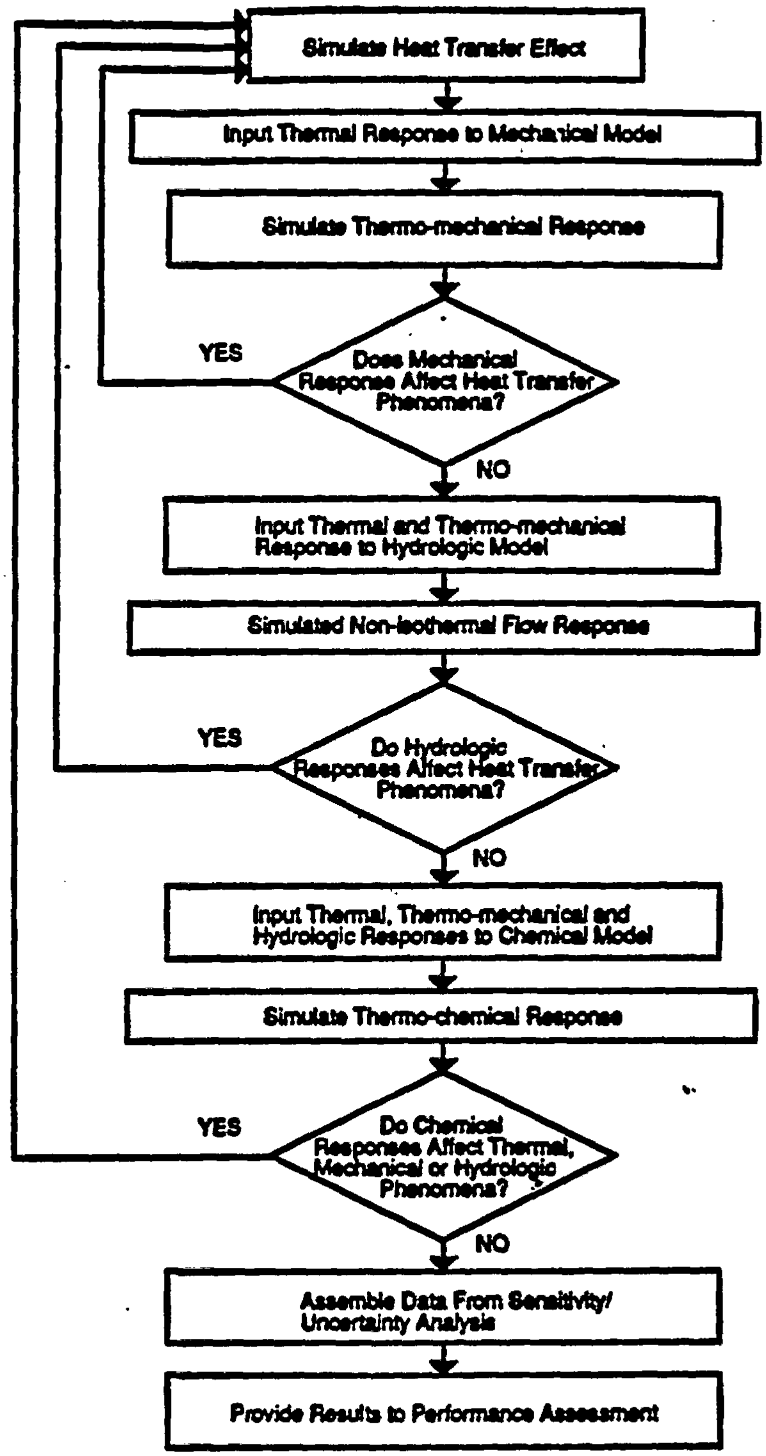

Figure 2. Iterative Process of Analyses

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?

<u>Coherence</u>	Are the main points clear and logically connected? Do they hang together?
<u>Emphasis</u>	Are the main points identifiable? Do the structure and format aid clarity (i.e., is it easy to read)?
<u>Unity</u>	Is the discussion focused?

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