ENCLOSURE 1

SUMMARY OF THE NRC/DOE TECHNICAL EXCHANGE ON THE DRAFT STAFF TECHNICAL POSITION ON "GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS"

March 17, 1992
Albuquerque, New Mexico

On March 17, 1992, staff from the Nuclear Regulatory Commission, the U.S. Department of Energy (DOE), the State of Nevada, and DOE program participants attended a technical exchange for the purpose of discussing how the NRC staff responded to the comments received on the July 1991 public comment draft staff technical position (STP) on "Geologic Repository Operations Area Underground Facility Design -- Thermal Loads." Other Affected Units of Local Government were notified of the meeting, but did not attend. The agenda is attachment 1; attachment 2 is the list of the attendees.

As a focus for the discussions, the NRC staff relied upon a draft comment response package (designated "REV 0") it had prepared as part of the development of the final STP. The comment response package contains the staff's proposed responses to the public comments it had received on the July 1991 public comment draft of the STP. (Unlike the version distributed at the technical exchange, the comment response package attached herein (designated "REV 1") has been revised to reflect comments received from NRC's technical editor (see attachment 3). However, no substantive revisions have been made to the responses themselves.)

In the opening presentation (see attachment 4), the NRC staff described the major elements of the technical positions contained in the STP. The NRC staff provided technical and regulatory background to support its positions regarding the need to develop a defensible methodology to demonstrate the acceptability of a geologic repository operations area (GROA) underground facility design with the requirements of 10 CFR 60.133(i). The NRC presentation concluded with a discussion of how the staff responded to the comments that were received on the public comment draft STP (see attachment 5). Each presentation was accompanied by questions and discussion. Following the NRC presentations, representatives from DOE, DOE program participants, and the State of Nevada provided comments.

For its part, DOE generally questioned the need for the STP by raising concerns in two areas. First, DOE questioned NRC's position regarding the need to develop "fully" coupled models that reflect consideration of the thermal, mechanical, hyrologic, or chemical (T-M-H-C) effects of waste emplacement as part of the GROA design process. DOE argued that the level of T-M-H-C coupling reflected in the GROA design process would be established through its performance assessment program and not as suggested by the NRC staff in its proposed STP. DOE stated that coupling of T-M-H-C effects in models needs to be evaluated to the extent that a potential coupling or linkage is relevant or physically possible. DOE would need to document and justify the effects that are or are not coupled, but DOE has no intention of developing a "fully" coupled model of T-M-H-C effects as a standard for comparison against which linkages could be considered as not relevant.

108.22

In this regard, DOE noted that other international geologic repository disposal programs were yielding results that suggested that the level of T-M-H-C coupling needed to be demonstrated in a particular design was not as extensive as that being recommended by the NRC in its proposed STP, thereby obviating the need for the STP.

The NRC staff responded to this first comment by noting that the level of T-M-H-C coupling to be demonstrated by DOE in its GROA design is a matter for DOE to decide. In a review of a License Application, the NRC staff cautioned that, based on the requirements of 10 CFR Part 60, DOE would need to defend its design decisions on what level of T-M-H-C coupling DOE chose to consider in a particular GROA design including those aspects of T-M-H-C coupling DOE chose to discount. In order to assure that there was no confusion on this point, the NRC staff indicated that it will review the draft STP to determine if additional description or modification to the language in the STP is needed to clarify the staff's expectations. As a point of clarification, the staff would eliminate the use of the adjectives "fully" and "partially" in reference to models and/or processes.

Second, DOE argued that the "disturbed zone" concept described in 10 CFR 60.2 and the containment period requirement, 10 CFR 60.113, appeared to relieve DOE from the need to consider the T-M-H-C effects of waste emplacement owing to the complexity of and uncertainty associated with the analyses in the part of the repository very near to the waste emplacement area.

The staff responded to this second comment by noting that the boundary of the disturbed zone was used only to facilitate calculation of the pre-waste emplacement groundwater travel time subsystem performance objective (10 CFR 60.113(a)(2)), and it was not intended to preempt or simplify consideration of the T-M-H-C effects on GROA design. In addition, the staff pointed out that in order to design the engineered barrier system (including the waste package and its constituent parts per 10 CFR 60.135(a)(1)), an adequate understanding of the near-field thermal environment is necessary.

Overall, DOE reported that it was satisfied with NRC's responses, and that NRC had provided responses to the comments it had submitted.

In a related matter, the NRC staff was also queried on the status of the draft generic technical position (GTP) on the interpretation and identification of the disturbed zone, dated July 1986. The staff noted that this and other older GTPs issued in either draft or final form were undergoing consideration for expungment from the NRC products list owing to their obsolescence, and that the NRC would publish its decision in the Federal Register sometime soon.

ENCLOSURE 1

The State of Nevada's comments regarding the NRC staff responses to its comments on the July 1991 public comment draft are summarized in attachment 6. Overall, the State of Nevada reported that it was satisfied with the staff's responses to it's comments and found them to be responsive. The State concluded that it had no objection if the staff chose to issue the STP in final form.

4.1.92

Michael P. Lee
Repository Licensing and Quality Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety and Safeguards
Nuclear Regulatory Commission

4/8/92

Priscilla Bunton
Regulatory Integration Branch
Office of Systems and Compliance
Office of Civilian Radioactive Waste Management
U.S. Department of Energy

ATTACHMENT 1

AGENDA
NRC/DOE TECHNICAL EXCHANGE ON DRAFT STAFF TECHNICAL POSITION (STP) ON GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS

AGENDA ITEM	DISCUSSION LEAD
- Opening Remarks	NRC, DOE, State
- NRC Final Draft STP - Introduction - Staff Technical Positions	NRC
- NRC Staff Discussion of Responses to Public Comments	NRC
LUNCH	
- Comments by DOE	DOE
- Comments by the State of Nevada	State
- Open Discussion	All
- Closing Remarks	All

ATTACHMENT 2

ATTENDEES AT THE MARCH 17, 1992, NRC/DOE TECHNICAL EXCHANGE ON DRAFT STAFF TECHNICAL POSITION ON GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS

DOE
P. Bunton
T. Bjerstedt
J. Boak
C. Einberg
A. Berusch
D. Harrison-Giesler

TESS**
S. LeRoy
M. Lugo
R. Datta
B. Distel
B. Packer
W. Matysriela
M. Reeves
C. Johnson

SAIC+
U. Park
C. Pflum
R. Morissete

SNL+++
E. Ryder
T. Blejwas

USGS#
R. Wallace
D. Hoxie

BNL###
T. Sullivan

NRC
M. Nataraja
M. Lee

CNWRA*
S. Hsuing
R. Manteufel

ITASCA
T. Brandshaug

State of Nevada
C.A. Johnson

LLNL***
T. Buscheck
R. van Konynenburg

LANL++
D. Bish

Weston
C. Noronha
H. Minwalla
D. Rasmussen
H. Cleary

NWTRB##
R. Luce
R. McFarland

* Center for Nuclear Waste Regulatory Analyses
** TRW Environmental Safety Systems
*** Lawrence Livermore National Laboratory
\+ Science Application International Corporation
++ Los Alamos National Laboratory
+++ Sandia National Laboratory
\# U.S. Geological Survey
\## U.S. Nuclear Waste Technical Review Board
\### Brookhaven National Laboratory

APPENDIX D
DISPOSITION OF PUBLIC COMMENTS

Note: Throughout this comment response package, "STP" refers to the staff technical position noticed in the Federal Register on July 22, 1992 (56 FR 33478).

DEPARTMENT OF ENERGY (DOE) COMMENTS
GENERAL COMMENTS

Over the past ten years, the U.S. Nuclear Regulatory Commission (NRC) staff has urged the U.S. Department of Energy (DOE) to assess the coupled thermal (T), mechanical (M), hydrological (H), and chemical (C) [(T-M-H-C)] responses associated with a geologic repository. In response, the Yucca Mountain Site Characterization Plan (SCP) stated that although not completely defined, tests will investigate coupled interactions (page 8.3.2.1-14). Also, in our Exploratory Shaft Facility (ESF) Alternatives Study, we examined different testing layouts and chose one that would accommodate most testing programs, including tests for coupled interactions. Test Planning Packages and the Title II design of the ESF should give the NRC staff more information, but we have no immediate plans to examine coupled interactions at the level of detail that the draft Staff Technical Position (STP) recommends.

The STP outlines a step-wise approach by which the T-M-H-C assessment would be accomplished. It is a demanding approach entailing many computer codes whose development will push DOE well beyond the state-of-the-art. Ultimately, the NRC staff expects DOE to "... demonstrate a comprehensive, systematic, and logical understanding of the coupled T-M-H-C responses associated with a particular geologic repository operations area (GROA) underground facility design." (page 1). We seriously doubt that the staff's expectations will be realized, at least within the next five to ten years.

The STP does not convince us that a fully coupled model is needed for demonstrating compliance with 10 CFR 60.133(i) or, for that matter, any requirement in 10 CFR Part 60. We believe that simplified models would work as well, if not better. The STP does not explain what makes a model "fully coupled." An example would be helpful. The STP voids the NRC's justification for requiring a disturbed zone and a containment period. Both were justified because they permitted simplified analyses, not the highly complex and possibly unattainable analyses that the STP expects.

We suggest that the NRC staff limit this STP to one-way thermomechanical coupling as the title suggests, as other NRC guidance (NUREG/CR-5428) has done, and as 10 CFR 60.133(i) requires. We discourage the staff from pursuing fully coupled models at least until the staff and DOE know more about them.

The STP lacks a regulatory basis. It cites the requirements that supposedly require an assessment of coupled processes, yet the terms "coupled processes" or "fully coupled models" never appear in 10 CFR Part 60, in the draft rule, or in the supplementary and background information. To the contrary, NRC sought to avoid analyses of these highly complex and uncertain interactions. To do so, NRC confined thermally driven phenomena to the "disturbed zone;" a portion of the host rock for which DOE could not take credit. Likewise, NRC required containment until the thermal loads subside. By doing so, NRC sought to simplify DOE's evaluation of the repository's performance. In short, by requiring a "... comprehensive, systematic, and logical understanding of the coupled T-M-H-C responses," this STP voids NRC's justification for requiring a disturbed zone and a containment period.

The STP is too generic and lacks pertinent details to meet its stated purpose. The acceptable methodology for demonstrating compliance with 10 CFR 60.133(i), as described on pages 7-10, is incomplete and lacks some crucial details of acceptable method for decision making, especially in the case where the available information will reflect large uncertainty at the programmatic and technical decision points shown in Figure 1.

On pages 1-5 of the STP, the expectations of the NRC staff at each stage of the program such as Construction Authorization, Construction, Waste Acceptance, Performance Confirmation Monitoring, and Closure, are not clearly stated. The text switches back and forth between these various stages of the program leaving the reader somewhat confused about the various expectations. It would be useful to the designers and modelers of the repository if the expectations of the NRC staff were stated clearly at each stage of the program.

RESPONSE

Regulatory requirement 10 CFR 60.133(i) is one of several criteria for the design of the underground facility. It requires that the underground facility for the geologic repository operations area 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. This regulation specifically refers to the groundwater in the context of thermal loads and the design of the underground facility. The effect of temperature on the groundwater must, therefore, be considered. Because the hydrology/radionuclide-transport is "tied" strongly to the in-situ geochemistry, it becomes necessary to include chemical effects in the evaluation of the thermal load, to the extent that it has an impact on the repository performance. Therefore, the staff believes that the compliance evaluation of 10 CFR 60.133(i) should include an investigation of thermally-induced M-H-C effects. This STP provides an acceptable methodology to demonstrate compliance with 10 CFR 60.133(i).

The governing principle that serves as the foundation for the STP is that to demonstrate compliance with 10 CFR 60.133(i), DOE needs to consider thermal coupling of processes in a manner that is not likely to underestimate the unfavorable aspects of repository performance or overestimate the favorable aspects in the context of design and analyses.

DOE's general comment states that the guidance in the STP is too demanding, and therefore, DOE does not think that NRC's expectations will be fulfilled. However, the staff believes that the technical positions expressed in Sections 3.1, 3.2, and 3.3, when considered collectively, provide guidance and a realistic approach for dealing with the complexities of coupled processes in light of the principle stated above. The text of the STP shows ample recognition of the difficulties involved in developing defensible predictive models, and has provided alternative approaches (see Technical Position 3.3) for dealing with the long time periods that must be considered. This STP also emphasizes the progressive development of predictive models. As more information is gathered, and mechanistic understanding advanced, the capability of the predictive models is expected to evolve progressively at different stages of the underground facility design, construction, and operations. The staff believes that such an approach would be achievable, but only if DOE makes an early commitment to its implementation.

The staff does not have any insight to support the assertion that "Simplified models would work as well, if not better," as mentioned in the DOE general comment, than "fully coupled" models. However, if DOE substantiates that its use of such models is consistent with the principle stated above, the staff has no objection to the use of such models in demonstrating compliance with 10 CFR 60.133(i). The staff notes that DOE finds the definition of "fully-coupled" models in this STP to be "unconventional" and "ambiguous," and suggests that this term be defined in more detail. In response to this comment, the staff has made the following revisions to the STP:

(1) replaced the term "fully coupled" models with the term "coupled" models;

(2) replaced the terms "partially coupled," and "one-way coupled" models with the term "simplified" models; and

(3) defined "coupled" models and "simplified" models.

In the context of thermal load considerations, coupled behavior means that each of the T-M-H-C processes has an effect on the initiation and propagation of any of the other processes and vice versa. A coupled model can represent such an interactive behavior. A simplified model is an approximation of a coupled model that may ignore some of the processes and their interactions.

The DOE asserts that this STP voids NRC's justification for requiring the "disturbed zone." The staff points out that the boundary of the "disturbed zone" (see 10 CFR 60.2) is used to facilitate the calculation of the pre-emplacement groundwater travel time (10 CFR 60.113(a)(2)). The disturbed zone boundary will need to be established during the site characterization phase on the basis of an understanding of physical and chemical changes within the rock surrounding the waste emplacement area as a result of underground facility construction and heat (thermal load) generated by emplaced radioactive waste. It should be noted that the "disturbed zone" concept is only associated with one of the six performance objectives; other performance objectives must also be complied with. Compliance with these other performance objectives would also need an understanding of the thermally induced responses and their associated uncertainties. Therefore, the staff believes that the "disturbed zone" concept does not relieve DOE from considering thermal impacts and associated uncertainties on repository performance. (For a related discussion on this issue, the DOE is referred to the staff's response to the DOE Specific Comment No. 2.)

The DOE general comment implies that, because the waste packages are to be designed for a containment life of 300 to 1000 years at the end of which time the thermal loads would have subsided, there is no need to understand the near-field environment of the waste packages. However, the staff believes that the understanding of the near-field T-M-H-C environment would contribute to the design of the engineered barrier system (EBS), in particular, the thermal loads aspect of the underground facility design. Therefore, the staff disagrees with DOE's contention that the containment period provision of the rule relieves DOE of a need to understand and analyze the T-M-H-C processes that affect the waste package performance.

Regarding the need for coupled models, the staff maintains that DOE should develop models to predict the thermal impacts based on a mechanistic understanding of T-M-H-C interactions, to the extent practical and necessary. There are plausible conditions under which T-H-C effects can result in changes to a repository host rock environment (Lin and Daily, 1989). The staff's intent is that a logical approach be used to predict the M-H-C response of the system to the maximum design thermal loading. The "level of coupling" that needs to be considered should be determined from an established technical basis. It is not the intent of the staff to <u>require</u> DOE to develop a highly complex numerical code from the T-M-H-C coupled model, regardless of a need. The staff believes that, while simplified models are necessary and useful, they may not be sufficient to demonstrate the adequacy of the underground facility design to meet the requirements of 10 CFR 60.133(i). NUREG/CR-5428 (Brandshaug, 1989) referenced by DOE in its general comment, is strictly a description of a three-dimensional analysis of the single process of transient conduction heat transfer in the host rock in the vicinity of waste packages and storage rooms. It neither contains an evaluation of thermally induced mechanical effects (i.e., T-M) as mentioned in the DOE general comment, nor does it consider the combined effects of heat and water, which may be important to EBS design. The sole purpose of this reference in the STP is to provide a specific example of the process of performing analyses and comparing the results of these analyses to "design goals" (i.e., Step Nos. 6 and 7 in Figure 1) over a range of design conditions. The reference should in no way be construed to mean that the staff endorses the single process model used in the report.

The staff provides the following response to the DOE comment regarding a lack of regulatory basis for this STP. As stated earlier in the staff's response, regulatory requirement 10 CFR 60.133(i) is one of several criteria for the design of the underground facility. It 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. This regulation specifically refers to the groundwater in the context of "thermal loads" and the design of the underground facility. The effect of temperature on the groundwater must, therefore, be considered. Because the hydrology/radionuclide transport is "tied" strongly to the in-situ geochemistry, it becomes necessary to include chemical effects in the evaluation of the thermal load, to the extent that it has an impact on the repository performance. Therefore, the staff believes that the compliance evaluation of 10 CFR 60.133(i) should include an investigation of thermally-induced M-H-C effects.

The requirement in 10 CFR 60.133(i) alone provides the necessary and sufficient regulatory basis for this STP. However, there are other regulatory requirements that provide additional basis. For example, in 10 CFR 60.21(c)(1)(i)(F), the content of the license application is specified to include "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." Such an evaluation of thermal responses should be based on an understanding of the T-M-H-C processes, and their interactions. Therefore, the staff disagrees with DOE that the STP lacks a regulatory basis.

The staff does not agree with DOE that "The STP is too generic and lacks pertinent details to meet its stated purpose." It is the staff's intent in this STP to outline an acceptable methodology for demonstrating compliance with 10 CFR 60.133(i) without unduly constraining DOE in its choice of methods that may be used in implementing the intent of the STP. This approach identifies several programmatic and technical decision points to facilitate the process for compliance demonstration. The methods that may be used for decision-making at each decision point should be selected by DOE under the premise that they are defensible and consistent with the overall repository design and performance assessment philosophy and strategy. Regarding the DOE concern on "...decision making... where the available information will reflect large uncertainty...," it is the staff's position that DOE should apply appropriate conservatism in its design and performance calculations, so that NRC will be able to make the necessary findings, under 10 CFR 60.31, with reasonable assurance.

Regarding DOE's comment related to the staff's expectations not being clearly stated in the STP, the following clarification is provided. The staff expects at the time of construction authorization that DOE clearly demonstrate that the models used to predict thermal responses are not likely to underestimate the unfavorable aspects of repository performance or overestimate the favorable aspects, in the context of design and analyses. Subsequently, the underlying assumptions used in the projected performances should be confirmed, during the period of performance confirmation, by appropriate continued testing and/or model refinements.

SPECIFIC COMMENTS

1. Page iii, "Abstract"

> The NRC staff anticipates that the methodology to demonstrate compliance with 10 CFR 60.133(i) "... will require development of fully coupled models." No such requirement appears in 10 CFR 60 nor has this STP justified the need for one. Moreover, STPs cannot "require" but may recommend or suggest a particular approach.

RESPONSE

With regard to the first portion of DOE's specific comment, DOE correctly notes that STPs do not express requirements per se. Rather, as noted in Section 1.3, STPs express staff positions and recommendations. The staff also agrees that 10 CFR 60.133(i) does not explicitly "require" the development of coupled models. However, as discussed in the response to DOE's "General Comments," the staff believes that a demonstration of compliance with 10 CFR 60.133(i) would need to be based on an understanding of thermally-induced M-H-C effects, on the repository performance, associated with a given thermal load. The staff further believes that such understanding would need to include an assessment of the importance of coupled processes in quantifying the extent of these effects before such need can be dismissed.

At the present time in the repository program, with limited site-specific information, it is not clear what level of coupling (if any) will be adequate in expressing the anticipated thermally-induced M-H-C responses associated with a thermal load. From the viewpoint of the NRC staff, it seems prudent that an approach to deal with compliance with 10 CFR 60.133(i) should not dismiss the need to take account of coupled processes, before such a need has been investigated. As a result, therefore, the staff considers it prudent to follow a conservative course of recommending the use of coupled models in the demonstration of compliance with 10 CFR 60.133(i).

However, in view of the fact that the term "require" has a potential to be misinterpreted as a regulatory requirement, the "Abstract" has been changed to reflect this by replacing the phrase "... will require development ..." with "... will include evaluation and appropriate development ...." Moreover, it is expected that DOE would investigate the attendant coupled T-M-H-C effects commensurate with the uncertainties generated as a result of a given thermal load.

2. Page 2, Section 1.1, "Background"

The STP states, "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." According to 10 CFR 60.2, thermal loads that "may have a significant effect on the performance of the geologic repository" are confined to the "disturbed zone." Provisions at 10 CFR 60.113(a)(2) exclude this thermally disturbed rock from the calculation of ground water travel time, i.e., the calculation cannot take credit for the rock within the disturbed zone. By creating a disturbed zone, NRC relieved DOE from having to understand the uncertainties associated with predicting thermal loads. NRC justified a disturbed zone because physical and chemical processes therein "are especially difficult to understand in the area close to the emplaced wastes because that area is physically and chemically disturbed by the heat generated by those wastes." (46 FR 35281)

Likewise, NRC requires containment for at least 300 to 1,000 years because during this time, decay heat would drop three orders of magnitude. (Ibid.) NRC wanted containment "during the period when the thermal conditions around the waste packages are most severe ... [so that] ... evaluation of repository performance ... [would be] ... greatly simplified ...." (Ibid.). The rationale for 10 CFR Part 60 elaborates:

> "During this critical [thermal] period the uncertainties in predicting release rates are very great. Even if we did understand the mechanisms completely, the data scatter increases with temperature so that test programs to gather the data to narrow the uncertainties to reasonable bounds are very cumbersome." (NRC, 1983, p. 472)

This STP burdens DOE with the types of assessments that NRC sought to avoid. The STP would have DOE assess the fully coupled thermal, hydrological, mechanical, and chemical processes, plus all uncertainties. But NRC sought to avoid these assessments by confining these processes to a disturbed zone and by requiring that the waste be contained until the processes have attenuated. If DOE must provide the information that this STP requests, there is no longer any justification for 10 CFR Part 60 to require a disturbed zone or a containment period.

It is also worthwhile to note that other uncertainties in the overall systems, such as the model and parameter uncertainties and the highly uncertain probability and consequences of human intrusion, far outweigh the uncertainties resulting from the use of uncoupled or partially coupled models.

The NRC staff should state that this STP does not apply to the rock within the disturbed zone nor does it apply during the containment period. The disturbed zone includes "that portion of the controlled area the physical or chemical properties of which have changed as a result of ... heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository" (10 CFR 60.2). The containment period would last, at the minimum, 300 to 1,000 years.

We must add, however, that if the STP applies after the containment period and only to the rock beyond the disturbed zone, most of the guidance would be irrelevant. When attenuated in time and space, thermal loads and gradients as well as fully coupled T-M-H-C processes would not significantly affect the repository's long-term performance.

RESPONSE

In its specific comment, DOE seeks to dismiss the need to understand the effects of thermally-induced M-H-C processes and the uncertainties associated with those processes in dealing with the underground facility design. It is stated that the "disturbed zone" concept (10 CFR 60.2) and the "containment period" requirement (10 CFR 60.113(a)(1)(ii)(A)) were introduced by NRC to relieve DOE from such understanding.

The boundary of the "disturbed zone" is used to facilitate the calculation of the pre-emplacement groudwater travel time (10 CFR 60.113(a)(2)). The disturbed zone boundary is established during the site characterization phase, on the basis of an understanding of physical and chemical changes within the rock surrounding the waste emplacement area. While necessary for all conceptual designs, understanding of the character and extent of the disturbed zone is particularly important in those design options that call for elevated temperatures being maintained for extended time periods. Whereas the pre-waste emplacement groudwater travel time calculation is associated with one of the six performance objectives, 10 CFR 60.133(i) deals with all six performance objectives. The design of the waste package that deals with two other subsystem performance objectives (e.g., 60.113(a)(1)(ii)(A-B)) and contributes to the overall performance of the repository (under 10 CFR 60.112), requires a clear understanding of the near-field environment (which is contained within the disturbed zone). The staff refers DOE to 10 CFR 60.135(a).

In view of the aforementioned discussion, the staff disagrees with DOE's interpretation that the "disturbed zone" concept relieves DOE from considering thermal impacts on repository performance in the pre- and post-closure periods, as specified in 10 CFR 60.133(i). The staff believes that a prudent evaluation of thermal impacts would also include an assessment of the effects of uncertainties, which should be incorporated into the underground facility design.

The staff further believes that the understanding of the near-field T-M-H-C environment would contribute to the design of the EBS, in particular, the thermal loads aspect of the underground facility design. The capacity of a canister to contain waste depends on, among other things, the local environment of the canister. Under different environments, the rate, mechanism, and processes of canister degradation may be different. Therefore, assessment of the performance of substantially complete containment must rely on the understanding of the T-M-H-C processes at the container-scale, including an understanding of the importance of the effects of coupled processes and related uncertainties.

The staff recognizes that there are other potential uncertainties associated with the overall system, as indicated in DOE's comment; some of them may very well outweigh the uncertainties resulting from the use of predictive models for thermal loads. However, this is not to say that an understanding of the thermally induced phenomena is not necessary. It is the staff's contention that DOE first will have to demonstrate that the uncertainties associated with thermal load consideration is indeed less important and, second, to demonstrate that reasonable assurance for compliance with the performance objectives will still be obtained without quantifying and/or reducing these uncertainties. Until such time, the staff considers that it is appropriate and necessary to obtain a better understanding of the T-M-H-C effects on the repository performance.

The unsubstantiated assertion, as expressed in this comment ("When attenuated in time and space, thermal loads and gradients as well as fully coupled T-M-H-C processes would not significantly affect the repository's long-term performance") reinforces the staff's view regarding the need for the current STP. The staff's concern is that the DOE statement conveys the notion that DOE's current understanding of the T-M-H-C processes associated with a thermal load is sufficient to proceed with the design of the underground facility, even before site characterization, and before a reference thermal load has been established and its effects have been evaluated.

3. Page 3, Section I.I, "Background"

In line 5 and elsewhere the STP references heat-induced effects on groundwater flow. The STP should also acknowledge the possibility for steam generation and water-vapor transport. Otherwise, the term "ground water" could be interpreted narrowly to mean only liquid-phase transport.

RESPONSE

It is conceivable that the level of the thermal load will be sufficiently high to induce rock temperatures that result in boiling of porewater. Accordingly, the meaning of the term "flow" in the STP has been expanded to include both liquid- and vapor-phase transport.

4. Pages 3 and 4, Section 1.1, "Background"

The STP states that for "repository-generated thermal regimes that are beyond the range of current engineering experiences," the use of existing models as a first step in establishing an expected range of effects of thermal loads is "not satisfactory" unless there is "a programmatic need for evaluation of such thermal loads."

This STP should not discourage the use of established models in preliminary programmatic evaluations of thermal loadings. Some established models would be useful in sensitivity and tradeoff studies.

Also, the above passage contradicts statements made on page four that state that an initial understanding of thermally induced phenomena is expected to be gained from the use of models, that are reasonably available. The guidance stated above is hardly new, and does not contribute to a demonstration of compliance. There is a need to demonstrate what the thermal loads are, the effects of those loads, and whether the effects are significant to performance and/or design. (Thermomechanical testing is described in SCP section 8.3.1.15.)

RESPONSE

The STP does not discourage the use of existing models as long as they are reliable (refer to Step No. 2 in Technical Position 3.1). Some "established" models may be reliable, and therefore, could be useful in sensitivity and tradeoff studies. The staff notes that DOE finds an apparent contradiction in the STP text between STP Sections 1.1 and 1.2. However, in an effort to avoid the potential for misunderstanding in the future, the third, fourth, and fifth paragraphs of Section I.I have been combined and revised as follows:

"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 evaluate 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, may produce effects that involve prediction considerations that are well beyond current engineering practice. For such situations, the use of an existing model, to predict the likely repository effects of such loads, may not be satisfactory. 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 investigate and evaluate the effects of coupled processes in the predictions of the underground facility performance."

5. Page 3, Section 1.1, "Background"

In the second paragraph, the authors of the STP appear to believe that DOE will make a decision that results in an extraordinarily high repository-generated thermal regime. This may be a reflection of NRC using available but outdated information on repository conceptual design in the Conceptual Design Report or in the Site Characterization Plan (SCP), Chapters 6 and/or 7. Currently, there is no reference waste package design or heat load. DOE is currently reviewing EBS concepts. Even if this assumption was true and DOE developed "state-of-the-art" models, how would NRC independently evaluate the unproven methodology?

RESPONSE

The recommended approach adopted in the STP is generic in nature. It was not formulated using information on the repository conceptual design contained in DOE's Conceptual Design Report (MacDougall and others, 1987) nor in SCP Chapters 6 and 7 (DOE, 1988a and 1988b). The recommended approach requires a determination of whether there is a sufficient scientific understanding and/or engineering experience to conclude that the performance objectives are insensitive to the effects of thermal loading. To make such a determination it is self-evident that parameters such as waste package design and thermal load will need to be considered.

The staff notes that, at this time, DOE does not have a reference thermal load or an EBS design, as asserted in its comment. The staff also notes that this comment does not appear to be consistent with DOE's assertion in the Specific Comment No. 2, which expresses that "When attenuated in time and space, thermal loads and gradients as well as fully coupled T-M-H-C processes would not significantly affect the repository's long-term performance." To make such an assertion, it would seem that DOE would need to have reliable models, and appropriate design and site-specific input parameters (for example, the level of the thermal load).

Finally, in response to DOE's question regarding how NRC would develop an independent review capability, it should be noted that NRC has an ongoing research activity to investigate and examine thermally induced phenomena, including T-M-H-C coupled effects, and also, NRC is actively participating in an international joint effort on developing coupled predictive models, referred to as DECOVALEX (an acronym for "International Cooperative Project for the DEvelopment of COupled models and their VALidation Against EXperiments in Nuclear Waste Isolation"). These activities are part of NRC's plans to develop an independent capability for the purpose of determining compliance with 10 CFR 60.133(i).

6. Page 4, Section 1.1, "Background"

The second sentence states, "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."

This statement gives DOE flexibility, but it is inconsistent with the rest of the STP. Overall, the STP implies that fully coupled models and an understanding of fully coupled processes are required. For example, the STP recommends a methodology which "is based on an expected understanding of the fully coupled effects of thermally induced phenomena" (Section 3.0). Apparently, the staff believes that only fully coupled models can produce reliable information. We believe that reliable information can be obtained from simplified uncoupled or partially coupled models and codes.

RESPONSE

The staff does not have any insight to support the assertion "... that reliable information can be obtained from simplified uncoupled or partially coupled models and codes." However, if DOE substantiates that the use of such models is consistent with the principle stated in the second paragraph of the staff's response to DOE's "General Comments," the staff has no objection to the use of such models. This concept is described in Step No. 2 of Sections 3.1 and Section 4.1, respectively, of the STP.

7. Page 4, Section 1.2, "The Use of Models in Thermal-Response Predictions"

The third sentence of the first paragraph states, "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." The staff expects fully coupled models "by the time of application for the license to receive, possess, and emplace waste...."

If NRC finds, with reasonable assurance, that the models are sufficient at the time of construction, there is no reason to develop fully coupled models at the time of licensing. Up until the repository is closed, we will continue improving our models and our understanding of coupled responses. But is it premature for the staff to expect that the processes will ever be fully understood and that these models will be fully coupled.

RESPONSE

The staff disagrees with DOE's specific comment, that the STP conveys an expectation of DOE to develop coupled T-M-H-C models "by the time of application for the license to receive, possess, and emplace waste...." Rather, Section 1.2 of the STP expresses an expectation of progressively better understanding the M-H-C responses associated with the repository thermal load, and that this understanding be reflected through the development of new predictive models. This expectation seems to be consistent with the idea expressed in the second sentence of the second paragraph of DOE's specific comment. It is certainly conceivable that "This could result in more comprehensive models (e.g., fully-coupled models) by the time of application for license to receive, possess, ... , and, subsequently, an application for license amendment for permanent closure."

Furthermore, the staff would like to clarify the points raised in the second paragraph in DOE's specific comment. At the time of issuance of license for construction, the judgment of reasonable assurance may very well rely on projections of performance, together with a proposed performance confirmation program required under 10 CFR 60.137. Then, as the repository program moves along, further information will be obtained through confirmation of the understanding of the site and the ability to predict thermal and thermomechanical responses of the host rock, surrounding strata, and groundwater system. It is entirely possible that there is no need to further develop predictive models after the construction authorization stage, so long as DOE can demonstrate in the License Application that there is no such need. Otherwise, DOE may be required to provide in its License Application "... a detailed description of the programs designed to resolve safety questions ....," as stated in 10 CFR 60.21(c)(ii)(F)(14) and explained in Section 1.2 of the STP.

Whether or not a construction authorization will be granted depends on the nature of the unresolved safety questions. As part of the performance confirmation program (see Subpart F of 10 CFR Part 60), the staff expects model development/refinement to continue as needed. The need for development/refinement of models should be viewed in the context of confirming the projected performance used in arriving at reasonable assurance at the time of construction authorization.

8. Page 7, Section 3.0, Staff Technical Positions

The fourth sentence states that the staff's approach for demonstrating compliance with 10 CFR 60.133(i) "is based on an expected understanding of the fully coupled effects of thermally induced phenomena."

The protection of public health and safety and compliance with 10 CFR Part 60 do not necessarily depend on understanding the fully coupled effects of thermally induced phenomena. The restricted spatial and relatively short temporal extent over which the coupled effects are significant, combined with other precautions mandated by the regulations (i.e., the disturbed zone and a containment period), remove the necessity to fully understand coupled effects. From our reading of the regulations, we conclude that a safety analysis need only demonstrate that thermal loads will not adversely affect the design of the underground facility, and that the design will not preclude compliance with the performance objectives.

RESPONSE

The staff response to this specific comment has already been addressed in its responses to DOE's "General Comments" and Specific Comment No. 7. Although a complete understanding of coupled processes may never be fully realized, the staff maintains that understanding of the T-M-H-C processes should be pursued, consistent with the principle stated in paragraph 2 of the staff's response to DOE "General Comments." Thus, the "disturbed zone" concept (10 CFR 60.2) and the "containment period" requirement (10 CFR 60.113(a)(1)(ii)(A)) do not relieve DOE from pursuing an understanding of T-M-H-C processes in the context of the overall repository. Section 60.133(i) is specific in the requirement that "... the underground facility shall be designed so that the performance objectives will be met ...." The staff regards this statement as "proactive," which implies that the design process is impacted directly by the requirement. For example, design goals/criteria that are correlated to the performance objectives are established to ensure that the design will meet the performance objectives. On the contrary, if the requirement were as DOE suggests, the design process may not take into consideration the performance objectives, and consequently may face the risk of not meeting the 10 CFR Part 60 performance objectives.

9. Pages 8 to 10, Section 3.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

This section suggests a step-wise approach for developing a fully coupled model which, according to the STP, is needed to demonstrate compliance with requirements for the underground facility at 10 CFR 60.133(i).

Before requesting a fully coupled model, this STP should establish that the model is needed to design an underground facility. The recommended approach does not establish the need for a fully coupled model nor does it explain the degree of coupling that the NRC desires (see our general comments and comments on the definition of fully coupled models). The need for a fully coupled model cannot be simply presumed by the authors.

NRC should at least admit that a fully coupled model is not necessary to resolve all design problems. We recommend that the approach presented in this section expand upon the more sensible approach described in Appendix C, paragraph 4.

RESPONSE

The intent of Technical Position 3.1 is not to develop a fully-coupled model, but to describe an example approach for meeting the requirements of 10 CFR 60.133(i). Elements of the example approach include gaining understanding of the T-M-H-C processes associated with a repository-induced thermal load, and the conversion of this understanding into predictive models. The "expectation" of the staff regarding the need for "fully-coupled" T-M-H-C models has already been commented on in the staff response to DOE's "General Comments" and Specific Comments Nos. 1, 6, and 7.

The need for, and desired level of coupling, depend on what is learned through the examination of thermally-induced phenomena, as indicated in Step No. 3 of Figure 1. Certain levels of coupled processes may turn out not to be important and therefore may be excluded from the predictive models. At the present stage, with limited knowledge on the site information and coupled processes, it is not clear what level of coupling will be adequate. It is expected that DOE will assume the responsibility to advance the state-of-the-art, as appropriate, in its pursuit to understand the importance of T-M-H-C coupled processes.

Finally, the approach described in Appendix C of this STP is intended as an example of a model that could be developed through iterations between Step Nos. 2 and 5 of Figure 1, i.e., gain an understanding, and convert this understanding into a predictive T-M-H-C model. It is not intended to replace the overall concept of the acceptable methodology for demonstrating compliance with 10 CFR 60.133(i). Rather, if DOE can show that this approach satisfies the principle stated in paragraph 2 of the staff's response to DOE's "General Comments," it would be acceptable to the staff.

10. <u>Page 8, Section 3.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"</u>

The proposed approach suggests eight steps that "can be used to demonstrate the acceptability of the underground facility design."

Steps two and four should be reversed. Step two would use existing models to show compliance with 10 CFR 60.133(i), and step four would develop design goals/criteria for the underground facility. Even if the existing models were adequate, they cannot be used to show compliance until after design goals and criteria are developed. Later, the STP says the same, "The purpose of developing design goals/criteria... is ... to contribute to the assurance that the design of the underground facility has the likelihood of meeting these performance objectives" (pages 14 - 15).

<u>RESPONSE</u>

The staff disagrees with DOE's recommendation that Step Nos. 2 and 4 in Technical Position 3.1 should be reversed. The STP text for Step No. 2 states that if reliable predictive models exist, they should be used, and the process proceeds directly to Step No. 4, the development of design goals/criteria (i.e., bypassing Step Nos. 3 and 5). This logic flow is shown in Figure 1. Step No. 2A was included to indicate this alternative path. Thus, Figure 1 shows that compliance with 10 CFR 60.133(i) is facilitated by first developing design goals/criteria for the underground facility.

Because there is no activity <u>per se</u> associated with Step No. 2A, the staff has decided to remove Step No. 2A in Figure 1, without altering the "yes" exit path from Step No.2. In addition, the iterative process indicated by the return from Step No. 5 to Step No. 3 has been changed to indicate an iteration between Step Nos. 5 and 2. The latter change was made so that the approach includes an explicit check of the adequacy of the models as they are developed.

11. Page 8, Section 3.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

Step No. 3 needs to be clarified since it is not apparent if "defensible models" used in Step No. 3 are in fact those "existing models" that will show compliance with 10 CFR 60.133(i), as illustrated in Step No. 2A, Figure 1.

RESPONSE

The staff finds this specific comment to be unclear, since Step No. 3 pertains to the research and development necessary to develop predictive models and not to the "use of defensible" models.

12. Page 9, Section 3.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

In Step No. 8, the incorporation of predicted results in the pre- and post-closure performance assessment models appears to contradict other NRC guidance. NRC has consistently advised DOE to perform preliminary and iterative performance assessments using available models. DOE might be able to perform preliminary performance assessments using the models examined in Step No. 2 or developed in Step No. 5. The NRC's performance assessment staff might think DOE remiss were it not to use these available models. NRC should consider revising the STP in consultation with its performance assessment staff. DOE would appreciate a clarification of guidance on this point as it may apply to other modeling and performance assessment effects.

RESPONSE

The staff does not believe that incorporating the predicted results from the approach outlined in this STP in the performance assessment model(s) contradicts other NRC guidance. The approach described in Technical Position 3.1 and illustrated in Figure 1 clearly suggests that the entire process is iterative (see the loop-back from Step No. 8 to Step No. 3 in Figure 1).

Regardless of which types of models are used for performance assessment, simple or complex, the reasonableness and adequacy of the input data (in this case the results from the predictive T-M-H-C model(s)) are of primary concern. Without a reliable data set, there is no reason to believe that the results generated from the performance assessment models will be reliable. The predictive models developed through the systematic approach outlined in this STP will provide a portion of the input data needed for the performance assessment models. In the context of NRC's iterative performance assessment efforts (NRC, in press), the staff positions advocated in this STP are consistent with this effort.

13. Page 10, Section 3.2, "Development of Detailed Predictive Models"

The STP states, "To the extent practical, DOE should develop models ... based on a mechanistic understanding of fully coupled T-M-H-C behavior."

As commented earlier, NRC has not clearly explained what constitutes a fully coupled model, what these models will accomplish in terms of meeting NRC regulations, or what advantage these models have over simple uncoupled models. In short, NRC has not provided any compelling reason to develop fully coupled models.

Also, this type of fully coupled mechanistic model may be impossible to validate in the classical sense of the term. NRC's performance assessment staff has stated that classical model validation cannot be accomplished for a repository. Consultation with NRC's performance assessment staff should be considered in revising the STP, concerning the listing of scenarios and use or formulation of strategies on how DOE could make a demonstration with reasonable assurance.

RESPONSE

As regards the first portion of this comment, the STP has been revised to reduce the potential for the misinterpretation that might have been created by the use of the phrase "fully-coupled" models.

As regards the second portion of this comment, as previously stated in the staff response to DOE Specific Comment Nos. 1 and 9, the need and desired level of coupling depends on the understanding developed made through the examination of thermally-induced processes as indicated in Step No. 3 of Figure 1. Such a need cannot be simply dismissed without some assessment of the importance of T-M-H-C coupling in evaluating the performance of the repository. Therefore, at this point, whether or not coupled models are better than simple uncoupled models should not be a concern. The main concern should be whether there is sufficient understanding of the in-situ site conditions, including the coupled T-M-H-C processes, to determine what level of coupling (if any) is adequate for demonstrating compliance. For this reason, Step No. 3 of the example approach establishes a requirement to evaluate the need and extent of coupling for development of predictive models.

The comment also raises the issue of validation suggesting that fully-coupled models may be impossible to validate in the classical sense. The staff agrees, but would note that this is also true of models exhibiting lesser degree of coupling. The real issue is whether such models can adequately represent the effects of coupling on repository performance.

14. Page 10, Section 3.3, "Alternative Predictive Models"

This section or the glossary in Appendix A should clarify or provide a precise meaning of "the synergistic effects of T-M-H-C interactions." This phrase is also found on page 18, Section 4.2, first paragraph, last sentence.

RESPONSE

The staff notes that there has been considerable difficulty in interpreting the phrase "synergistic effects of T-M-H-C interactions." In the STP, the staff has used several terms to explain coupled effects (e.g., synergistic effects, interactions). For consistency, these terms have been replaced with the term "coupled effects," the definition of which has been included in the final version of the STP. DOE is directed to the staff's response in the fourth paragraph to DOE's "General Comments," where the staff specifically described the revisions made to the STP in order to clarify these terms.

15. Page 10, Section 3.3, "Alternative Predictive Models"

The suggested action in (a) should be clarified. Models cannot affect performance objectives in any way. They can affect one's ability to demonstrate compliance or the receptivity of a reviewer to the information presented.

RESPONSE

The staff agrees that models cannot affect performance objectives. Accordingly, Section (a) of the technical position has been modified, as suggested in this comment.

16. Page 10, Section 4.0, "Discussion"

The STP repeatedly states that a repository's design must comply with the 10 CFR 60 performance objectives. Here it states, "Also, this methodology [for demonstrating compliance with 10 CFR 60.133(i)] takes into account the performance objective of 10 CFR 60.111, 60.112, and 60.113, all of which must be satisfied by any design." (emphasis added)

Two of the six performance objectives, a repository's overall performance (10 CFR 60.112) and groundwater travel time (10 CFR 60.113(a)(2)) are more oriented towards natural barriers that cannot be designed. Moreover, according to 10 CFR 60.133(i), "The underground facility shall be designed so that the performance objectives will be met ....". Thus the STP should state that the design of the underground facility should not preclude compliance with the performance objectives; rather that the design must satisfy the performance objectives.

RESPONSE

Section 60.133(i) is specific in the design requirement that "The underground facility shall be designed so that the performance objectives will be met ....". The staff regards this statement as "proactive," which implies that the design process is impacted directly by the requirement. For example, design goals/criteria that are correlated to the performance objectives are established to ensure that the design will meet the performance objectives.

The STP is not intended to discuss "natural barriers." Rather, it is a description of an example approach of how to design the underground facility in accordance with 10 CFR 60.133(i). In this context, the design may have an impact on the ability to meet the performance objectives. Thus, considerations must be given in the design (i.e., through design goals/criteria) to meet (as required by 10 CFR 60.133(i)) these performance objectives. For further elaboration on this point, DOE is referred to the staff's response to DOE's

"General Comments."

17. <u>Page 11, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"</u>

The first paragraph states that "a decision will be made if the thermal loads have significant impacts on the performance of the geologic repository." Later, the STP states that this would be an early "programmatic" decision.

Since fully coupled models do not exist (and probable never will), early programmatic decisions must be based on the results of simplified models. DOE recommends that the NRC staff explicitly connect early decisions with simplified models.

<u>RESPONSE</u>

The staff recognizes the need to make preliminary programmatic decisions based on existing models. If these models reflect the understanding and experience that are necessary to make a finding that a 10 CFR Part 60 performance objective is insensitive to the effects of thermal loading, and the models used are reliable and defensible, then the need for more sophisticated models is eliminated, as noted in the STP. (Also see the staff response to DOE Specific Comment No. 4.)

18. <u>Page 11, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"</u>

These are six performance objectives, not three as stated in the second paragraph, second sentence.

RESPONSE

The three 10 CFR Part 60 performance objectives referred to in the STP are 10 CFR 60.111, 60.112, and 60.113. The staff acknowledges the need to clarify the STP in this area and has modified the text accordingly.

19. Page 11, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

That performance assessment takes place, as stated in the STP, only after all design goals/criteria have been met, is inconsistent with the advice given to DOE by NRC. Performance assessment only at the end of the process would be too late, particularly if goals and criteria can be met, but performance objectives may not be met. The STP should be clarified on this point.

RESPONSE

Regarding the first portion of DOE's specific comment, the example approach described in Technical Position 3.1 and illustrated Figure 1 clearly suggests that the entire process is iterative (see loop-back from Step No. 8 to Step No. 3 in Figure 1). The text to which DOE refers in Section 4.1 ("Discussion") speaks of the sequence of the process within one iteration. The staff disagrees with the DOE contention that the approach is inconsistent with previous advice given to DOE by NRC.

Regarding the second portion of DOE's specific comment, DOE is directed to the text in Step No. 4 of Section 4.1, which expresses that "... design goals/ criteria ... correlated to the repository performance objectives are expected to be essential in the development of the underground facility design." An approach to developing the performance-based design goals/criteria is suggested by the Steps (a) through (c) in Section 4.1. Although not explicitly stated, Step (c) in this approach may very well include an evaluation of the design goals/criteria by a performance assessment model(s). The specific procedures by which this is accomplished is left up to DOE.

However, in view of DOE's overall comment, the first sentence of Paragraph 3 of Section 4.1 has been changed to read as follows:

> "For each iteration, the fourth evaluation point, performance assessment evaluation (Step No. 8 of Figure 1), takes place after all the underground facility design goals/criteria have been satisfied."

20. Page 12, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

The second paragraph states, "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."

Other than the first step, Figure 1 does not indicate decision points at which the process may be terminated. Either add these decision points or do not say that they are present.

RESPONSE

The staff agrees that the flow logic shown in Figure 1 for Technical Position 3.1 does not indicate any decision points for termination of the process other than the first step. Consequently, the 5th paragraph of Section 4.1 ("Discussion") has been deleted from the STP.

21. Page 13, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

At Step No. 3, the first paragraph, last sentence states, "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."

NRC should define "phenomenological coupling" and specify the degree of coupling desired. For example, does the staff want only direct couplings or both direct and crossed couplings? As commented earlier, the staff has not established a need for such a detailed assessment particularly when the total number of direct and crossed couplings are so numerous. If the staff can justify an assessment of phenomenological coupling, the assessment should be limited to direct couplings.

RESPONSE

The staff notes the concerns raised with the use of the term "phenomenological." Accordingly, this term has been deleted from the STP and the sentence in question has been modified to read as follows:

"This understanding would include an assessment of the level of coupling that may be necessary between processes to reasonably predict the responses."

Also, a definition of "coupled behavior" is now provided in the STP as well as in the "Glossary." (For a description of what is meant by "coupled behavior," see the staff's response to DOE's "General Comments.")

22. Page 16, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

At Step No. 6, the STP cites NUREG/CR-5428 (Brandshaug, 1989) as an example of "heat-transfer predictions." This citation conflicts with previous text where the STP expects an understanding of "fully coupled effects of thermally induced phenomena" (page seven). Brandshaug's model only represents the one-way T-M coupling. We recommend that NRC reconcile the conflict by acknowledging that valuable insight can be gained by using simplified models.

RESPONSE

The reference in the STP to NUREG/CR-5428 is strictly intended as a description of a three-dimensional analysis of the single process of transient conduction heat transfer in the host rock in the vicinity of waste packages and storage rooms. The reference does not contain an evaluation of thermally-induced mechanical effects (i.e., T-M), as mentioned in DOE's "General Comments," nor does it consider the combined effects of heat and water, which may be important to the EBS design. The sole purpose of the use of this reference in the STP is to provide a specific example of performing analyses and comparing the results of these analyses to "design goals" (i.e., Step Nos. 6 and 7 in Figure 1) over a range of design conditions. The reference should in no way be construed to mean that the staff endorses the single process model used in the report.

Therefore, the staff does not consider that any conflict exists, as suggested by DOE in its specific comment.

23. Page 17, Section 4.1, "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 60.133(i)"

At Step No. 9, the second sentence states that the final step is reached "when the design goals/criteria as well as the performance objectives have been satisfied ... [then] ... it can be concluded that 10 CFR 60.133(i) requirements have been complied with."

This step falsely implies that compliance with the performance objectives (10 CFR 60.111, 60.112, and 60.113) is a prerequisite for the demonstration of compliance with 60.133(i). As we read 10 CFR 60.133(i), the sequence should be: (1) design an underground facility; and (2) meet the performance objectives.

RESPONSE

Section 60.133(i) requires that "The underground facility shall be designed so that the performance objectives will be met ...." Clearly, there are many aspects of repository siting and design which contribute to meeting the 10 CFR Part 60 performance objectives. Demonstrating compliance with 10 CFR 60.133(i) is one such aspect of the repository design that contributes to meeting the performance objectives. Because the design contributes to meeting the performance objectives, it must be conducted in parallel and/or iteratively with the evaluation of the performance objectives. Sequential but independent design and performance objective evaluations, as suggested by DOE's specific comment, would not accomplish the intent of the regulations. The methodology in this STP recognizes that the product of such a design process might lead to an underground facility design that fails to meet the performance objectives. Therefore, Figure 1 in the STP describes a process with appropriate feedback loops to avoid this.

24. Page 18, Section 4.2, "Development of Detailed Predictive Models"

The second paragraph, last sentence, states, "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."

We do not believe that this is possible. Predictive models, at their best, can discern the engineered from the natural barriers, but they could never analyze canister-scale, room-scale, repository-scale, and regional-scale with phenomenological detail. Instead, bounding analyses can insure that the repository will meet the performance objectives. It should also be noted that the system performance objectives at 10 CFR 60.113 were crafted to accommodate the uncertainties that may arise from the lack of mechanistic understanding of the phenomenological couplings (see our general comments).

RESPONSE

The staff believes that it is possible to develop predictive models that are capable of analyzing canister-scale, room-scale, repository-scale, and regional-scale problems with appropriate levels of detail. The staff emphasized the words "appropriate levels of detail," and refers DOE to computer codes that are based on coupled models and have been applied to different geometric scales (see, for example, Noorishad and Tsang, 1989; Kelkar and Zyvoloski, 1990; and Ohnishi and others, 1990). The knowledge of the T-M-H-C processes and site characteristics for the different scales of resolution may vary. For this reason, the levels-of-detail included in the models may vary accordingly.

However, as recommended by this specific comment, the word "phenomenological" has been deleted from the STP to avoid any misinterpretation that it applies equally to all four scales of resolution.

25. Page 19, Section 4.2, "Development of Detailed Predictive Models"

The STP states in the first paragraph, second sentence, "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."

Please delete this statement. Overly complex models, even more so than simple models, may obscure (through the influence of competing effects) an understanding of one of the coupled processes.

RESPONSE

This comment is noted. However, the staff directs DOE's attention to the paragraph to which DOE's specific comment refers, in which the staff notes that:

"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 scale 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."

The staff considers that in the context of the overall STP, the sentence in question is appropriate.

26. Page 19, Section 4.2, "Development of Detailed Predictive Models"

The last sentence of the second paragraph indicates that "porosity and permeability of the geologic material" should be considered for the chemical model. The sentence should be corrected to reflect the fact that porosity and permeability are hydrologic properties, and therefore, should be considered in the hydrologic model. In addition, working the porosity and permeability into a chemical model without also employing the range of grain sizes would prove difficult, since particle surface area per unit volume is a major factor in determining reaction rates.

RESPONSE

The major focus of the cited paragraph (4th paragraph of Section 4.2) is to give examples of the potential response measures that may be used for the evaluation of the adequacy of the underground facility design. This paragraph does not discuss input parameters that are needed for proper modeling. Thus, the staff does not believe that the STP warrants modification, as suggested by this specific comment.

27. Page 21, Section 4.2, "Development of Detailed Predictive Models"

The first sentence in the last paragraph states, "Finally all predictive models used for licensing are likely to require a certain degree of verification and validation."

Unless offered only for information, the text on model validation and code verification should be deleted. All model validation issues, whether the model is coupled or uncoupled, should be confined to NUREG-0856, or a separate STP. If the NRC staff keeps the text, please use the terms "verification" and "validation" consistently with the way they are defined in Appendix A and NUREG-0856. Models are not verified; rather models are validated and computer codes are verified.

RESPONSE

The staff agrees with this comment and has modified the STP to reflect this distinction.

28. Page 25, Figure 1

The logic flow after Step No. 8B is not closed. Clarification should also be provided as to what drives Step No. 7A, "Modify underground facility design," and how it enters the logic flow for an example of an acceptable methodology for demonstrating compliance with 10 CFR 60.133(i).

RESPONSE

Regarding the first portion of this comment, DOE is referred to the last paragraph of Step No. 8, under Section 4.1 ("Discussion"), where a discussion is provided of what takes place beyond Step No. 8B.

Regarding the second portion of DOE's specific comment concerning what drives Step No. 7A (e.g., the need to modify the underground facility design), Step No. 7A will result if there is noncompliance with the design goals/criteria evaluated in Step No. 7. For example, if a goal/criterion exists for a maximum borehole wall temperature, and this criterion is exceeded as a result of either a very high initial power output from the waste package, or very close spacing between emplacement boreholes, this would result in a "visit" to Step No. 7A. Once the underground facility design is modified, as shown in Step No. 7A, the iterative process returns to Step No. 6.

29. Page 26, Appendix A, "Glossary"

Appendix A defines fully coupled model as "a model that incorporates in its formulation the interdependency of the four phenomena (thermal, mechanical, hydrological, chemical)." (emphasis added)

The interdependency of the phenomena can be incorporated in the formulation at many different levels. Individual codes representing each phenomenon can be incorporated under a system code in which the output of one code provides the input to the other code(s) in an iterative manner until the problem is solved. Alternatively, a model can be constructed with all equations formulated with the interdependencies built in and solved simultaneously. Whether such a detailed formulation is possible with the current scientific understanding of the phenomena and their interdependency or whether the equations can be solved considering the non-linearities in the equations is beside the issue. What is really meant by the definition is not at all clear.

Most natural phenomena occur through many competing interactive processes. Any change in one process, be it thermal, mechanical, hydrological, or chemical, influences the other processes, which, in turn, affect the original process by either enhancing it or counteracting it. The degree of interaction among the processes, i.e., degree of coupling, can be strong or weak. From a thermodynamic point of view, the coupling can also be classified as primary or secondary, depending on the flux and the gradient relationship. The secondary couplings are generally weak. Under certain conditions, however, they could be several orders-of-magnitude higher than the effects from primary coupling. For example, the Soret effect (mass flux due to thermal gradient) in a clay backfill could easily exceed any water influx due to hydraulic gradient (Jamet and others, 1990). This is why for some processes the secondary effects cannot be ignored and a fully coupled model that includes weak couplings may be needed.

The secondary effects, sometimes call Onsager's coupled processes (Carnahan, 1987), are very complicated, as shown below [see Table D1] with a few examples of such couplings in a fluid medium (de Marsily, 1986).

A fully coupled model generally means a model that includes both the primary and secondary couplings. These are debates in the scientific community about whether such models are needed or even technically feasible within practical limits of current state of knowledge, and whether a numerical code implementing a fully coupled model can be run efficiently on currently available computer hardware.

In addition, even if we ignore the secondary effects, 11 distinct combinations of processes can be considered by combining the T, M, H and C processes. There can be six two-process, four three-process, and one four-process combinations (Tsang, 1987). Any of these combinations could be modeled fully uncoupled, sequentially coupled, one-way coupled or two-way (feedback) coupled. In other words, they can be fully coupled with only two, three, or with all four processes as they are needed. A fully coupled model does not necessarily have to include all four processes unless the need for such a fully coupled model is established.

It also appears that this STP uses the word "model" to represent both the conceptual model and numerical codes. In this sense, it is not clear whether the term "fully coupled model" is also intended to mean fully coupled codes, whose meaning could be controversial.

The definition of fully coupled model is unconventional and ambiguous. It needs to be defined with more details. Also, NRC staff should demonstrate the feasibility of its STP by giving an example of a fully coupled model. Aside from this debate of technical feasibility, it is not clear in this STP (text and the definition in Appendix A) what degree of coupling NRC expects when it requests a fully coupled model.

FORCE / FLUX	TEMPERATURE GRADIENT	POTENTIAL GRADIENT Pressure	POTENTIAL GRADIENT Concentration	ELECTRIC FIELD
Heat	FOURIER's law	Thermal osmosis	Dufour effect	Electrothermal effect
Mass	Soret effect	Reverse osmosis	FICK's law	Electrophoresis
Current	Seebeck effect	Electrochemical effects		OHM's law
Percolation	Thermoosmosis	DARCY's law	Chemical osmosis	Electroosmosis

Table D1.A few examples of possible couplings in a fluid medium (after de Marsily, 1986)

RESPONSE

The staff notes the difficulty in interpreting the meaning of the phrase "fully coupled," as it appears in the "Glossary." In this regard, DOE is directed to the fourth paragraph of the staff's response to DOE's "General Comments," where the staff describes the revisions that have been made to the STP in order to clarify what is meant by the staff's use of these terms.

The NRC staff also recognizes the difficulties and complexities associated with the characterization of coupled processes. Despite these difficulties, the staff recognizes that the importance of coupled processes should be explored, so that their effects if necessary could be: (1) included in a model(s) for use to predict the M-H-C responses associated with a thermal load, and the effects on the performance of the repository; and/or (2) included as an uncertainty into the results of models which may not directly account for the effects of such coupling. As the DOE's specific comment points out, "... for some processes" [even] the secondary effects cannot be ignored and a fully coupled model that includes weak coupling may be needed." The staff recognizes that the characterization of coupled processes and the evaluation of their importance to the prediction of the T-M-H-C responses in the context of the repository may not be fully accomplished by the time of issuing the license to close the repository. However, an assessment of the importance of the coupled effects will contribute to the "reasonable assurance finding" that the repository will perform as intended.

Finally, the term "model," as used in the STP, does not refer to a numerical code.

STATE OF NEVADA COMMENTS

GENERAL COMMENTS

The STP is a generic, non-technical document which, based on a flow diagram, discusses and recommends an iterative procedure for demonstrating compliance of the underground repository facility with the requirements pertaining to thermal loads as they appear in applicable portions of 10 CFR Part 60 regulations. There is no indication of when this iterative process should be initiated, since there is little reference to the process of site characterization or of what kinds and levels of data are expected to be derived from site characterization for use in the procedure developed in this STP. This is of more than passing importance since the DOE is planning that the Exploratory Shaft (now "Studies") Facility be incorporated into the underground repository facility and it is already in the design process without benefit of the considerations outlined in the STP.

The DOE's assumption appears to be that thermal loading can be back-fit to any repository design, which is an approach opposite to that advanced in the STP. This is important in the context of this STP since implicit in the DOE assumption is the notion that thermal loading is a design feature of an underground repository facility, rather than a potential adverse impact that has waste isolation implications, as appears to be the case in the STP. If it is to be treated as a design feature, then the NRC, in its STP, should be concerned also with the design basis of the selected magnitude and rate of thermal loading and should require that the selection be supported by a thorough evaluation of alternative loads and their consequences for waste isolation performance. These incompatible views of the role of thermal loading in a repository must be reconciled before further development of a thermal load STP is undertaken.

The STP is based on the premise that performance assessment models for the evaluation of compliance with the performance objectives of 10 CFR Part 60 will exist at the time of license application. The suggested iterative process involves the use of increasingly advanced models, which are referred to as fully, partially, or one-way coupled thermal-mechanical-hydrological-chemical (T-M-H-C) models. These are inadequately defined in the STP in regard to their underlying assumptions and the kinds and levels of information needed for their acceptable application. This leads to what appears to be an endorsement of the use of expert judgment when either the data base is insufficient or the iterative process fails to resolve an issue.

In general, the STP lacks sufficient technical specificity to determine whether the suggested methodology is feasible for implementation, but more important, the suggested methodology is not compatible with the ongoing implementation of the DOE site characterization program, and therefore likely will be of little use as guidance to DOE.

RESPONSE

In the first portion of its general comment, the State of Nevada notes that "The STP is a generic non-technical document which, based upon a flow diagram, discusses and recommends an iterative procedure for demonstrating compliance ..." and raises questions as to when such an iterative procedure should be initiated. The staff agrees with the State of Nevada that this STP is generic in nature because it is intended to be applicable to any site or design. However, the staff disagrees with the State that the STP is a nontechnical document because the STP is based on complex technical concepts related to the interaction of T-M-H-C processes.

As for when this iterative process is initiated, the staff notes, in Section 1.3 of this STP, that "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." Therefore, given the progressive nature of the approach, it is apparent that

DOE's iterative design process should start as early as possible. The STP emphasizes that this is an evolving process that covers the entire period of repository design, construction, and operation.

Regarding the kinds and levels of data derived from site characterization for use in the iterative process recommended in the STP, the staff believes that it is DOE's responsibility to demonstrate that it identified and obtained the appropriate kinds and levels of data as part of its demonstration of compliance with 10 CFR 60.133(i). The State of Nevada should recall that the NRC staff will use Draft Regulatory Guide DG-3003, "Format and Content Regulatory Guide for the License Application for the High-Level Waste Repository" (FCRG) (which has already been issued in draft form; see NRC, 1990) to indicate to DOE the information to be provided in the License Application. The License Application Review Plan, which will guide the NRC staff's review of the License Application, will be publicly available and should provide additional insight to DOE. It is further noted that DOE's submittal of data and analyses are subject to continued pre-licensing review by NRC.

The State of Nevada is also concerned that DOE is proceeding with the ESF design process without the benefit of the guidance provided in this STP. The staff wishes to note that it has already provided guidance to DOE on the ESF design process (see Gupta and others, 1991) and in doing so, has identified 10 CFR 60.133(i) as one of the applicable technical criteria that needs to be considered in the ESF design process. This STP provides guidance to DOE specifically for demonstrating compliance with 10 CFR 60.133(i).

The second portion of the general comment suggests that DOE's approach in dealing with thermal loading is incompatible with the approach advanced in the STP, and therefore recommends that no further development on this STP be made until the two approaches have been reconciled. In this regard, the State of Nevada is referred to Section 1.3 of this STP, where the role of STPs is discussed, including the fact that STPs are not substitutes for regulations, and compliance with them is not required. In view of this discussion, the staff does not find any reason not to proceed with the publication of this STP in its final form.

Furthermore, the State of Nevada is concerned that DOE treats the thermal load as a design feature. For this reason, it recommended that the STP should be concerned with the design basis of the thermal load and that the basis should be supported through an evaluation of alternative thermal loads, regarding their effect on waste isolation performance. The staff refers the State to 10 CFR 60.21(c)(ii)(D), which specifically calls for a comparative evaluation of alternatives to major design features, that are important to waste isolation, for assessing the effectiveness of engineered and natural barriers. Therefore, the staff believes that, as long as a design goal/criterion associated with a design feature is tied to the performance objectives, as suggested in this STP, the resulting underground facility design would evolve from a thorough evaluation of alternative thermal loads. Moreover, the analysis of waste isolation implications and establishment of the design basis for the thermal load are integral parts of this iterative process.

As regards the third portion of the State of Nevada's "General Comment," the staff agrees that there has been considerable difficulty in interpreting the meaning of the various terms such as "fully," "partially," and "one-way coupled" T-M-H-C models, as used in this STP. The staff agrees that there is a need to more clearly define these terms, and has made the following revisions to the STP:

(1) replaced the term "fully-coupled" models with the term "coupled" models;

(2) replaced the terms "partially coupled," and "one-way coupled" models with the term "simplified" models; and

(3) defined "coupled" models and "simplified" models.

In the context of thermal load considerations, "coupled behavior" means that each of the T-M-H-C processes has an effect on the initiation and propagation of any of the other processes, and vice versa. A coupled model can represent such an interactive behavior. A simplified model is an approximation, of a coupled model, that may ignore some of the processes and their interactions.

As to the kinds and levels of data needed for the acceptable application of these models, the staff reiterates that it is DOE's responsibility to demonstrate the acceptability of these models and the associated data needs. Such demonstration and assessment of data needs will be subject to NRC review. Also, the State of Nevada raises an issue with the use of expert judgment. As Bonano et al., (1990, p. 46) have noted:

> "Expert judgments should not be considered equivalent to technical calculations based on universally accepted scientific laws or to the availability of extensive data on precisely the quantities of interest .... Expert judgments are sometimes inappropriately used to avoid gathering additional management or scientific information."

The staff agrees with Bonano et al., and has stated that expert judgment should not be used as a substitute for investigations needed to support a complete and high-quality license application. This is particularly true for reasonably available or obtainable data and/or analyses.

Finally, in its "General Comment," the State of Nevada questions the feasibility of the proposed methodology in this STP on the grounds that the STP lacks sufficient technical specificity and that it is incompatible with the ongoing DOE program. The State concludes that this STP will be of little use as guidance to DOE. The staff has no reason to believe that the proposed methodology in this STP is not feasible, because the STP is based on a logical, comprehensive, and systematic approach. The staff points out that the intent of this STP is to provide sufficient generic guidance to DOE without being too prescriptive or overly restrictive with regard to the implementation techniques that may be chosen by DOE. In the staff's view, the guidance in this STP is not incompatible with the ongoing DOE program as known to the staff through its pre-licensing consultations. Therefore, the staff believes that useful and timely guidance is being provided in this STP for DOE to develop its ability to demonstrate compliance with 10 CFR 60.133(i).

SPECIFIC COMMENTS

1. Page 1, paragraph 1

It is emphasized in the STP that the DOE is expected to demonstrate a comprehensive, systematic and logical understanding of T-M-H-C of the underground facility. This should be elaborated. It is not clear how such demonstration is expected to be accomplished, and whether both the theoretical and site-specific basis for such understanding should be presented.

RESPONSE

The staff believes that sufficient details are provided, in the STP, to demonstrate a comprehensive, systematic, and logical understanding of the coupled T-M-H-C responses associated with a particular underground facility design. These details are discussed in Sections 3.0 and 4.0 of the STP.

2. Page 2, paragraph 1

The STP states: "The staff expects that, through the pursuit of appropriate technical programs, DOE would develop information that would enhance considerably the approach in this document."

This presumes that DOE will choose to adhere to the staff approach (see general comments), and if DOE does so choose, the statement suggests that the staff has some doubts about whether the approach, as presented, will lead to an adequate determination of compliance. If such doubts exist, the staff itself should attempt to enhance the approach before it is reissued as information and guidance.

RESPONSE

Since STPs are not substitutes for regulations, and compliance with them is not required, DOE may or may not choose to follow the example approach recommended in this STP. If DOE chooses to follow the recommended methodology, the staff believes, at the present time, that this methodology will lead to an adequate demonstration of compliance with 10 CFR 60.133(i). Likewise, a different methodology chosen and implemented by DOE may also lead to a demonstration that will be acceptable to NRC. This is sufficiently recognized by NRC, as stated in Section 1.3 of the STP. The staff will make every attempt to enhance the suggested methodology if and when new information warrants such enhancement.

3. Page 2, paragraph 2

The STP states: "In this STP, the NRC staff assumes that performance assessment models will exist for evaluating compliance with 10 CFR Part 60 performance objectives." See discussion of this assumption in "General Comments."

RESPONSE

The staff's statement that "... performance assessment models will exist," it believes, is a reasonable assumption. This judgment is based on the observation that both the DOE and NRC programs (as well as those of groups such as the Electric Power Research Institute) are focused on developing and testing such models, using such broad-based approaches as those used in Performance Assessment Calculational Exercises (PACE), and the respective NRC/DOE Performance Assessment activities.

4. Page 2, paragraph 2

The STP states: "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."

Some elaboration would be helpful in this STP in order to expose at least some of what the staff believes is appropriate for data collection and analysis during site characterization. This could result in a beneficial reduction in uncertainty in the thermal loading assessment in a license application, since the STP appears to expect that uncertainties will be relatively large at the time of license application, and will reduce significantly during construction and operation.

RESPONSE

The staff agrees with this specific comment that elaboration on the different aspects of performance assessments would be helpful in identifying appropriate data collection; however, the staff maintains that doing so is beyond the scope of this STP.

In this regard, the NRC staff has previously noted the it will use the FCRG (which has already been issued in draft form) to provide additional guidance to DOE regarding the kinds and levels of data to be presented in the License Application. It is further noted that DOE's submittal of data and analyses are subject to continued NRC review.

5. Page 4, paragraph 1

The STP states: "The guidance in the STP focuses on the prediction of repository-generated thermal regimes beyond the range of current engineering experience."

"Current engineering experience" should be elaborated in this section in order to better understand the focus of this STP. Is there "current engineering experience" that the staff believes is relevant under the range of thermal load scenarios that the DOE is likely to consider, given the repository development and operation schedule it is attempting to meet?

RESPONSE

The staff believes that current hard-rock mining experience, at very deep levels (e.g., 10,000 feet), where the geothermal gradient results in a very warm environment, would be relevant to the operational period of the repository. The staff believes that this experience could be useful in DOE's efforts to demonstrate that its design complies with the pre-closure performance objectives (e.g., 10 CFR 60.111). In addition, as natural analogs, conditions associated with geothermal regions could be used in guiding post-closure performance evaluations (e.g., 10 CFR 60.112 and 60.113).

6. Page 5, paragraph 2

The STP states: "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 issuance of a construction authorization (so long as there is reasonable assurance of safety)."

The word "could" should be replaced by "should." If there is an unresolved safety question relating to model validation, the standard of reasonable assurance will be diminished unnecessarily to some extent if the issues involved in the lack of resolution are not described.

RESPONSE

The staff agrees with the recommended change suggested by the State of Nevada's specific comment. The third sentence of the last paragraph in Section 1.2 has been revised to read as follows:

If there is an unresolved safety question relating to model validation, this should be described in the application. The existence of such a question may, of course, reduce the Commission's confidence that the standards for issuance of a construction authorization have been satisfied. Depending upon the nature of the unresolved safety question and the prospects for resolving it favorably, there may be reasonable assurance that applicable requirements have been met and, on that basis, a construction authorization might be issued.

Moreover, the staff also points out the prerogative of the Commission to place "conditions" on the construction authorization, in accordance with 10 CFR 60.32. More specifically, 10 CFR 60.32(b)(4) identifies "programs being conducted to resolve safety questions" as a particular basis for placing "conditions" on the license.

7. Page 8, paragraph 2

Step No. 1 calls for a preliminary evaluation of the sensitivity of the performance objectives to thermal loading. The STP should outline the type and level of data and the maturity of facility design necessary to make this evaluation since the Step No. 1 determination, according to the STP approach, may never be revisited.

RESPONSE

The staff believes that a preliminary, conceptual understanding of the underground facility design is sufficient when considering Step No. 1 in the recommended approach. It is DOE's responsibility to justify the type and the level of the data used in the evaluation of each step, including Step No. 1. The suggested methodology applies to any given thermal load design concept. Therefore, whenever significant changes are made to the design concept, the suggested methodology depicted in Figure 1 should be reapplied.

8. Page 8, paragraph 3

Step No. 2 calls for the determination of the existence of predictive models to quantify the effect of thermal loadings.

This step should require, in addition, a demonstration of the reliability of such models relative to the specific site being evaluated by DOE. According to the STP approach, this determination may never be revisited.

RESPONSE

Regarding the need for site-specific information to demonstrate the reliability of the models in Step No. 2, the staff points out that in Section 3.0 of the STP, Step No. 2 requires that models be reliable. For a discussion on the use of reliable models, the State of Nevada is referred to Section 4.2 of the STP.

The staff agrees with the State of Nevada comment regarding the need to revisit Step No. 2, and has modified the recommended approach accordingly. The modification involves a return from Step No. 5 to Step No. 2 in Figure 1. In addition the text for Step No. 5 has been changed in Technical Position 3.1.

9. Page 8, paragraph 4

Step No. 3 calls for an examination of the thermally induced phenomena.

The STP should outline the type and level of data necessary for this examination, and should elaborate on what methods and scope of examination might be expected to be employed.

RESPONSE

The staff agrees that the types and the levels of data, and methods of examination are important issues. However, the staff does not believe that it is appropriate to include such information in this STP. Selection of methodologies or approaches that may be used for accomplishing the objective of each step should be left to the purview of DOE.

In this regard, the NRC staff has previously noted the it will use the FCRG (which has already been issued in draft form) to provide additional guidance to DOE regarding the kinds and levels of data to be presented in the License

Application. It is further noted that DOE's submittal of data and analyses are subject to continued NRC review.

10. Page 8, paragraph 5

Step No. 4 calls for development of design goals/criteria.

In such development, the STP should call for an evaluation of alternative design goals/criteria based on varying the magnitude and rate of thermal loading. The basis for the design goals/criteria selected should be demonstrated.

RESPONSE

The recommended approach in the STP calls for the development of design goals/criteria that are derived from 10 CFR Part 60 performance objectives. Design goals/criteria should not be determined on the basis of a variation of thermal loads, as the State of Nevada suggests. Rather, alternative thermal loads should be determined on the basis of the design goals/criteria, derived from the performance objectives. The State of Nevada is referred to Step No. 4 of Section 4.1 for a detailed discussion of the development of design goals/criteria.

11. Page 9, paragraph 6

The STP states: "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)."

This step suggests that the "other" engineering criteria have been set independent of thermal load considerations and their relationship to thermal loading need not be considered except as a means of compensating for unresolvable problems in performance of the underground facility and its design. It should not be acceptable that the underground facility design be considered the "weak link" in performance relative to thermal loads.

RESPONSE

The State of Nevada's comment implies that the example approach in the STP precludes thermal load considerations for waste package design, boreholes, shafts, and seal design and the assessment of the geologic setting. The staff disagrees that the suggested methodology conveys this implication. The staff points out that the suggested methodology is specifically to demonstrate compliance with 10 CFR 60.133(i) (i.e., the underground facility design in the context of the thermal load).

Thermal load considerations will also need to be included in the waste package design, borehole, shaft, and seals design and the geologic setting concerns; however, these design concerns are outside the scope of this STP.

12. Page 10, paragraph 3

The STP states: "Develop models that approximate fully coupled behavior in a manner that is not likely to adversely affect the performance objectives ...."

This could be stated more clearly. Performance objectives are not affected by behavior.

The STP should provide some guidance on the intended bounds of such an approximation, and the type and level of data necessary to make and demonstrate such an approximation.

RESPONSE

The staff agrees with the first portion of the State of Nevada's specific comment that models cannot affect performance objectives. Therefore, Section (a) of Technical Position 3.3 has been modified to read as follows:

"(a) Develop models that approximate coupled behavior in a manner that is not likely to underestimate the unfavorable or overestimate the favorable aspects of repository performance (e.g., 10 CFR 60.111, 60.112, and 60.113)."

As regards the second portion of the State of Nevada's specific comment, the staff believes that the issue of providing guidance has been adequately covered in Section (b) of Technical Position 3.3, and the "Discussion," in Section 4.3 of the STP.

13. Page 17, paragraph 2

The STP states: "If unacceptable results are encountered, it may become necessary to return to Step No. 3, from Step No. 8 (see Figure 1)."

If there is continued noncompliance, then disqualification of the site should be considered also.

RESPONSE

The staff notes the State of Nevada's comment regarding continued noncompliance of a design and the recommendation for the subsequent disqualification of the site. However, this STP is concerned with the demonstration of compliance with 10 CFR 60.133(i), and not with the question of site qualification. The steps that are part of the example approach described in this STP cannot, and are not designed to, lead to a determination whether or not the site would qualify for licensing. That decision rests with DOE, in accordance with the Nuclear Waste Policy Act of 1982, as amended.

If after numerous iterations, an underground facilty design is not found to be acceptable, according to the derived design goals/criteria, the recommendation in the STP is to look at components of the "disposal system" other than those of the underground facility (e.g., Step Nos. 8A and 8B). Whether a site qualifies for licensing is an issue that should be determined from a demonstration of the site's ability to meet all pertinent 10 CFR Part 60 regulatory requirements.

<u>14. Page 17, paragraph 3</u>

The STP states: "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."

See Comment No. 11 above.

<u>RESPONSE</u>

See staff response to State of Nevada Specific Comment No. 11.

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

TECHNICAL EXCHANGE
WITH
DEPARTMENT OF ENERGY

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

PRESENTED
BY
DR. MYSORE NATARAJA
DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

MARCH 17, 1992

ATTACHMENT 4

SUMMARY OF BRIEFING

- Why This STP
- Regulatory Framework
- Technical Background
- Staff Technical Positions
- Discussions

WHY THIS STP

DOE's STATEMENTS FROM THE SCP

- Limitations in the Ability to Model the Physical-Chemical Processes Around the Waste package
- Development of Fully Coupled Models Beyond the Current State-of-the-Art
- Simplifications Necessary to Understand T-M-H-C Interactions

NWTRB COMMENTS ON DOE's DESIGN

- 275°C Maximum Borehole Wall Temperature Higher Than in Any Other HLW Repository Program.
- Repository-Induced Effects May Be Well Beyond Current Scientific Understanding and Engineering Experience.

NEED FOR STP

Based on DOE's Design and NWTRB Comments, Staff Realized the Need For Developing Guidance in the Area of Underground Facility Design (Thermal Loads)

REGULATORY FRAMEWORK

PRIMARY REGULATION

10 CFR 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 surrounding strata, groundwater system."

RELATED REGULATION

10 CFR 60.21(c)(1)(i)(F) Content of Application. "The Safety Analysis Report Shall include:---
(F) The anticipated response of the geo-mechanical, hydrologic, 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."

TECHNICAL BACKGROUND

PERFORMANCE OBJECTIVES AND DESIGN CRITERIA

- Underground Facility design Accomplished By Meeting Design Criteria
- Design Criteria Derived From Performance Objectives

EXAMPLES OF DOE DESIGN GOALS/CRITERIA

- Maximum Borehole Wall Temperature Below 275°C
- Maximum Temperature 1 m From Borehole Wall Below 200°C
- Drift Wall Temperature of 50°C at 50 Years
- Other Criteria

DESIGN ANALYSES

- Predictive Models are the Only Means Available
- Uncertainties With Predictive Models

TIME & SPACE SCALES

- Problem Spans Three Scales:
  - Canister
  - Room
  - Repository
- Problem Spans Three Durations:
  - 100 Years
  - 300/1000 Years
  - 10000 Years

STAFF TECHNICAL POSITIONS

DEFENSIBLE APPROACH

(1) The DOE Should Develop a Defensible Approach to Demonstrate That the Design of the Underground Facility meets 10 CFR 60.133(i)

Further Elaboration on Defensible Approach will be Presented later

DETAILED PREDICTIVE MODELS

(2) To the extent practical, the DOE Should Develop Models to Predict the Thermal and Thermomechanical Response of the Host Rock, Surrounding Strata, and Groundwater System based on Mechanistic Understanding of the Fully Coupled T-M-H-C Behavior.

ALTERNATIVE PREDICTIVE MODELS

(3) If a Detailed Understanding of the Synergistic Effects of T-M-H-C Interactions cannot be Gained Prior to Submittal of an Application for Construction Authorization, DOE Should:

(a) Develop Approximate Models

(b) Present Confirmatory Plans

ALTERNATIVE PREDICTIVE MODELS
(CONTINUED)

(a) Develop Models That Approximate Fully Coupled Behavior in a Manner That is Likely to Result in Conservative Estimates With Respect to Performance Objectives 60.111, 112, and 113

ALTERNATIVE PREDICTIVE MODELS
(Continued)

(b) Develop Such Plans for In Situ and Laboratory Monitoring and Testing, and for Additional Model Developments, as May be Appropriate to Confirm the Adequacy of the Approximate Models Used to Support the Application for Construction Authorization

DISCUSSIONS
OF THE STAFF TECHNICAL POSITIONS

EXAMPLE OF AN ACCEPTABLE APPROACH FOR DEMONSTRATING COMPLIANCE WITH 10 CFR 60.133(i)

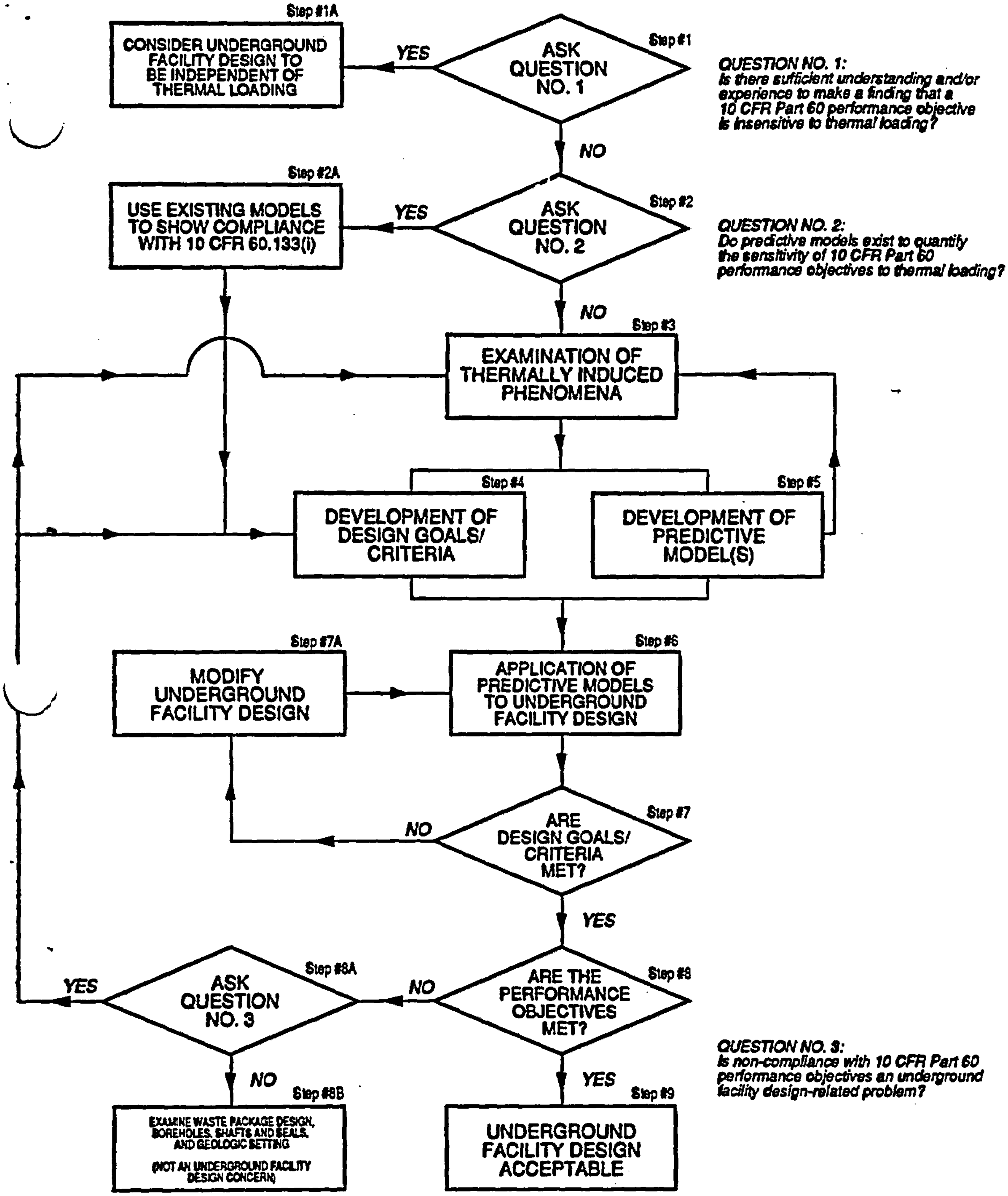


FIGURE 1 -- The Logic Flow for an Example of an Acceptable Methodology for Demonstrating Compliance with 10 CFR 60.133(i). The numbers next to the process blocks refer to the steps necessary to implement technical position 3.1. These steps are described in Sections 3.0 and 4.0 of the text.

EXAMPLE APPROACH

Step 1 - Preliminary Evaluation to Determine Sensitivity of the Performance Objectives to Thermal Loading

Step 2 - Determination of the Existence of Validated Models to Quantify the Effects of Thermal Loading

Step 3 - Examination of the Thermally Induced Phenomena

EXAMPLE APPROACH (CONTD.)

Step 4 - Development of Design Goals/Criteria (Based on Performance Objectives)

Step 5 - Development of Detailed Predictive Models

Step 6 - Comparison of Results from Predictive Models with the Design Goals/Criteria

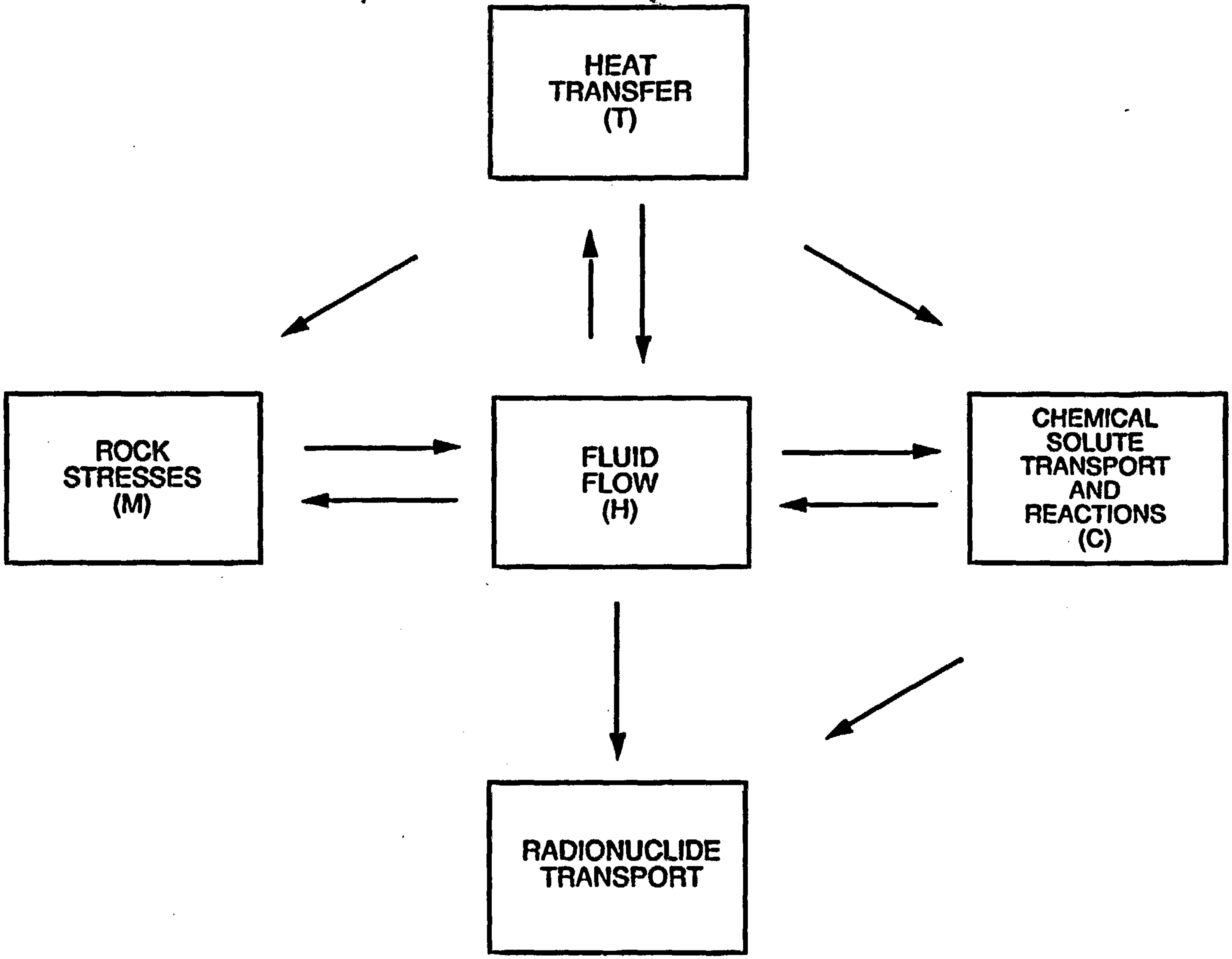
EXAMPLE APPROACH (CONTD.)

Step 7 - Iterative Predictions to Check if Design Goals/Criteria are Met

Step 8 - Incorporation of Predicted Results in Performance Assessment Models (60.111, 112, and 113)

Step 9 - End of Compliance Demonstration with 60.133(i)

CONCEPTUAL T-M-H-C INTERACTIONS



CONCEPTUAL T-M-H-C INTERACTIONS
(After NUREG/CR-2910)

EXAMPLE OF AN APPROXIMATE MODEL

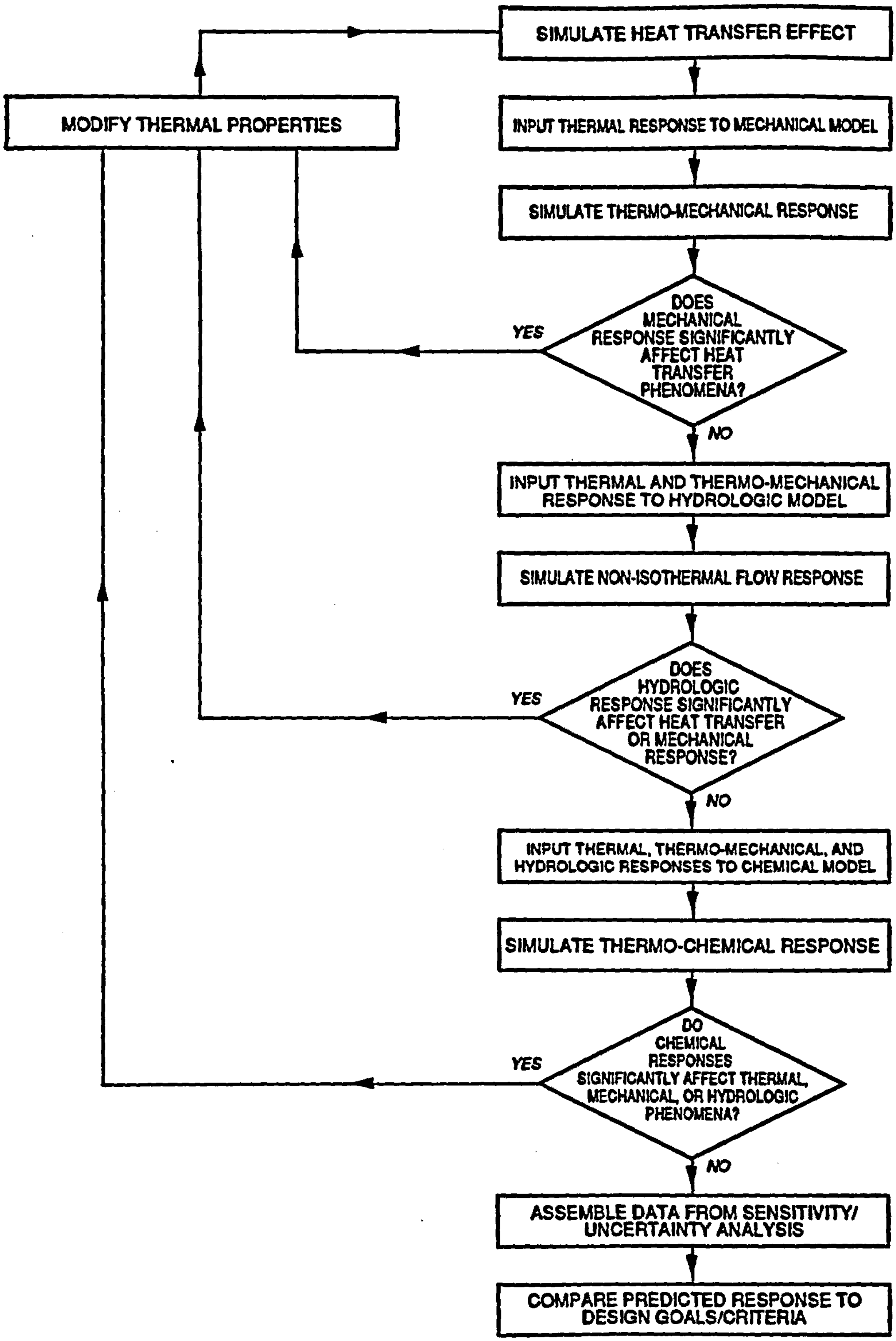


FIGURE C1 -- Iterative Process for the Analysis of Thermally Induced Phenomena Based on One-Way Coupling.

ATTACHMENT 5

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

TECHNICAL EXCHANGE
WITH THE
U.S. DEPARTMENT OF ENERGY

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

STAFF RESPONSE TO PUBLIC COMMENTS

PRESENTED BY
DR. MYSORE NATARAJA
DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

MARCH 17, 1992

DOE COMMENTS

- ONE GENERAL AND 29 SPECIFIC COMMENTS

- GENERAL COMMENT ADDRESSES A NUMBER OF POINTS

- MANY OF THE DOE SPECIFIC COMMENTS REITERATE THE GENERAL THEME OF THE GENERAL COMMENT

NRC RESPONSES

- GENERAL COMMENT IS ADDRESSED POINT-BY-POINT
- EACH SPECIFIC COMMENT IS ADDRESSED IN ORDER
- BECAUSE THE COMMENTS REPEAT THE GENERAL THEME, THE RESPONSE PACKAGE ALSO TENDS TO REPEAT SOME GENERAL CONCEPTS
- PRESENTATION WILL FOCUS ON THE MAIN IDEAS AND GENERAL CONCEPTS

REGULATORY REQUIREMENT 10 CFR 60.133(I)

- 60.133 ADDITIONAL DESIGN CRITERIA FOR THE UNDERGROUND FACILITY

- 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, SURROUNDING STRATA, AND GROUNDWATER SYSTEM"

- NRC STAFF INTERPRETATION (T-M-H-C)

5

GOVERNING PRINCIPLE OF THE STP

"THE METHODOLOGY IN THIS STP IS BASED ON THE PRINCIPLE THAT, TO DEMONSTRATE COMPLIANCE WITH 10 CFR 60.133(I), DOE MUST CONSIDER THERMAL COUPLING OF PROCESSES IN A MANNER THAT IS NOT LIKELY TO UNDERESTIMATE THE UNFAVORABLE ASPECTS OF REPOSITORY PERFORMANCE OR OVERESTIMATE THE FAVORABLE ASPECTS IN THE CONTEXT OF UGF DESIGN AND ANALYSES"

COMMENT

- GUIDANCE IN THE STP TOO DEMANDING
- DOE DOES NOT THINK STAFF EXPECTATIONS WILL BE FULFILLED

RESPONSE

- STAFF TECHNICAL POSITIONS WHEN CONSIDERED COLLECTIVELY, PROVIDE A REALISTIC APPROACH
- STP EMPHASIZES THE PROGRESSIVE DEVELOPMENT OF PREDICTIVE MODELS
- APPROACH ACHIEVABLE IF DOE MAKES AN EARLY COMMITMENT TO ITS IMPLEMENTATION

COMMENT

- "SIMPLIFIED MODELS WOULD WORK AS WELL, IF NOT BETTER THAN FULLY COUPLED MODELS"

RESPONSE

- STAFF HAS NO BASIS TO SUPPORT THE DOE ASSERTION
- IF DOE SUBSTANTIATES ITS ASSERTION STAFF HAS NO OBJECTION TO THE USE OF 'SIMPLIFIED' MODELS
- DOE'S SUBSTANTIATION SHOULD BE BASED ON THE GOVERNING PRINCIPLE STATED EARLIER

COMMENT

- DEFINITION OF "FULLY COUPLED" MODELS 'UNCONVENTIONAL' AND 'AMBIGUOUS'

RESPONSES

(1) REPLACE THE PHRASE "FULLY COUPLED MODELS" WITH "COUPLED MODELS'

(2) REPLACE THE PHRASES "PARTIALLY COUPLED" AND "ONE-WAY COUPLED" MODELS WITH "SIMPLIFIED MODELS"

(3) CLARIFICATIONS

- IN THE CONTEXT OF THERMAL LOAD CONSIDERATIONS, COUPLED BEHAVIOR MEANS THAT EACH OF THE T-M-H-C PROCESSES HAS AN EFFECT ON THE INITIATION AND PROPAGATION OF ANY OF THE OTHER PROCESSES AND VICE VERSA

- A COUPLED MODEL CAN REPRESENT THE ABOVE BEHAVIOR

- A SIMPLIFIED MODEL IS AN APPROXIMATION OF THE COUPLED MODEL

COMMENT

- STP VOIDS NRC'S JUSTIFICATION FOR REQUIRING "DISTURBED ZONE"

RESPONSE

- BOUNDARY OF DISTURBED ZONE APPLIES ONLY TO PRE-EMPLACEMENT GROUNDWATER TRAVEL TIME CALCULATION

- DISTURBED ZONE CONCEPT IS ASSOCIATED WITH ONLY ONE OF SIX PERFORMANCE OBJECTIVES (ALL OF THEM NEED TO BE COMPLIED WITH)

- COMPLIANCE WITH OTHER PERFORMANCE OBJECTIVES NEEDS AN UNDERSTANDING OF THERMALLY INDUCED RESPONSES

- DISTURBED ZONE CONCEPT DOES NOT RELIEVE DOE FROM CONSIDERING THERMAL IMPACTS AND THEIR UNCERTAINTIES ON REPOSITORY PERFORMANCE

COMMENT

- BECAUSE NRC HAS CONTAINMENT PERIOD REQUIREMENT, THERE IS NO NEED TO UNDERSTAND NEAR-FIELD ENVIRONMENT OF THE WASTE PACKAGES

RESPONSE

- UNDERSTANDING NEEDED TO DEMONSTRATE CONTAINMENT
- UNDERSTANDING NEAR-FIELD THERMAL ENVIRONMENT CONTRIBUTES TO A SATISFACTORY DESIGN OF THE EBS
- UNDERSTANDING NEEDED FOR DEMONSTRATING TOTAL SYSTEM PERFORMANCE
- THEREFORE, CONTAINMENT PERIOD REQUIREMENT DOES NOT RELIEVE THE DOE OF A NEED TO UNDERSTAND AND ANALYZE THE T-M-H-C PROCESSES THAT AFFECT THE EBS PERFORMANCE

COMMENT

- STP DOES NOT CONVINCE DOE THAT 'FULLY COUPLED' MODEL IS NEEDED

RESPONSE

- STP DOES NOT REQUIRE "FULLY COUPLED" MODELS
- EXAMPLES IN LITERATURE OF T-H-C INTERACTIONS (LIN AND DAILY 1989) AND T-M-H INTERACTIONS (RUTQVIST ET AL. 1991)
- DOE SHOULD DEVELOP MODELS TO PREDICT THERMAL IMPACTS BASED ON A MECHANISTIC UNDERSTANDING OF T-M-H-C INTERACTIONS TO THE EXTENT PRACTICAL AND NECESSARY

COMMENT

- LIMIT THE STP TO ONE-WAY T-M COUPLING (AS IN NUREG/CR 5428)

RESPONSE

- NUREG/CR 5428 IS NOT AN EXAMPLE OF COUPLED ANALYSIS OF THERMAL INTERACTIONS. IT ONLY DEALS WITH THE TRANSIENT HEAT TRANSFER BY CONDUCTION (ONLY ONE PROCESS-T)
- LEVEL OF NEEDED COUPLING SHOULD BE ESTABLISHED ALONG WITH A TECHNICAL RATIONALE
- CAN ELIMINATE CERTAIN PROCESSES BASED ON SCIENTIFIC UNDERSTANDING/ENGINEERING EXPERIENCE
- CANNOT AND SHOULD NOT SIMPLY DISMISS THE NEED WITH NO TECHNICAL BASES

COMMENT

- STP LACKS A REGULATORY BASIS

RESPONSE

- REQUIREMENT IN 10 CFR 60.133(I) ALONE PROVIDES THE NECESSARY AND SUFFICIENT REGULATORY BASIS FOR THE STP

- THERE ARE ADDITIONAL REQUIREMENTS THAT SUPPORT THE STP

  FOR EXAMPLE 60.21(C)(1)(I)(F)

  CONTENT OF LA TO INCLUDE:

  "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"

COMMENT

- STP IS TOO GENERIC AND LACKS PERTINENT DETAILS TO MEET ITS STATED PURPOSE

RESPONSE

- STP OUTLINES AN ACCEPTABLE METHODOLOGY FOR DEMONSTRATING COMPLIANCE WITH 10 CFR 60.133(I)
- NO INTENT TO UNDULY CONSTRAIN DOE IN ITS CHOICE OF METHODS
- NO INTENT TO BE UNDULY PRESCRIPTIVE
- METHODOLOGY APPLICABLE TO ANY SITE, ANY DESIGN

COMMENT

- METHODOLOGY INCOMPLETE
- LACKS CRUCIAL DETAILS FOR DECISION MAKING ESPECIALLY WHEN DEALING WITH LARGE UNCERTAINTIES

RESPONSE

- APPROACH IDENTIFIES DECISION POINTS
- DECISION MAKING METHODS ARE LEFT TO DOE
- UNCERTAINTIES SHOULD BE DEALT WITH BY USING APPROPRIATE CONSERVATIVE APPROACHES

COMMENT

- NRC STAFF'S EXPECTATIONS AT VARIOUS STAGES OF REPOSITORY DESIGN, CONSTRUCTION, AND OPERATION NOT CLEARLY STATED

RESPONSE

- CLARIFICATIONS PROVIDED
- CA STAGE: PREDICTIVE MODELS USED TO DEMONSTRATE COMPLIANCE WITH 60.133(I) SHOULD BE CONSISTENT WITH THE GOVERNING PRINCIPLE OF THE STP
- SUBSEQUENTLY: ASSUMPTIONS AND PERFORMANCE PREDICTIONS SHOULD BE CONFIRMED BY APPROPRIATE TESTING AND/OR MODEL REFINEMENTS

SUMMARY OF RESPONSES TO DOE GENERAL COMMENT

- NO BASIC CHANGE TO THE STP
- SEVERAL CLARIFICATIONS PROVIDED
- MINOR CHANGES TO THE TEXT
- MINOR CHANGES TO THE FIGURE
- OVERALL DOE'S COMMENTS HELPFUL IN REDUCING SOME AMBIGUITIES AND CLARIFYING THE TEXT OF THE STP

STATE OF NEVADA

COMMENTS

- ONE GENERAL AND 17 SPECIFIC COMMENTS
- GENERAL COMMENT ADDRESSES A NUMBER OF POINTS
- MANY OF THE STATE'S SPECIFIC COMMENTS REITERATE THE GENERAL THEME OF THE GENERAL COMMENT

COMMENT

- STP IS A GENERIC NON-TECHNICAL DOCUMENT

RESPONSE

- STP IS A GENERIC DOCUMENT BECAUSE IT IS APPLICABLE TO ANY SITE/DESIGN
- STP IS NOT A NON-TECHNICAL DOCUMENT BECAUSE IT DEALS WITH COMPLEX TECHNICAL ISSUES

COMMENT

- WHEN SHOULD THE ITERATIVE PROCEDURE BE INITIATED

RESPONSE

- AS EARLY AS POSSIBLE

COMMENT

- WHAT KINDS AND LEVELS OF DATA ARE EXPECTED TO BE DERIVED FROM SITE CHARACTERIZATION FOR USE IN THE ITERATIVE PROCEDURE

RESPONSE

- IT IS DOE'S RESPONSIBILITY TO IDENTIFY AND GATHER THE APPROPRIATE KINDS AND LEVELS OF DATA DURING SITE CHARACTERIZATION
- THIS STP IS NOT INTENDED TO PROVIDE GUIDANCE ON THE KINDS AND LEVELS OF DATA
- FCRG AND LARP WILL PROVIDE GUIDANCE ON SUCH ISSUES
- DOE'S SUBMITTAL OF DATA AND ANALYSES ARE SUBJECT TO NRC REVIEW

COMMENT

- DOE IS PROCEEDING WITH THE ESF DESIGN PROCESS WITHOUT THE BENEFIT OF THE GUIDANCE PROVIDED IN THIS STP

RESPONSE

- NRC HAS ALREADY PROVIDED GUIDANCE TO DOE ON THE ESF/REPOSITORY DESIGN INTERFACE (NUREG-1439)
- NUREG-1439 IDENTIFIES 60.133(I) AS ONE OF THE APPLICABLE REGULATORY CRITERIA FOR ESF
- THIS STP PROVIDES GUIDANCE SPECIFICALLY ON COMPLIANCE DEMONSTRATION FOR 60.133(I)

COMMENT

- DOE'S APPROACH IN DEALING WITH THE ISSUE OF THERMAL LOADS OPPOSITE TO NRC'S APPROACH
  - DOE TREATS THERMAL LOAD AS A DESIGN FEATURE RATHER THAN A POTENTIAL ADVERSE FEATURE
  - STP SHOULD BE CONCERNED WITH THE EVALUATION OF ALTERNATIVE THERMAL LOADS TO ESTABLISH A DESIGN BASIS

RESPONSE

- 60.21(C)(II)(D) CALLS FOR A COMPARATIVE EVALUATION OF ALTERNATIVES TO MAJOR DESIGN FEATURES THAT ARE IMPORTANT FOR WASTE ISOLATION
- DESIGN GOALS/CRITERIA ARE TIED TO PERFORMANCE OBJECTIVES
- THE FINAL DESIGN RESULTING FROM THE STP PROCESS WILL HAVE AUTOMATICALLY CONSIDERED A COMPARATIVE EVALUATION
- CONSIDERATION OF WASTE ISOLATION IMPLICATIONS IS A PART OF THE ITERATIVE PROCESS

COMMENT

- NEED TO MORE CLEARLY DEFINE TERMS SUCH AS FULLY, PARTIALLY, ONE-WAY COUPLED ETC.

RESPONSE

(1) REPLACE THE PHRASE "FULLY COUPLED MODELS" WITH "COUPLED MODELS"

(2) REPLACE THE PHRASES "PARTIALLY COUPLED" AND "ONE-WAY COUPLED" MODELS WITH "SIMPLIFIED MODELS"

(3) CLARIFICATIONS

- IN THE CONTEXT OF THERMAL LOAD CONSIDERATIONS, COUPLED BEHAVIOR MEANS THAT EACH OF THE T-M-H-C PROCESSES HAS AN EFFECT ON THE INITIATION AND PROPAGATION OF ANY OF THE OTHER PROCESSES AND VICE VERSA
- A COUPLED MODEL CAN REPRESENT THE ABOVE BEHAVIOR
- A SIMPLIFIED MODEL IS AN APPROXIMATION OF THE COUPLED MODEL

COMMENT

- STP LEADS TO WHAT APPEARS TO BE AN ENDORSEMENT OF THE USE OF EXPERT JUDGEMENT WHEN EITHER THE DATA BASE IS INSUFFICIENT OR THE ITERATIVE PROCESS FAILS TO RESOLVE AN ISSUE

RESPONSE

- NUREG/CR-5411 STATES "EXPERT JUDGMENTS SHOULD NOT BE CONSIDERED EQUIVALENT TO TECHNICAL CALCULATIONS BASED ON UNIVERSALLY ACCEPTED SCIENTIFIC LAWS OR TO THE AVAILABILITY OF EXTENSIVE DATA ON PRECISELY THE QUANTITIES OF INTEREST ...... EXPERT JUDGMENTS ARE SOMETIMES INAPPROPRIATELY USED TO AVOID GATHERING ADDITIONAL MANAGEMENT OR SCIENTIFIC INFORMATION"

- STAFF ENDORSES THE NUREG/CR VIEWS

COMMENT

- PROPOSED STP METHODOLOGY NOT FEASIBLE
- LACKS TECHNICAL SPECIFICITY
- INCOMPATIBLE WITH ONGOING DOE PROGRAM

RESPONSE

- NO REASON TO BELIEVE THAT THE STP METHODOLOGY IS NOT FEASIBLE
- STP PROVIDES GENERIC GUIDANCE THROUGH A LOGICAL APPROACH
- NOT RESTRICTIVE OR OVERLY PRESCRIPTIVE
- STP APPROACH NOT INCOMPATIBLE WITH KNOWN DOE PROGRAM

SUMMARY OF RESPONSES TO THE
STATE OF NEVADA'S GENERAL COMMENT

- NO BASIC CHANGE TO THE STP
- SEVERAL CLARIFICATIONS PROVIDED
- MINOR CHANGES TO THE TEXT
- MINOR CHANGES TO THE FIGURE
- OVERALL THE STATE'S COMMENTS HELPFUL IN REDUCING AMBIGUITIES AND CLARIFYING THE TEXT OF THE STP

NRC/DOE TECHNICAL EXCHANGE

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

Presented by:

Terje Brandshaug

Itasca Consulting Group, Inc.
1313 Fifth Street SE
Suite 210
Minneapolis, Minnesota 55414

17 March 1992

SUMMARY OF DOE COMMENT NO. 1
Page iii, Abstract:

— NRC STPs cannot impose "requirements"; they may only recommend or suggest — e.g., an approach/ methodology.

— The current STP has not justified the need for coupled models.

SUMMARY OF NRC'S RESPONSE:

— DOE is correct, and the STP Abstract has been changed accordingly.

— The staff considers it prudent to follow the conservative course of recommending the use of coupled models in demonstrating compliance with 10 CFR 60.133(i).

SUMMARY OF DOE COMMENT NO. 2
Page 2, Section 1.1:

— The STP states that uncertainties associated with predicting thermally-induced responses should be understood and accommodated in the UGF design.

Because of the "disturbed zone" (DZ) concept, such understanding would not be needed.

Because of the "containment period" requirement, such understanding would not apply during this period.

SUMMARY OF NRC'S RESPONSE:

— The staff does not agree that the DZ concept and the "containment period" requirement relieve DOE from understanding thermally-induced responses in the host rock.

To establish the DZ boundary, an understanding of physical and chemical changes, including uncertainties, in the host rock is necessary.

10 CFR 60.133(i) deals with all performance objectives. Two subsystem performance objectives, 60.113(a)(1)(ii)(A-B), which contribute to the overall repository performance (under 60.112), require a clear understanding of the near-field environment (which is within the disturbed zone).

Understanding the near-field T-M-H-C environment would contribute to the design of the EBS. This would include the importance of the effects of coupled processes and related uncertainties.

SUMMARY OF DOE COMMENT NO. 3
Page 3, Section 1.1, Background:

— Groundwater flow should be expanded to mean both liquid- and vapor-phase transport.

SUMMARY OF NRC'S RESPONSE:

— The staff agrees with the DOE comment and has made the appropriate change in the STP.

SUMMARY OF DOE COMMENT NO. 4
Pages 3 and 4, Section 1.1:

— The STP discourages the use of established models in preliminary programmatic evaluations of thermal loadings.

— The STP text is also contradictory on this issue.

SUMMARY OF NRC'S RESPONSE:

— The STP does not discourage the use of established models as long as they are reliable.

— The STP text has been changed to avoid the misunderstanding.

SUMMARY OF DOE COMMENT NO. 5
Page 3, Section 1.1:

— The STP appears to be based on a notion that the thermal load will be very high. This may be a result of NRC using available but outdated information on repository conceptual design. Currently, there is no reference waste package design or heat load.

SUMMARY OF NRC'S RESPONSE:

— The recommended approach is generic.

The approach is not based on the SCP-CDR.

SUMMARY OF DOE COMMENT NO. 6
Page 4, Section 1.1:

— The staff seems to believe that only fully-coupled models can produce reliable information. We believe that reliable information can be obtained from simplified uncoupled or partially-coupled models and codes.

SUMMARY OF NRC'S RESPONSE:

— The staff has no objection to the use of simplified models if DOE substantiates that the use of such models is consistent with the principle stated in the staff's response to the DOE general comment.

SUMMARY OF DOE COMMENT NO. 7
Page 4, Section 1.2:

— The STP expresses the staff's expectation of fully-coupled models by the time of application for the license to receive, possess, and emplace waste.

— If, at CA, NRC finds, with reasonable assurance, that the models are reliable, then there is no reason to develop fully-coupled models at the time of licensing.

SUMMARY OF NRC'S RESPONSE:

— Section 1.2 of the STP does not convey an expectation of fully-coupled models, but an expectation of progressively better understanding of T-M-H-C responses which may be reflected in new (conceivably fully-coupled) predictive models.

— It is entirely possible that there is no need to further develop predictive models after CA as long as DOE can demonstrate this.

SUMMARY OF DOE COMMENT NO. 8
Page 7, Section 3.0:

- Compliance demonstration with 10 CFR 60.133(i) would not need a full understanding of coupled effects because of the restricted spatial and short temporal extent over which these effects are significant.

- Our interpretation of the regulations is that the design will not preclude compliance with the performance objectives (PO).

SUMMARY OF NRC'S RESPONSE:

- Understanding of the T-M-H-C processes should be pursued, consistent with the principle stated in the staff's response to the DOE general comment.

- In DOE's interpretation, the PO are peripheral to the design process. This may lead to a design which fails to meet the PO. 10 CFR 60.133(i) conveys the proactive response " ... shall be designed so that the performance objectives will be met." This implies that the design process is impacted directly by the requirement (e.g., via design goals/criteria correlated to PO).

SUMMARY OF DOE COMMENT NO. 9
Pages 8 to 10, Section 3.1:

— The STP suggests an approach for developing fully-coupled models which is needed to show compliance with 10 CFR 60.133(i).

— Before requesting a fully-coupled model, its need should be established. The recommended approach does not establish a need for a fully-coupled model.

— The suggested approach should expand on the more sensible concept presented in Appendix C.

SUMMARY OF NRC'S RESPONSE:

— The approach describes a logical process to demonstrate compliance with 10 CFR 60.133(i), and not a process for developing fully-coupled models.

— The need for and level of coupling depend on what is learned through the examination of thermally-induced phenomena, Step No. 3 in the approach.

— The concept in Appendix C could not take the place of the suggested approach. Rather, it may be a product of iterations between Step Nos. 2 and 5 of the approach.

SUMMARY OF DOE COMMENT NO. 10
Page 8, Section 3.1:

— Design goals/criteria must be developed before existing models are used to show compliance with 10 CFR 60.133(i). Therefore, steps two and four in the suggested approach should be reversed.

SUMMARY OF NRC'S RESPONSE:

— The development of design goals/criteria (Step No. 4) is an integral part of the suggested approach and will contribute to the UGF design meeting the PO. The use of existing models is an alternate "exit" path from Step No. 2 in this approach. Figure 1 shows that, regardless of the "exit" path from Step No. 2, the development of design goals/criteria is performed before the models are used in UGF design analyses to show compliance with 10 CFR 60.133(i).

SUMMARY OF DOE COMMENT NO. 11
Page 8, Section 3.1:

— Clarification is needed regarding the use of "defensible models" in Step No. 3.

SUMMARY OF NRC'S RESPONSE:

— This comment is unclear to the staff, as Step No. 3 does not pertain to the use of "models".

SUMMARY OF DOE COMMENT NO. 12
Page 9, Section 3.1:

— Step No. 8 in the suggested approach appears to contradict other NRC guidance which advises DOE to perform preliminary and iterative performance assessments.

SUMMARY OF NRC'S RESPONSE:

— In the context of NRC's iterative performance assessment efforts (NRC, in press), the staff positions advocated in this STP are consistent with this effort. The approach described in Technical Position 3.1 and illustrated in Figure 1 clearly suggests that the entire process is iterative (see loop-back from Step No.8 in Figure 1).

SUMMARY OF DOE COMMENT NO. 13
Page 10, Section 3.2:

— NRC has not provided any compelling reason to develop fully-coupled models.

— A fully-coupled model may be impossible to validate in the classical sense of the term.

SUMMARY OF NRC'S RESPONSE:

— The staff has already responded to DOE's questioning of the need for coupled models in the responses to DOE comments Nos. 1 and 9.

— The staff agrees with DOE's assertion; however, the same assertion would be true of models exhibiting lesser degrees of coupling.

SUMMARY OF DOE COMMENT NO. 14
Page 10, Section 3.3:

— Define the meaning of "synergistic effects of T-M-H-C interactions".

SUMMARY OF NRC'S RESPONSE:

— This term has been replaced by "coupled effects", and has been defined in the STP.

SUMMARY OF DOE COMMENT NO. 15
Page 10, Section 3.3:

— Models cannot affect performance objectives.

SUMMARY OF NRC'S RESPONSE:

— The staff agrees, and the STP text has been changed.

SUMMARY OF DOE COMMENT NO. 16
Page 10, Section 4.0:

- In accordance with 10 CFR 60.133(i), the STP should state that the UGF design should not preclude compliance with the PO.

- The overall performance (10 CFR 60.112) and groundwater travel time (10 CFR 60.113(a)(2)) are oriented toward natural barriers that cannot be designed.

SUMMARY OF NRC'S RESPONSE:

- 10 CFR 60.133(i) expresses a requirement in proactive terms. This implies that the UGF design process will be impacted directly by the requirement, for example by developing design goals/criteria which are correlated to the performance objectives.

- The STP does not deal with "natural barriers". However, the UGF design may have an impact on the ability to meet the POs. Thus, considerations must be given in the design (e.g., through design goals/criteria) to meet (as required by 60.133(i)) these POs. Further elaboration is provided in NRC's response to the DOE general comment.

SUMMARY OF DOE COMMENT NO. 17
Page 11, Section 4.1:

— DOE recommends that the NRC staff explicitly connect early programmatic decisions with simplified models.

SUMMARY OF NRC'S RESPONSE:

— If simplified models reflect the understanding and experience that are necessary in the UGF design analyses, and they are reliable and defensible, then there is no need for more sophisticated models, as noted in the STP. Also, see the staff response to DOE comment No. 4.

SUMMARY OF DOE COMMENT NO. 18
Page 11, Section 4.1:

— There are six performance objectives — not three, as stated.

SUMMARY OF NRC'S RESPONSE:

— The three performance objectives referred to are 10 CFR 60 111, 60.112 and 60.113. The staff has clarified the STP text.

SUMMARY OF DOE COMMENT NO. 19
Page 11, Section 4.1:

— PA evaluation after meeting the design goals is inconsistent with advice given DOE by NRC.

— PA at the end of the process would be too late, particularly if goals and criteria can be met but the PO may not be met.

SUMMARY OF NRC'S RESPONSE:

— The staff disagrees with DOE's assertion regarding inconsistency. The approach, as illustrated in Figure 1, clearly suggests that the entire process is iterative.

— DOE is referred to STP Section 4.1, where a suggestion for developing design goals/criteria is provided via steps (a) to (c). Although not explicitly stated, Step (c) may very well include an evaluation of the design goals/criteria by PA model(s).

SUMMARY OF DOE COMMENT NO. 20
Page 12, Section 4.1:

— The STP text refers to Figure 1 and decision points at which the process may be terminated. No such termination is indicated in Figure 1.

SUMMARY OF NRC'S RESPONSE:

— The staff agrees with the DOE comment and has changed the STP text accordingly.

SUMMARY OF DOE COMMENT NO. 21
Page 13, Section 4.1:

— NRC should define the meaning of "phenomenological coupling".

SUMMARY OF NRC'S RESPONSE:

— The staff has removed the word "phenomenological" and changed the STP text accordingly. A definition of coupled behavior has been included in the STP.

SUMMARY OF DOE COMMENT NO. 22
Page 16, Section 4.1:

— The STP cites NUREG/CR-5428 as an example of heat transfer predictions. NUREG/CR-5428 reflects T-M coupling only and, therefore, is in conflict with previous STP text expecting understanding of coupled effects.

SUMMARY OF NRC'S RESPONSE:

— NUREG/CR-5428 reports only on transient conduction heat transfer analyses. No evaluation of mechanical effects are included. The citation is used in the STP context to illustrate the process of performing analyses and comparing the results to "design goals" over a range of design conditions. Thus, use of the citation is not in conflict with the STP text.

SUMMARY OF DOE COMMENT NO. 23
Page 17, Section 4.1:

- Step No. 9 in the suggested approach falsely implies that compliance with the PO is a prerequisite for compliance demonstration with 60.133(i).

- DOE's interpretation of 60.133(i) is to: (1) design an UGF; and (2) meet the PO.

SUMMARY OF NRC'S RESPONSE:

- Many aspects of repository siting and design contribute to 10 CFR 60 POs. Compliance demonstration with 60.133(i) is one such aspect. Because of this contributing aspect, the UGF design must be conducted in parallel and/or iteratively with the PO evaluation. The sequential but independent design and PO evaluation suggested by DOE would not accomplish the intent of the regulations.

SUMMARY OF DOE COMMENT NO. 24
Page 18, Section 4.2:

— DOE does not believe that predictive models can be used to analyze canister-scale, room-scale, repository-scale and regional-scale with phenomenological detail.

SUMMARY OF NRC'S RESPONSE:

— The STP text speaks of "appropriate" phenomenological detail in the context of DOE's comment, not of equal phenomenological detail. Understanding of T-M-H-C processes and site characteristics may vary for different scales. Therefore, the levels-of-detail in the models may vary accordingly.

SUMMARY OF DOE COMMENT NO. 25
Page 19, Section 4.2:

— The STP text expresses that oversimplification in modeling may obscure the understanding of coupled processes. Overly complex models, even more so than simple models, may obscure the understanding of coupled processes. Therefore, the STP text referring to oversimplification in modeling in this context should be deleted.

SUMMARY OF NRC'S RESPONSE:

— The staff directs DOE's attention to the entire paragraph, which expresses concern about the use of both overly complex and overly simple models, and the need to strike a balance that is workable. In this context, the STP text in question is appropriate.

SUMMARY OF DOE COMMENT NO. 26
Page 19, Section 4.2:

— Because the particle surface area per unit volume is a major factor in determining reaction rates, the range of grain size would be needed in order for porosity and permeability to be useful parameters in a chemical model. The STP text needs to be corrected.

SUMMARY OF NRC'S RESPONSE:

— The focus of the STP text referred to in DOE's comment is to give examples of potential response measures that may be used for the evaluation of UGF design adequacy. It is not a discussion of input parameters for proper modeling.

SUMMARY OF DOE COMMENT NO. 27
Page 21, Section 4.2:

— The STP text should use the terms "validation" and "verification" consistent with the definitions in Appendix A and in NUREG-0856.

SUMMARY OF NRC'S RESPONSE:

— The staff agrees, and the STP text has been changed accordingly.

SUMMARY OF DOE COMMENT NO. 28
Page 25, Figure 1:

- The logic flow after Step No. 8B is not closed.
- Clarification is needed as to when Step No. 7A is invoked.

SUMMARY OF NRC'S RESPONSE:

- Regarding Step No. 8B, DOE is referred to STP Section 4.1, where a discussion is provided of what takes place beyond Step No. 8B.
- If a design goal/criterion is exceeded (e.g., maximum borehole wall temperature), Step 7A is invoked. A design change is made (e.g., increase borehole spacing), and the logic flows back to Step No. 6 (i.e., re-analysis of the new UGF design).

SUMMARY OF DOE COMMENT NO. 29
Page 26, Appendix A:

— The definition of a fully-coupled model is not clear.

— What level of coupling is expected? For some processes, the secondary effects cannot be ignored and a fully-coupled model that includes weak coupling may be needed.

— It appears the word "model" is used to mean a conceptual mode as well as a numerical code.

SUMMARY OF NRC'S RESPONSE:

— Difficulty in interpreting the meaning of "fully-coupled" is noted. A new definition has been provided.

— Despite the complexities associated with characterization of coupled processes, the staff recognizes that the importance of coupled processes should be explored so that their effects if necessary could be (1) included in model(s), and/or (2) included as an uncertainty into the results of models, which may not directly account for the effects of coupling. An assessment of the importance of the coupled effects will contribute to the "reasonable assurance finding" that the repository will perform as intended.

— The term "model" as used in the STP does not refer to a numerical code.

NRC/DOE TECHNICAL EXCHANGE
STAFF TECHNICAL POSITION ON GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS

PRESENTED BY

SIMON HSIUNG

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

March 17, 1992

Summary of State Specific Comment No. 1
Page 1, paragraph 1

- Lack of detail regarding how to demonstrate a comprehensive, systematic and logical understanding of coupled T-M-H-C responses associated with an underground facility design

Summary of NRC's Response

- Sufficient details provided in Sections 3.0 and 4.0 of the STP

Summary of State Specific Comment No. 2
Page 2, paragraph 1

- The statement "The staff expects that, through the pursuit of appropriate technical programs, DOE would develop information that would enhance considerably the approach in this document" is to presume that DOE will choose the approach outlined in the STP.

- The staff seems to be lacking confidence regarding the adequacy of the suggested approach.

Summary of NRC's Response

- DOE does not have to follow this STP.

- Other methods may also lead to a compliance demonstration.

- The staff believes that the suggested approach will lead to an adequate demonstration of compliance with thermal loads considerations.

Summary of State Specific Comment No. 3
Page 2, paragraph 2

- Concern regarding the suggested methodology relying on the existence of performance assessment models

Summary of NRC's Response

- Ongoing focused DOE and EPRI programs for developing and testing performance assessment models

Summary of State Specific Comment No. 4
Page 2, paragraph 2

- Elaboration on the different aspects of performance assessments would be helpful in identifying appropriate data collection and analysis during site characterization.

Summary of NRC's Response

- Beyond the scope of this STP

- Format and Content Regulatory Guide (FCRG) providing additional guidance regarding the kinds and levels of data to be presented in the License application

Summary of State Specific Comment No. 5
Page 4, paragraph 1

- Elaboration on relevant "current engineering experience" to assist a better understanding on the focus of the thermal loads STP

Summary of NRC's Response

- Deep hard-rock mining experience -- pre-closure performance objectives

- Natural analogs, conditions associated with geothermal regions -- guiding post-closure performance evaluations

Summary of State Specific Comment No. 6
Page 5, paragraph 2

- Change the word "could" to "should" in the sentence "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 issuance of a construction authorization (so long as there is reasonable assurance of safety)."

Summary of NRC's Response

- The staff agrees with the recommendation.

  Revised to read "If there is an unresolved safety question relating to model validation, this should be described in the application. The existence of such a question may, of course, reduce the Commission's confidence that the standards for issuance of a construction authorization have been satisfied. Depending upon the nature of the unresolved safety question and the prospects for resolving it favorably, there may be reasonable assurance that applicable requirements have been met and, on that basis, a construction authorization might be issued."

Summary of State Specific Comment No. 7
Page 8, paragraph 2

- Step No. 1 of the suggested methodology will never be revisited.

- Outline the type and level of data and the maturity of underground facility design needed for the Step No. 1 determination

Summary of NRC's Response

- Reapplication of the entire methodology for any significant change to the design concept

- DOE's responsibility for justifying data used

Summary of State Specific Comment No. 8
Page 8, paragraph 3

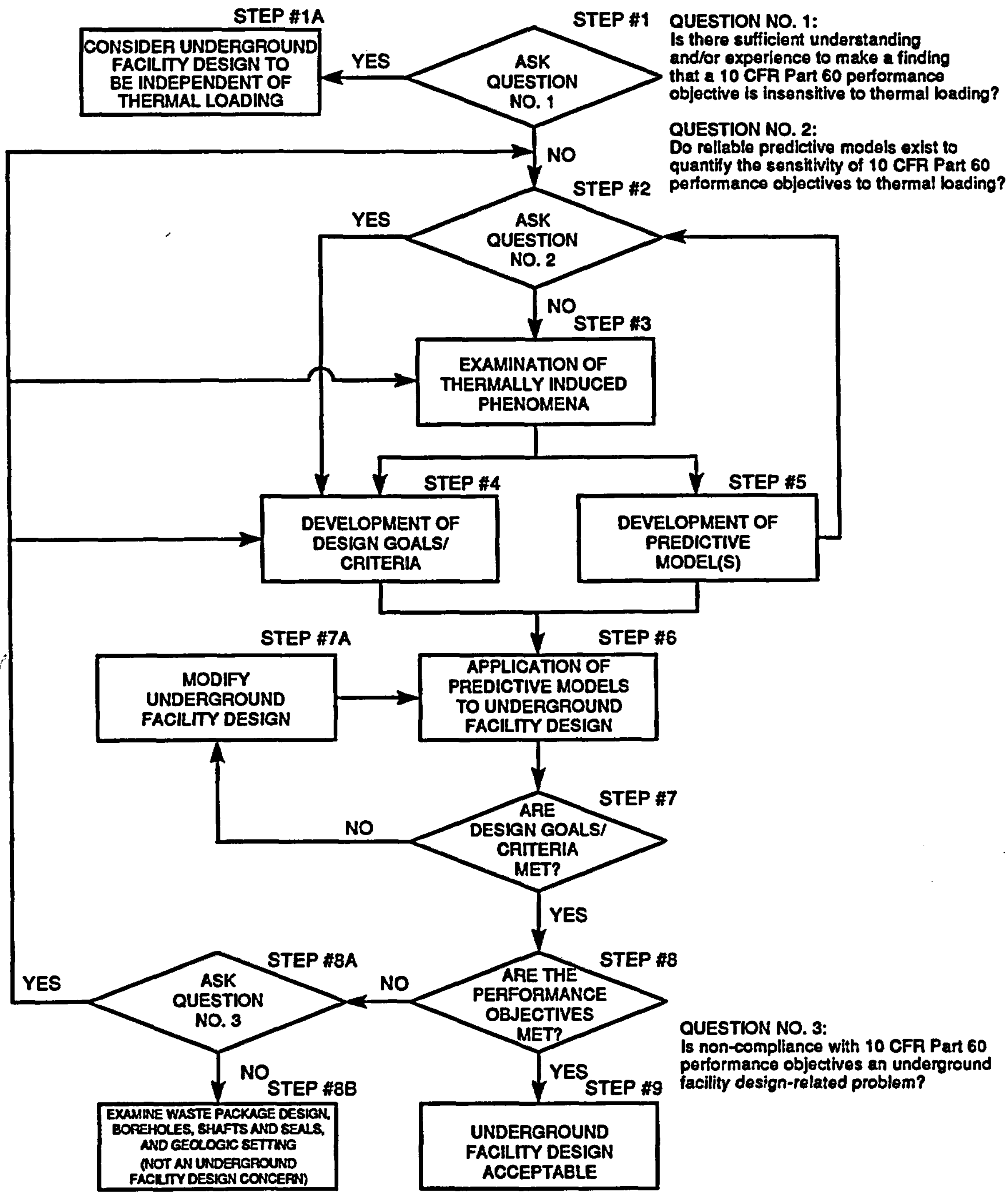
- Need for site-specific information to demonstrate the reliability of the models used in Step No. 2

- Need to revisit Step No. 2

Summary of NRC's Response

- Discussion regrading the first bullet is in the STP Section 4.2.

- Modify the recommended approach to include a return from Step No. 5 to Step No. 2 (Figure 1 changed according)


STEP #1A
CONSIDER UNDERGROUND FACILITY DESIGN TO BE INDEPENDENT OF THERMAL LOADING
YES
STEP #1
ASK QUESTION NO. 1
QUESTION NO. 1:
Is there sufficient understanding and/or experience to make a finding that a 10 CFR Part 60 performance objective is insensitive to thermal loading?
NO
QUESTION NO. 2:
Do reliable predictive models exist to quantify the sensitivity of 10 CFR Part 60 performance objectives to thermal loading?
STEP #2
YES
ASK QUESTION NO. 2
NO
STEP #3
EXAMINATION OF THERMALLY INDUCED PHENOMENA
STEP #4
DEVELOPMENT OF DESIGN GOALS/ CRITERIA
STEP #5
DEVELOPMENT OF PREDICTIVE MODEL(S)
STEP #7A
MODIFY UNDERGROUND FACILITY DESIGN
STEP #6
APPLICATION OF PREDICTIVE MODELS TO UNDERGROUND FACILITY DESIGN
STEP #7
NO
ARE DESIGN GOALS/ CRITERIA MET?
YES
STEP #8A
STEP #8
YES
ASK QUESTION NO. 3
NO
ARE THE PERFORMANCE OBJECTIVES MET?
QUESTION NO. 3:
Is non-compliance with 10 CFR Part 60 performance objectives an underground facility design-related problem?
NO
STEP #8B
YES
STEP #9
EXAMINE WASTE PACKAGE DESIGN, BOREHOLES, SHAFTS AND SEALS, AND GEOLOGIC SETTING (NOT AN UNDERGROUND FACILITY DESIGN CONCERN)
UNDERGROUND FACILITY DESIGN ACCEPTABLE

Summary of State Specific Comment No. 9
Page 8, paragraph 4

- Need to outline the type and level of data necessary for Step No. 3 (Examination of the thermally induced phenomena)

- Need to discuss the method for and scope of the examination

Summary of NRC's Response

- Purview of DOE

- DOE's submittal subject to continued NRC review

Summary of State Specific Comment No. 10
Page 8, paragraph 5

- Recommend to include an evaluation of alternative design goals/criteria based on various magnitudes and rates of thermal loading in Step No. 4

- Need to demonstrate basis for design goals/criteria

Summary of NRC's Response

- Design goals/criteria from performance objectives

- Alternative thermal loads based on design goals/criteria

Summary of State Specific Comment No. 11
Page 9, paragraph 6

- Step No. 8B precluding thermal load consideration for "other" engineering criteria such as those for waste package design, boreholes, shafts, and seal design.

Summary of NRC's Response

- Suggested methodology for 10 CFR 60.133(i) compliance demonstration

- Thermal loads considerations are needed for waste package design, boreholes, shafts, and seals design and the geologic setting concerns.

Summary of State Specific Comment No. 12
Page 10, paragraph 3

- Clarify the statement "Develop models that approximate fully coupled behavior in a manner that is not likely to adversely affect the performance objectives..."

- Provide guidance for bounding such an approximation and data needs

Summary of NRC's Response

- Modified to read "(a) develop models that approximate coupled behavior in a manner that is not likely to underestimate the unfavorable or overestimate the favorable aspects of repository performance (e.g., 10 CFR 60.111, 60.112, and 60.113)"

Summary of State Specific Comment No. 13
Page 17, paragraph 2

- Continued noncompliance of a design should result in a consideration of site disqualification.

Summary of NRC's Response

- This STP for 10 CFR 60.133(i) compliance demonstration

- The steps in the suggested approach not designed for site qualification determination

- Site qualification determination in accordance with the 10 CFR Part 960

Summary of State Specific Comment No. 14
Page 17, paragraph 3

- Same as Specific Comment No. 11

Summary of NRC's Response

- See response to Specific Comment No. 11

Summary of State Specific Comment No. 15
Page 19, paragraph 1

- The statement "The analyst should choose a model that strikes a balance between workable detail and oversimplification of the process 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 phenomenon being modeled." does not provide useful guidance and encourages the use of expert judgment.

Summary of NRC's Response

- The statement is a recognition of the complexity of the T-M-H-C coupled problem and should be viewed in context of the overall, more extensive discussion related to the development of detailed predictive models.

Summary of State Specific Comment No. 16
Page 34, paragraph 2

- Need for evaluating alternative orders of consideration for Figure C1 and demonstrating the basis for selection

- Word "licensee" should not be in the STP.

Summary of NRC's Response

- The order selected should be demonstrated to be the most appropriate.

- The staff agrees and the term "licensee" has been replaced by "DOE."

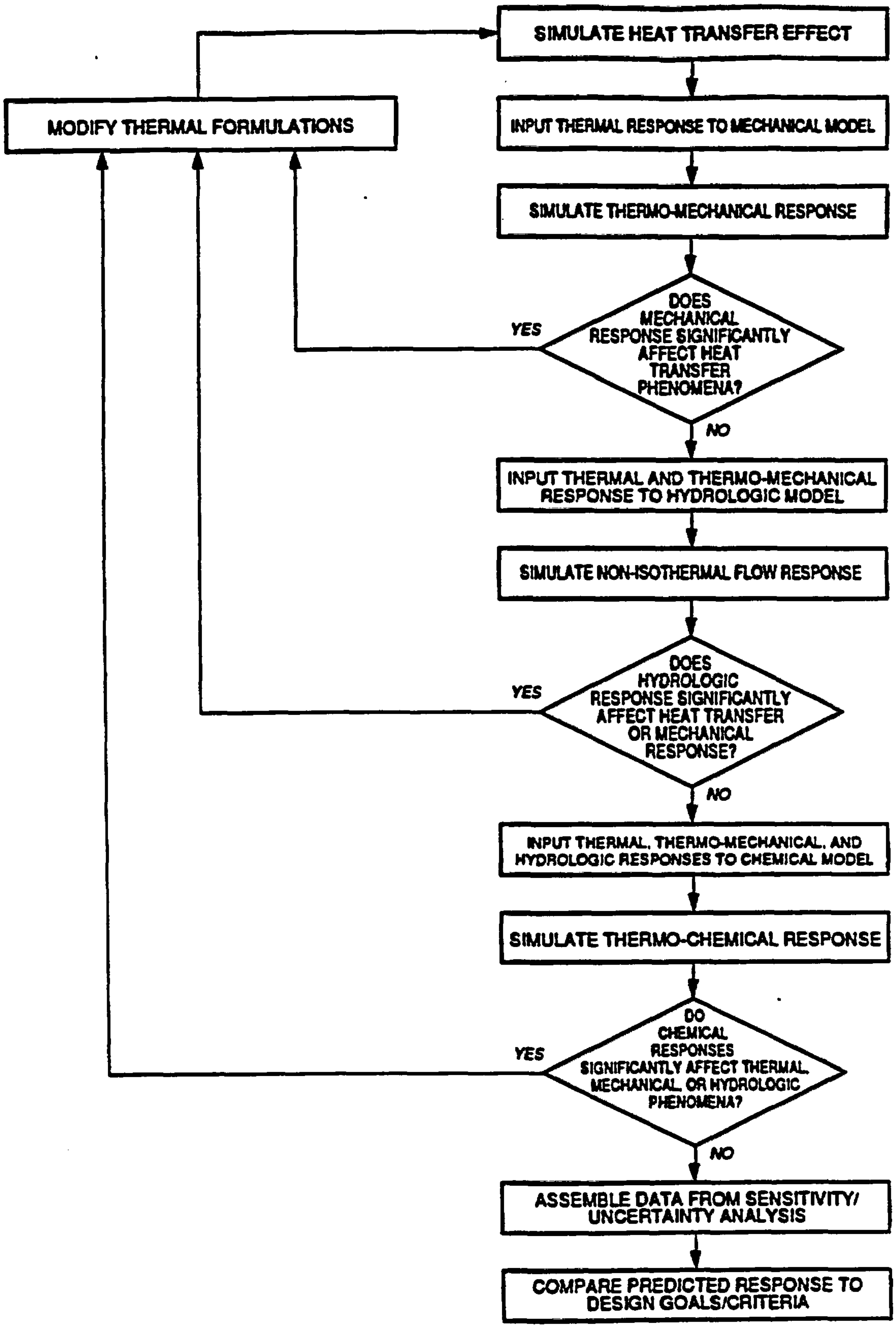


FIGURE C1 -- Example of an Iterative Process for the Analysis of Thermally Induced Phenomena Based on One-Way Coupling.

Summary of State Specific Comment No. 17
Page 34, paragraph 3

- Regarding the use of "licensee"

Summary of NRC's Response

- See response to Specific Comment No. 16

ATTACHMENT 6

NRC/DOE TECHNICAL EXCHANGE ON DRAFT STAFF TECHNICAL POSITION (STP) ON GEOLOGIC REPOSITORY OPERATIONS AREA UNDERGROUND FACILITY DESIGN -- THERMAL LOADS

STATE OF NEVADA COMMENTS

The State of Nevada is satisfied with the NRC staff's responses to the State's comments on the STP. In its closing remarks, the State reiterated two points presented in its comments and in staff responses.

1. A cornerstone of the STP is the assumption that Performance Assessment (PA) models will exist for evaluating compliance with 10 CFR Part 60 performance objectives. NRC staff in response to a State comment asserted that the assumption was reasonable, and cites the PA efforts of NRC, DOE, and the Electric Power Research Institute (EPRI) to support the assumption. While the State does acknowledge the present efforts of NRC, DOE, and EPRI in PA, it is skeptical of the staff's assertion that adequate PA models will exist for evaluating compliance with 10 CFR Part 60. The current level of PA model sophistication, especially when coupled with the present schedule for site characterization, does not seem to support such an optimistic view.

2. The State agrees with the staff's response that the Geologic Repository Operations Area design is an iterative process. Thermal loads are a key component in assessing whether designs meet performance objectives. The State does not agree with the staff's response that the iterative process covers the period of design, construction, and operation. For Yucca Mountain, the iterative process begins with Exploratory Studies Facility Title I design and continues to the final repository design which accompanies the construction license application. The design including the assessment of the effects of thermal loads on the design must be sufficiently mature to meet 10 CFR Part 60 requirements with reasonable assurance. Construction and operation phases provide confirmation that the design presented in the license application is adequate. As the State understands 10 CFR Part 60, construction and operation phases are not for iteratively increasing the maturity of repository design.

ENCLOSURE 2

SUMMARY OF THE NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT DUE TO THERMAL GRADIENTS

March 18, 1992
Albuquerque, New Mexico

On March 18, 1992, staff from the Nuclear Regulatory Commission, the U.S. Department of Energy (DOE), the State of Nevada, and DOE program participants attended a technical exchange for the purpose of discussing technical and regulatory issues related to evaluating gas transport and moisture redistribution due to repository-induced thermal gradients. Other Affected Units of Local Government were notified of the meeting, but did not attend. The technical exchange focused on gas flow in Yucca Mountain, Nevada, both natural and induced by repository thermal loads, and its potential for transporting gaseous radionuclides, especially carbon-14. Attachment 1 is the list of the attendees.

The opening series of presentations were made by DOE. (See attachment 2 for the agenda.) Overall, there were five DOE presentations. In its first presentation, E. Weeks, of the U.S. Geological Survey, provided some background on naturally occurring air flow at Yucca Mountain. The second presentation was made by K. Preuss of Lawrence Berkley Laboratories and focused on recent results of the modeling of two-phase flow at Yucca Mountain using the TOUGH code. T. Buscheck of Lawrence Livermore National Laboratories made the third presentation, again on the modeling of two-phase flow at Yucca Mountain. This presentation focused on the near-field phenomena in the vicinity of the waste packages using an adaption of the TOUGH code called V-TOUGH. The fourth presenter was B. Ross of Disposal Safety Inc. (DSI), a contractor to Sandia National Laboratories, who discussed the use of the TGIF model for gas flow at Yucca Mountain. The final DOE speaker was M. Wilson of Sandia National Laboratories who spoke about DOE's efforts to include carbon-14 modeling in its performance assessment efforts.

NRC's presentations consisted of two parts (see attachment 3). In the first part, R. Wescott made a series of short presentations that described NRC's Iterative Performance Assessment (IPA) efforts in regard to carbon-14 transport. It was noted that NRC's IPA program relies upon an adaption of the carbon-14 transport model developed by DSI.

The second series of presentations was conducted by R. Codell and covered three areas: NRC's geochemical model for carbon and carbon-14 transport through rock; NRC's carbon-14 source term model; and the release of volatile radionuclides other than carbon-14 due to volcanic disruptive events.

ENCLOSURE 2

The State of Nevada's comments regarding the technical exchange are summarized in attachment 4.

4.20.92

Michael P. Lee
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission

4/23/92

Priscilla Bunton
Regulatory Integration Branch
Office of Systems and
Compliance
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy

ATTACHMENT 1

ATTENDEES AT THE MARCH 18, 1992, NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT DUE TO THERMAL GRADIENTS

DOE
P. Bunton
T. Bjerstedt
J. Boak
C. Einberg
A. Berusch
D. Harrison-Giesler
S. Borg

TESS+
S. LeRoy
M. Lugo
R. Datta
B. Distel
B. Packer
W. Matysriela
M. Reeves
C. Johnson

SAIC###
R. Morissette
U. Park
C. Pflum

SNL$$
M. Wilson
G. Barr
T. Blejwas
H. Dockery
P. Kaplan
T. Robey

NRC
M. Lee
R. Codell
R. Wescott

CNWRA**
R. Manteufel

ITASCA
T. Brandshaug

State of Nevada
C.A. Johnson
M. Mifflin

LLNL#
T. Buscheck
R. van Konynenburg
J. Blink

LANL$
D. Bish
G. Zyuoloski
G. Valentine

Weston
D. Rasmussen
H. Cleary
C. Noronha
H. Minwalla

LBL*
K. Preuss

Intera
M. Reeves

DSI***
B. Ross

BNL++
T. Sullivan

USGS+++
R. Wallace
D. Hoxie

NWTRB##
R. Luce
R. McFarland

*	Lawrence Berkley Laboratory
**	Center for Nuclear Waste Regulatory Analyses
***	Disposal Systems Inc.
+	TRW Environmental Safety Systems
++	Brookhaven National Laboratory
+++	U.S. Geological Survey
#	Lawrence Livermore National Laboratory
##	U.S. Nuclear Waste Technical Review Board
###	Science Application International Corporation
$	Los Alamos National Laboratory
$$	Sandia National Laboratory

ATTACHMENT 2

AGENDA
NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT DUE TO THERMAL GRADIENTS

AGENDA ITEM	DISCUSSION LEAD
- Opening Remarks	NRC, DOE, State
- DOE Modeling Approach	DOE
- Introduction	
- Physical characteristics of air circulation through Yucca Mountain	
- Modeling of non-isothermal flow effects at Yucca Mountain	
- Modeling and analysis of repository-heat-driven flow at Yucca Mountain	
- Temperature-driven gas transport and carbon-14	
- Integration of gaseous release results in total system performance assessment	
- NRC Modeling Approach	NRC
- Introduction	
- Driving forces for gas flow through Yucca Mountain	
- NRC's gas flow model for Yucca Mountain	
- NRC/CNWRA carbon-14 geochemical model	
- Other volatile radionculides that should be considered in modeling	
- Incorporation of volcanic effects into the model	
LUNCH	
- State of Nevada Comments	State
- Open Discussion	All
- Closing Remarks	All

GAS TRANSPORT BY INDUCED THERMAL GRADIENTS THROUGH YUCCA MOUNTAIN NRC's ITERATIVE PERFORMANCE ASSESSMENT

Rex Wescott and Richard Codell

March 18, 1992

NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT DUE TO THERMAL GRADIENTS
Albuquerque, New Mexico

ATTACHMENT 3

NRC ITERATIVE PERFORMANCE ASSESSMENT
PHASE 1

SCOPING CALCULATION OF C-14 RELEASE

NRC SOURCE TERM MODEL

Probabilistic Failure Model

Prompt Release From Failed Canisters

Release Rate Based On Spallation
Of Uranium Dioxide

TRAVEL TIMES FROM DSI CALCULATIONS

Steady State Velocities Integrated Over Time

Fractional Release Of Source Based On Travel Time
And Radioactive Decay Rate

RESULTS WERE FRACTION OF RELEASE OF C-14 INVENTORY VS.TIME

IPA PHASE 2 OBJECTIVES

PRODUCE A COMPUTER MODULE FOR THE SYSTEMS CODE WHICH:

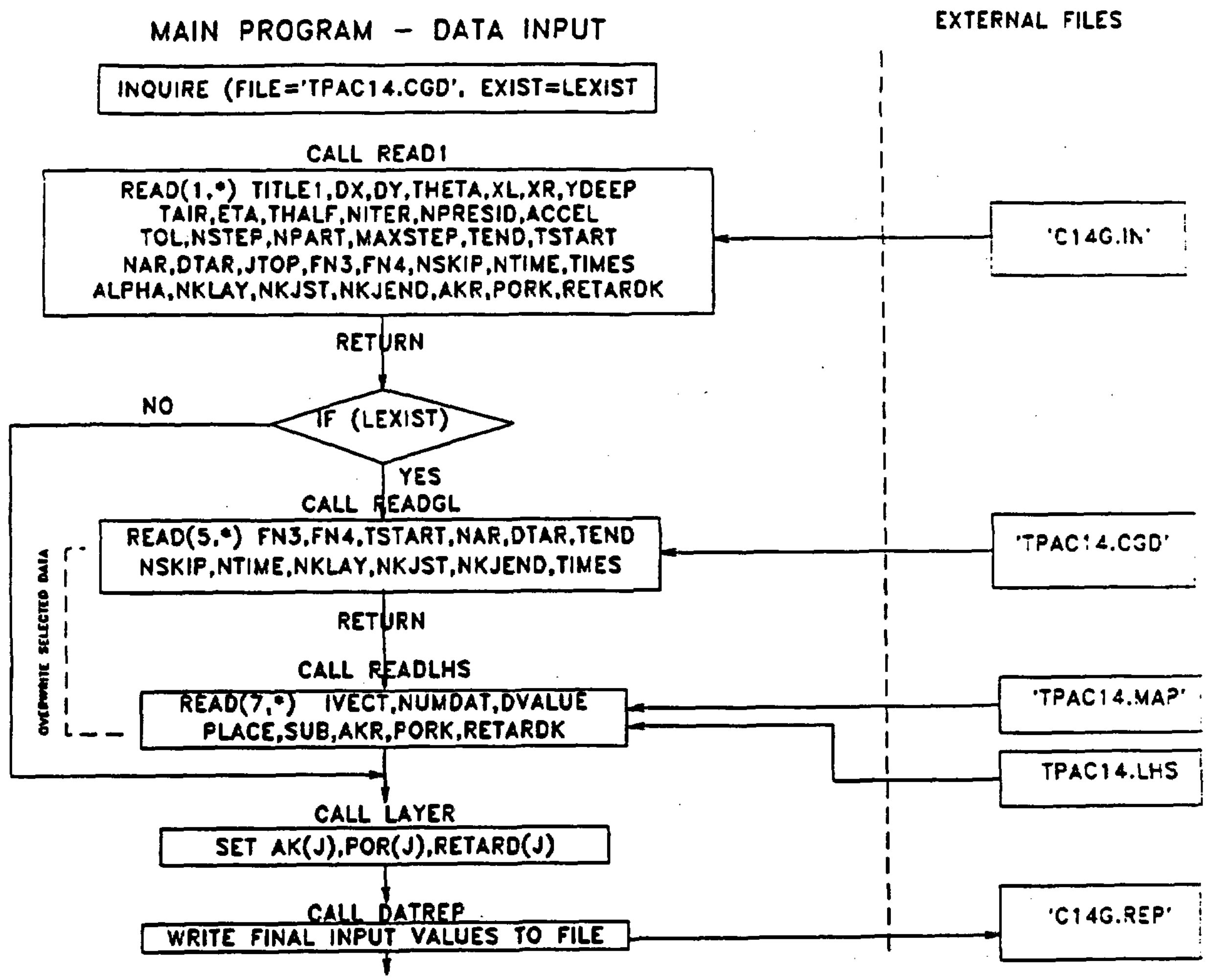
- Allows input of a range of hydrologic properties by the systems code
- Can be used with different thermal loadings and heat transfer conditions
- Will supply release factors compatible with source term and CCDF computational modules
- Has a reasonably fast convergence time
- May be used for scenarios affecting vapor transport

CHOICE OF DSI MODEL

- Results appeared to agree with those from TOUGH simulations (Tsang and Pruess, 1987)
- Derivation of terms was well documented
- Could be easily programmed and solved by simple solution methods
- Could be developed and run on a PC
- Working model could be developed early and evaluated

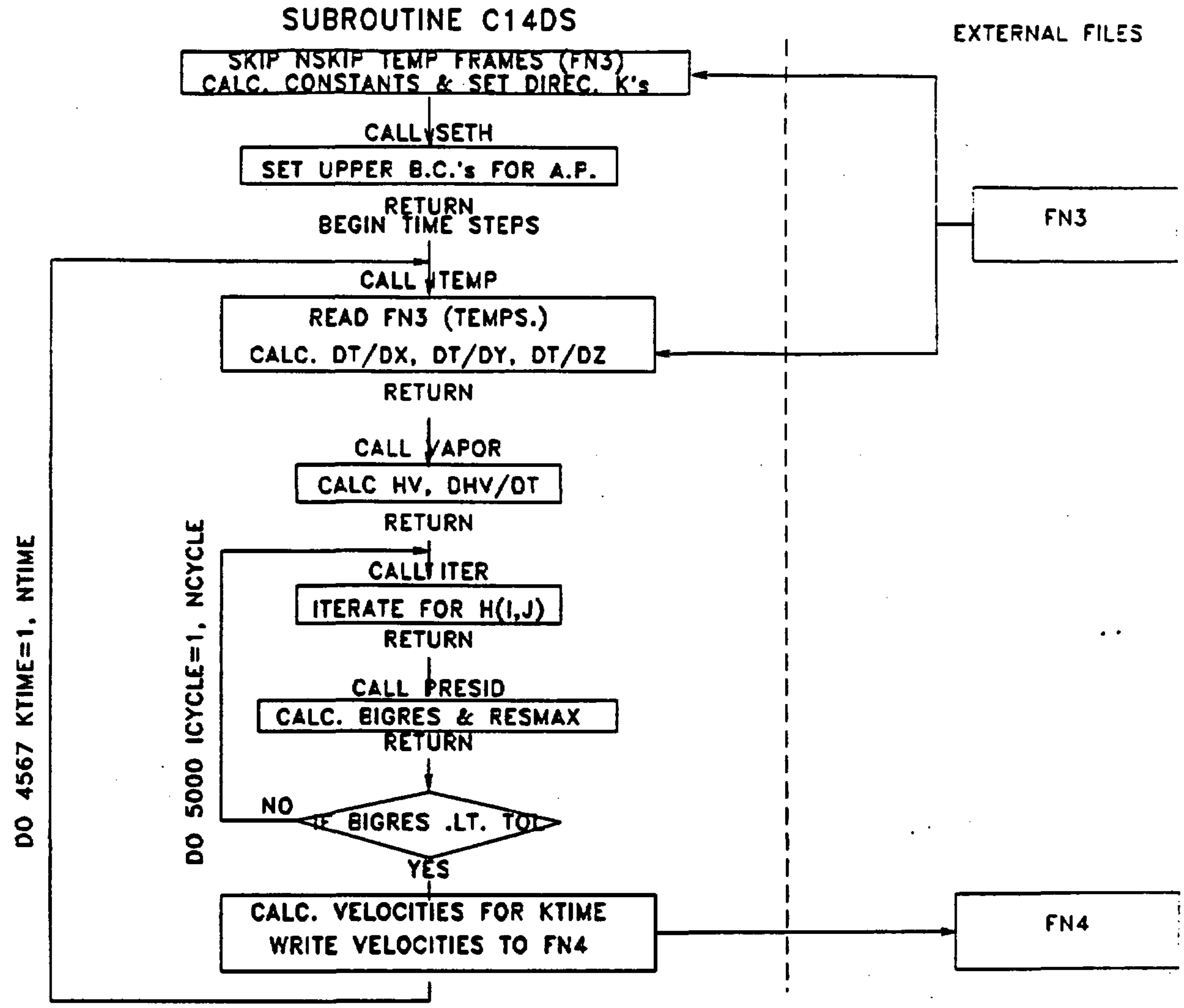
MODIFICATIONS TO DSI MODEL

- Use Of Block Centered Scheme
- Inclusion Of Permeability Gradient Term
- Use Of Formulas For Vapor Pressure And Viscosity As A Function Of Temperature
- Calculation Of Temperature From Repository Heat Load
- Multiple Steady State Velocity Fields Used For Particle Tracing



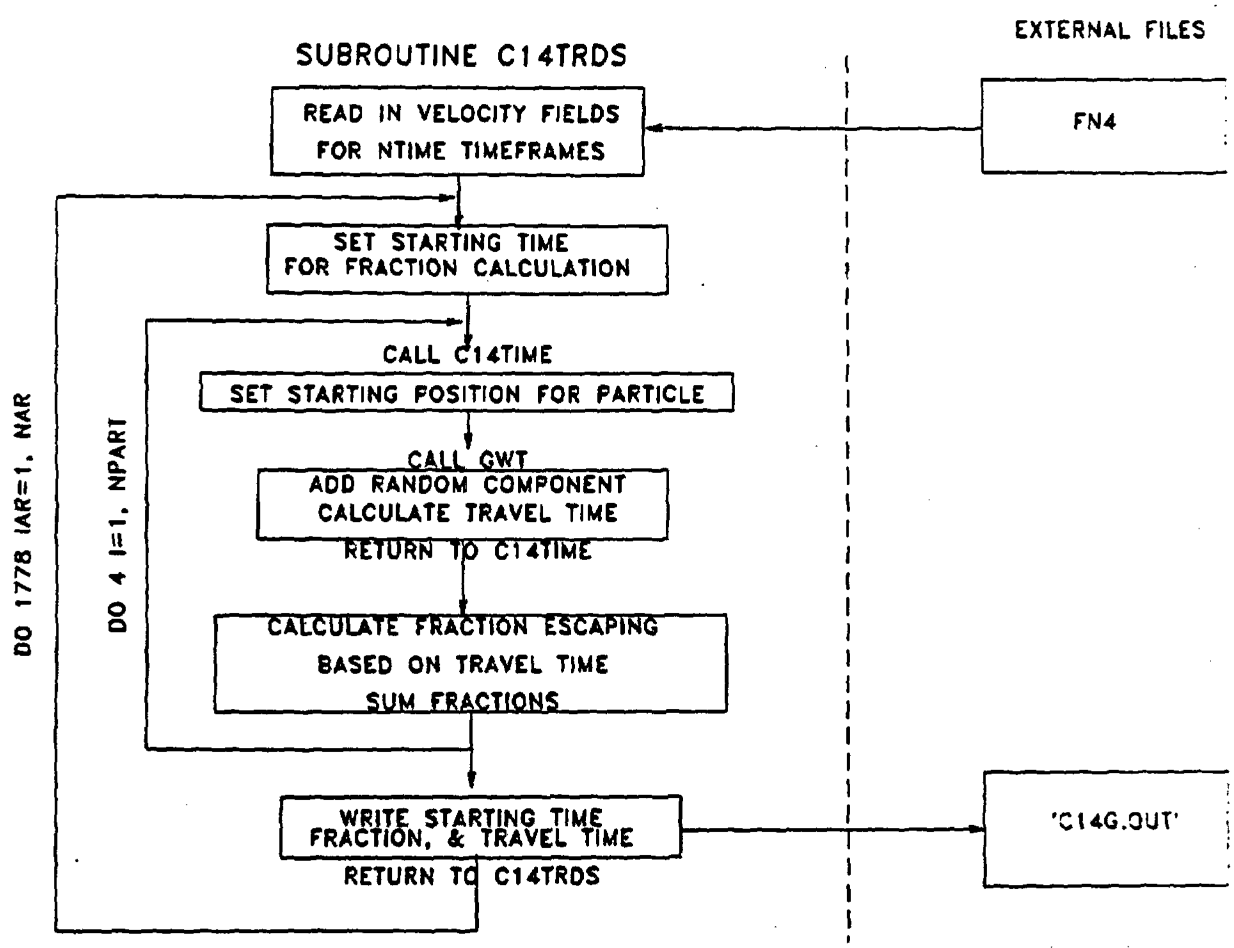
MAIN PROGRAM - DATA INPUT
EXTERNAL FILES
INQUIRE (FILE='TPAC14.CGD', EXIST=LEXIST
CALL READ1
READ(1,*) TITLE1,DX,DY,THETA,XL,XR,YDEEP
TAIR,ETA,THALF,NITER,NPRESID,ACCEL
TOL,NSTEP,NPART,MAXSTEP,TEND,TSTART
NAR,DTAR,JTOP,FN3,FN4,NSKIP,NTIME,TIMES
ALPHA,NKLAY,NKJST,NKJEND,AKR,PORK,RETARDK
'C14G.IN'
RETURN
NO
IF (LEXIST)
YES
CALL READGL
READ(5,*) FN3,FN4,TSTART,NAR,DTAR,TEND
NSKIP,NTIME,NKLAY,NKJST,NKJEND,TIMES
'TPAC14.CGD'
OVERWRITE SELECTED DATA
RETURN
CALL READLHS
READ(7,*) IVECT,NUMDAT,DVALUE
PLACE,SUB,AKR,PORK,RETARDK
'TPAC14.MAP'
TPAC14.LHS
CALL LAYER
SET AK(J),POR(J),RETARD(J)
CALL DATREP
WRITE FINAL INPUT VALUES TO FILE
'C14G.REP'

FIGURE 3A



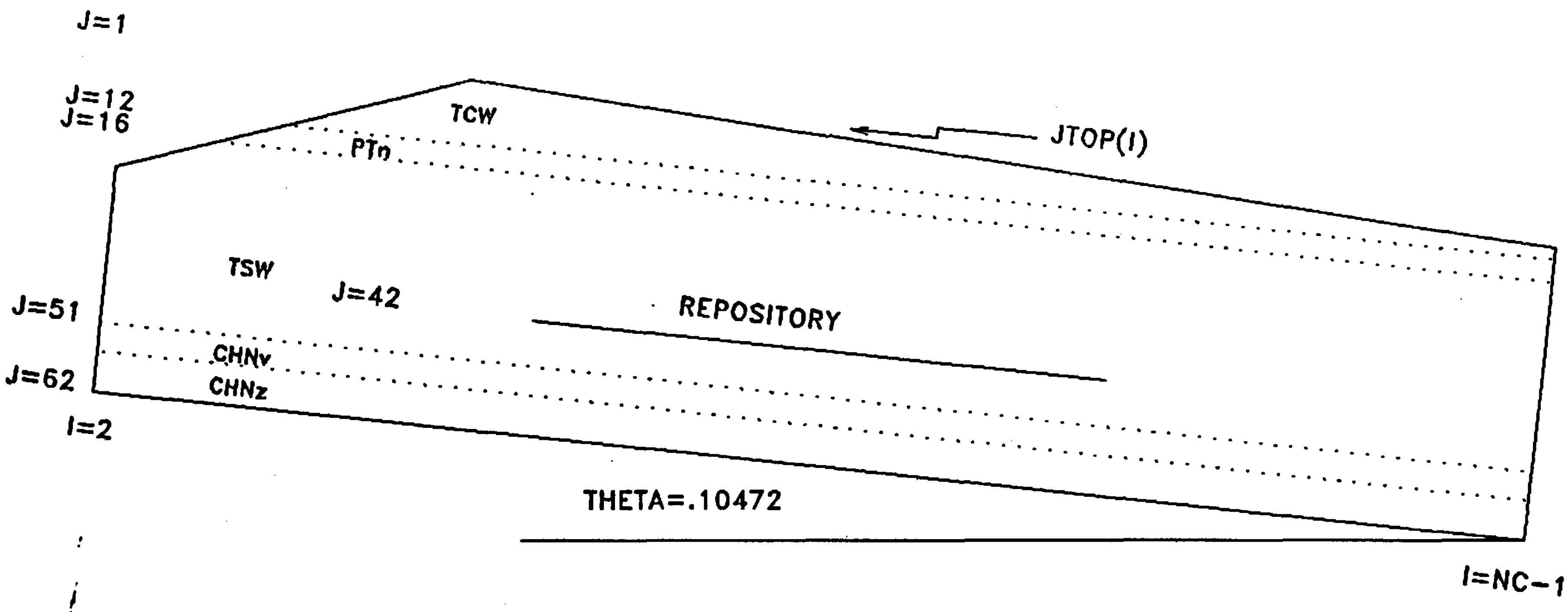
SUBROUTINE C14DS
EXTERNAL FILES
SKIP NSKIP TEMP FRAMES (FN3)
CALC. CONSTANTS & SET DIREC. K's
CALL SETH
SET UPPER B.C.'s FOR A.P.
RETURN
BEGIN TIME STEPS
CALL TEMP
READ FN3 (TEMPS.)
CALC. DT/DX, DT/DY, DT/DZ
RETURN
FN3
CALL VAPOR
CALC HV, DHV/DT
RETURN
DO 4567 KTIME=1, NTIME
DO 5000 ICYCLE=1, NCYCLE
CALL ITER
ITERATE FOR H(I,J)
RETURN
CALL PRESID
CALC. BIGRES & RESMAX
RETURN
NO
IF BIGRES .LT. TOL
YES
CALC. VELOCITIES FOR KTIME
WRITE VELOCITIES TO FN4
FN4

FIGURE 3B



EXTERNAL FILES
SUBROUTINE C14TRDS
READ IN VELOCITY FIELDS
FOR NTIME TIMEFRAMES
FN4
SET STARTING TIME
FOR FRACTION CALCULATION
CALL C14TIME
SET STARTING POSITION FOR PARTICLE
CALL GWT
ADD RANDOM COMPONENT
CALCULATE TRAVEL TIME
RETURN TO C14TIME
CALCULATE FRACTION ESCAPING
BASED ON TRAVEL TIME
SUM FRACTIONS
DO 1778 IAR=1, NAR
DO 4 I=1, NPART
WRITE STARTING TIME
FRACTION, & TRAVEL TIME
RETURN TO C14TRDS
'C14G.OUT'

FIGURE 3C



REPOSITORY CROSS SECTION FOR GAS FLOW MODEL

HYDROLOGIC PROPERTIES
TYPICAL CROSS SECTION

UNIT	PERMEABILITY (mm/yr) BULK FRACTURE	POROSITY
Tiva Canyon	160 (1.6-16,000)	.00014
Paintbrush	500 (5-50,000)	.000027
Topopah Spring	0.6 (.006-60.)	.000041
Calico Hills n	300 (3-30,000)	.000046
Calico Hills z	300 (3-30,000)	.000046

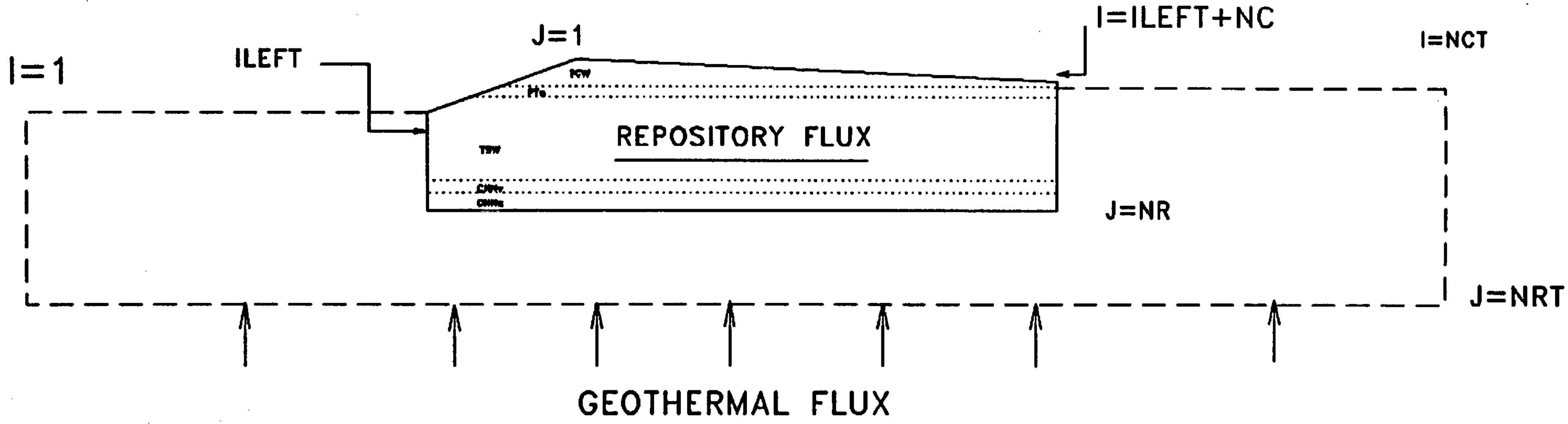
TEMPERATURE DISTRIBUTION

ANALYTICAL (GREEN'S FUNCTION) MODEL

- Capable of considering infinite depth
- Rapid calculation time
- Requires homogeneous heat transfer properties

NUMERICAL MODEL

- Can be used with layer varying properties
- Can be modified to incorporate volcanic scenarios
- Relatively slow convergence time
- Limited by no heat flow boundaries



REPRESENTATION OF REPOSITORY X-SECTION FOR HEAT TRANSFER

OUTPUT FROM TYPICAL CROSS SECTION
57 KW/AC

TIME OF RELEASE, yrs	TRAVEL TIME, yrs	FRACTION RELEASED
500	2114	.78
1000	2186	.77
1500	2367	.74
2000	2583	.72
2500	2849	.69
3000	3195	.65
3500	3501	.61
4000	3776	.56
4500	4002	.53
5000	4115	.46
5500	----	.34
6000	----	.22
6500	----	.00

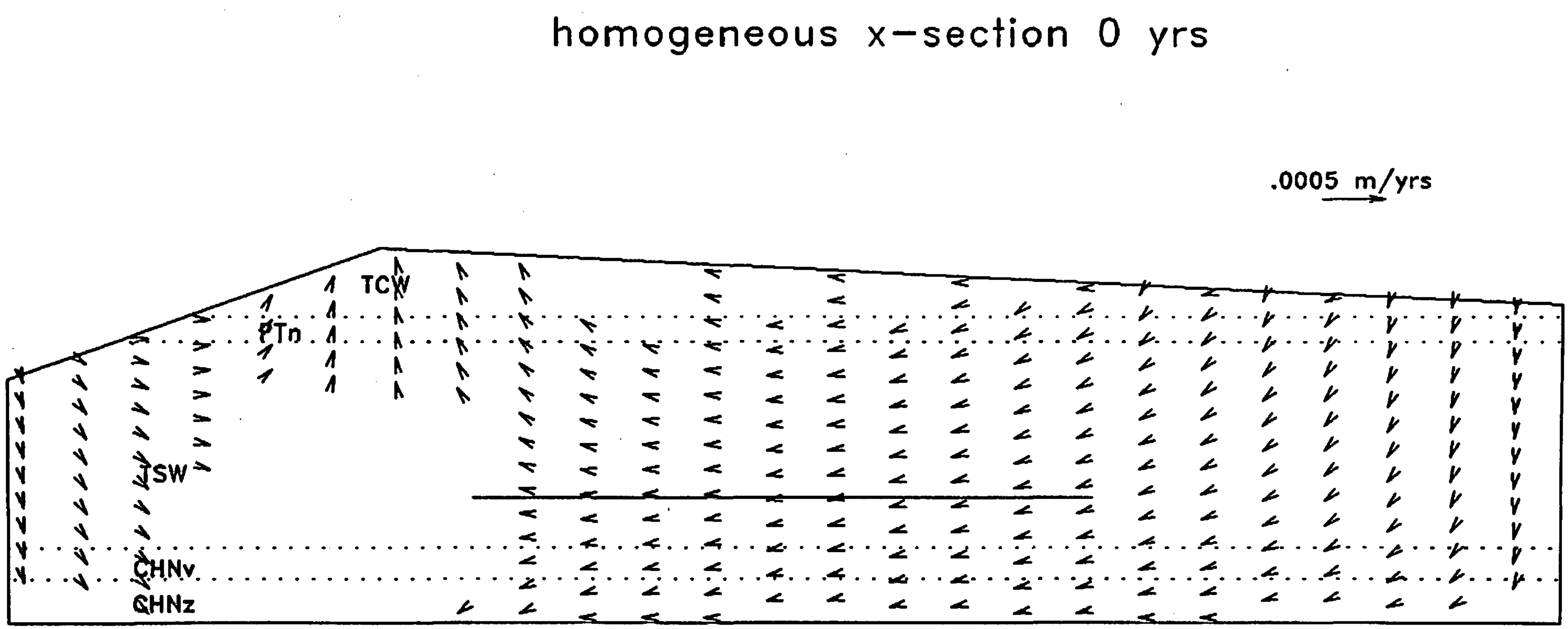
OUTPUT FROM TYPICAL CROSS SECTION
28 KW/AC

TIME OF RELEASE, yrs	TRAVEL TIME, yrs	FRACTION RELEASED
500	5870	.45
1000	6527	.36
1500	7008	.27
2000	7240	.22
2500	7351	.12
3000	----	.00

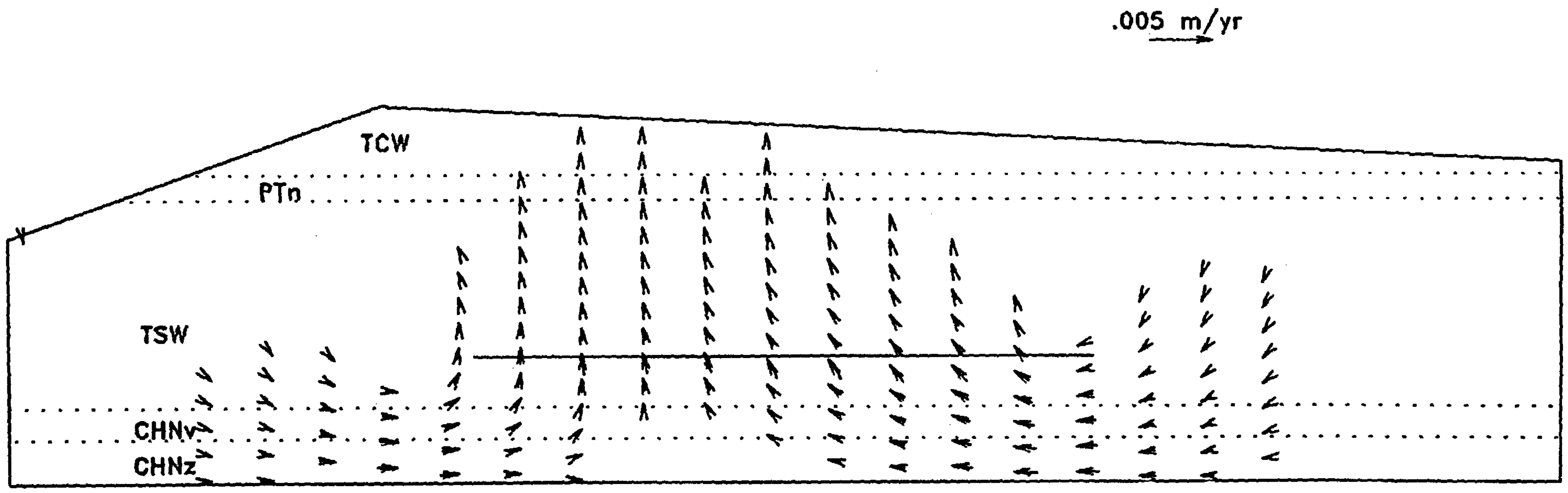
OUTPUT FROM TYPICAL CROSS SECTION

114 KW/AC

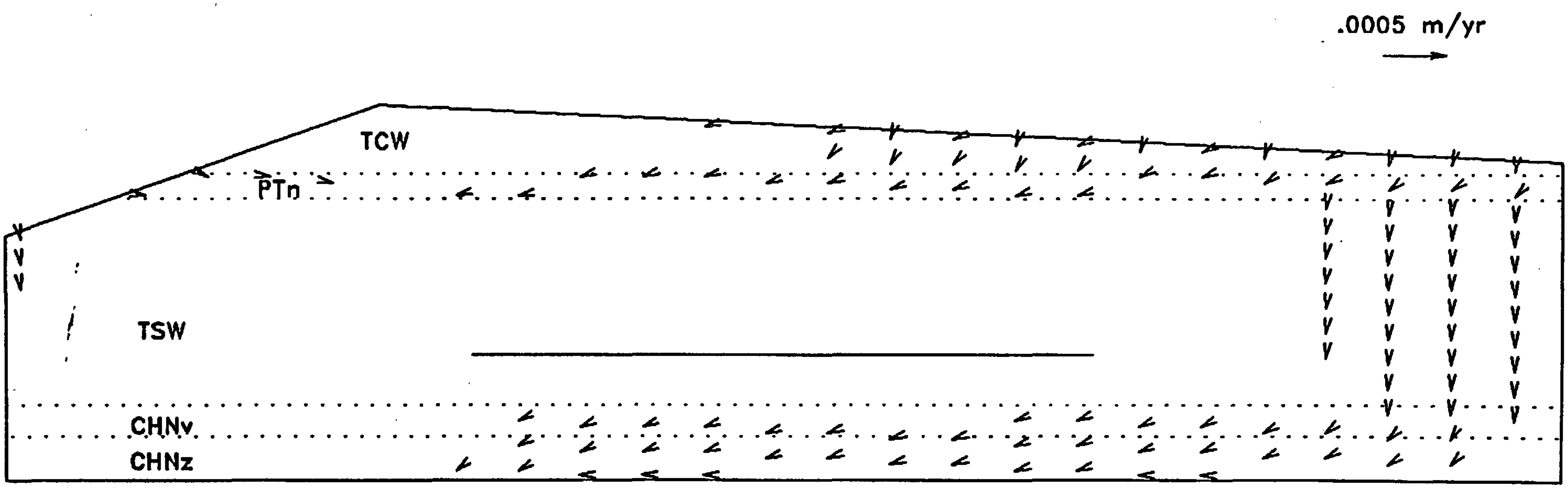
TIME OF RELEASE, yrs	TRAVEL TIME, yrs	FRACTION RELEASED
500	980	.89
1000	955	.89
1500	991	.89
2000	1034	.88
2500	1086	.88
3000	1155	.87
3500	1258	.86
4000	1403	.85
4500	1594	.83
5000	1731	.81
5500	1811	.81
6000	1886	.77
6500	1945	.75


homogeneous x-section 0 yrs
.0005 m/yrs
TCW
PTn
TSW
CHNv
CHNz

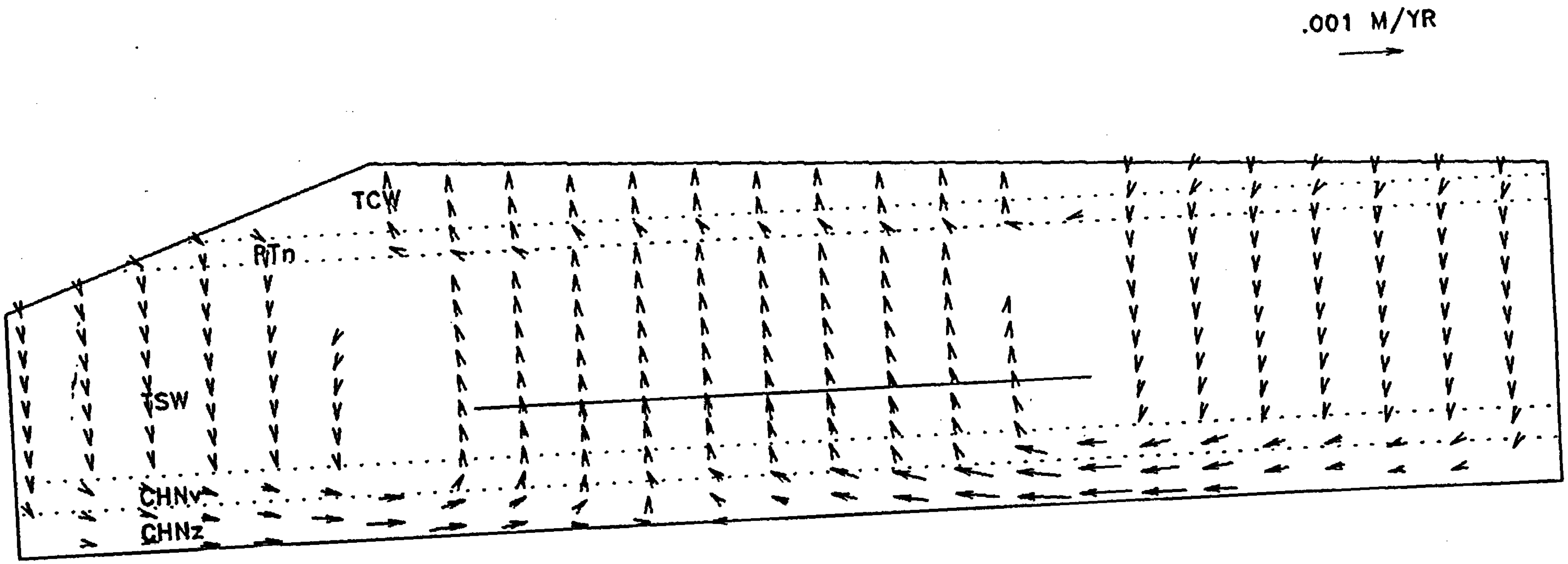
homogeneous x-section 500 yrs



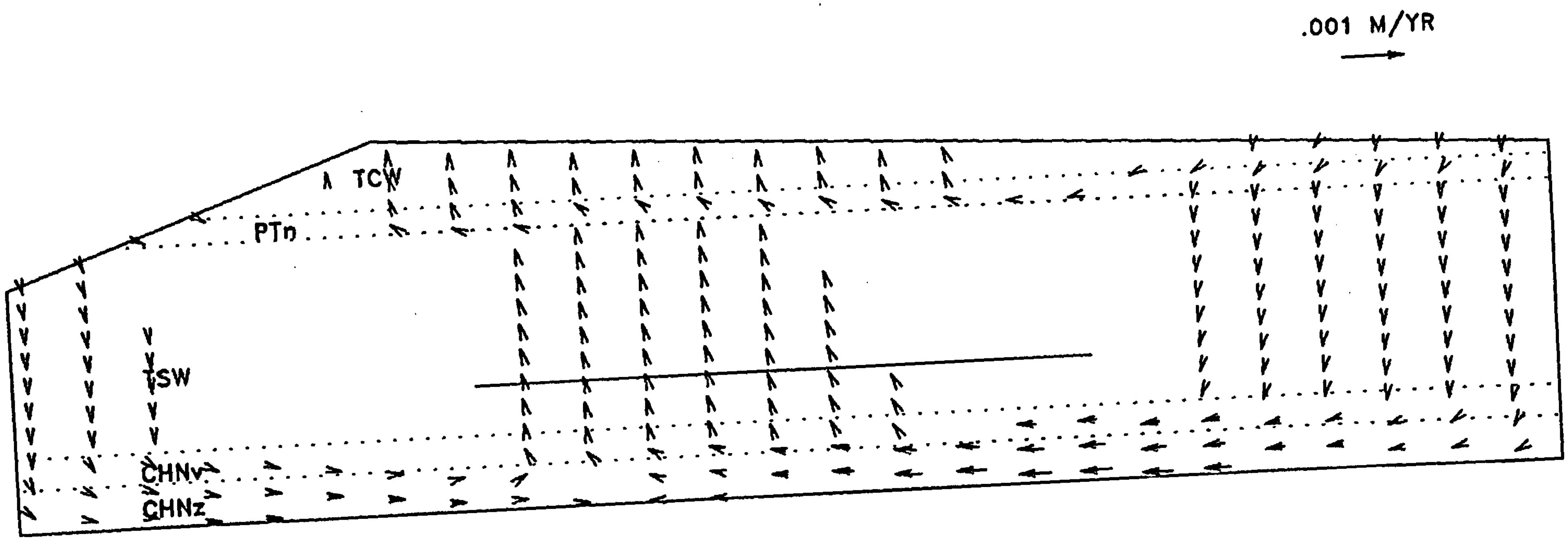
TYPICAL X-SECTION 0 YEARS



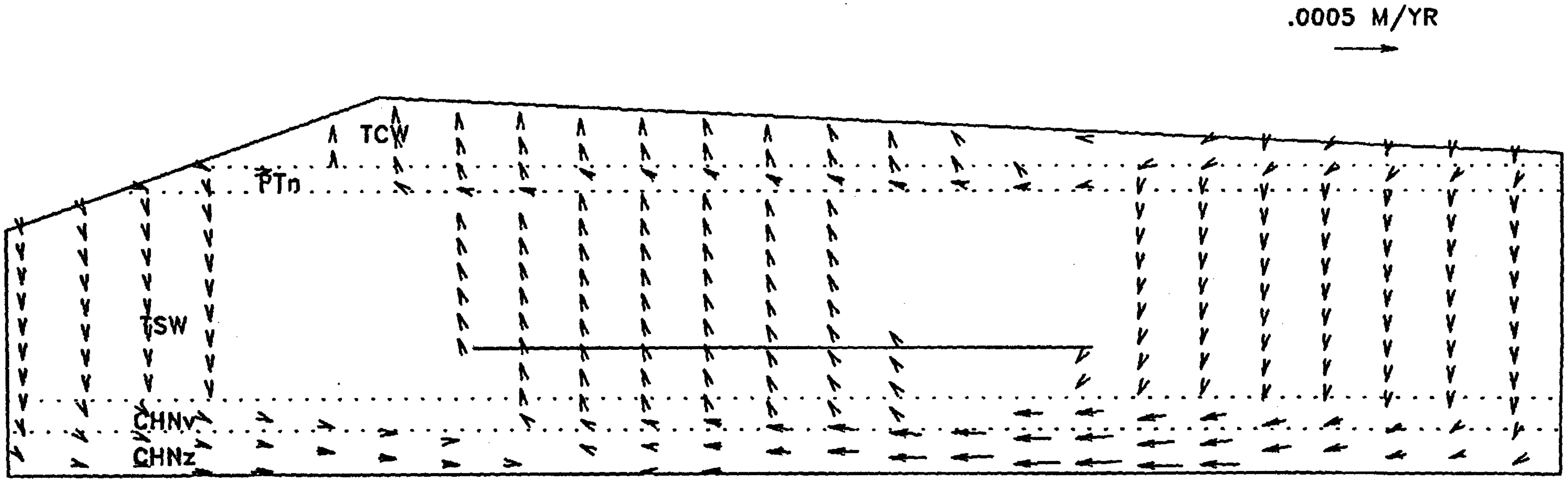
TYPICAL X-SECTION 500 YRS



TYPICAL X-SECTION 5000 YRS

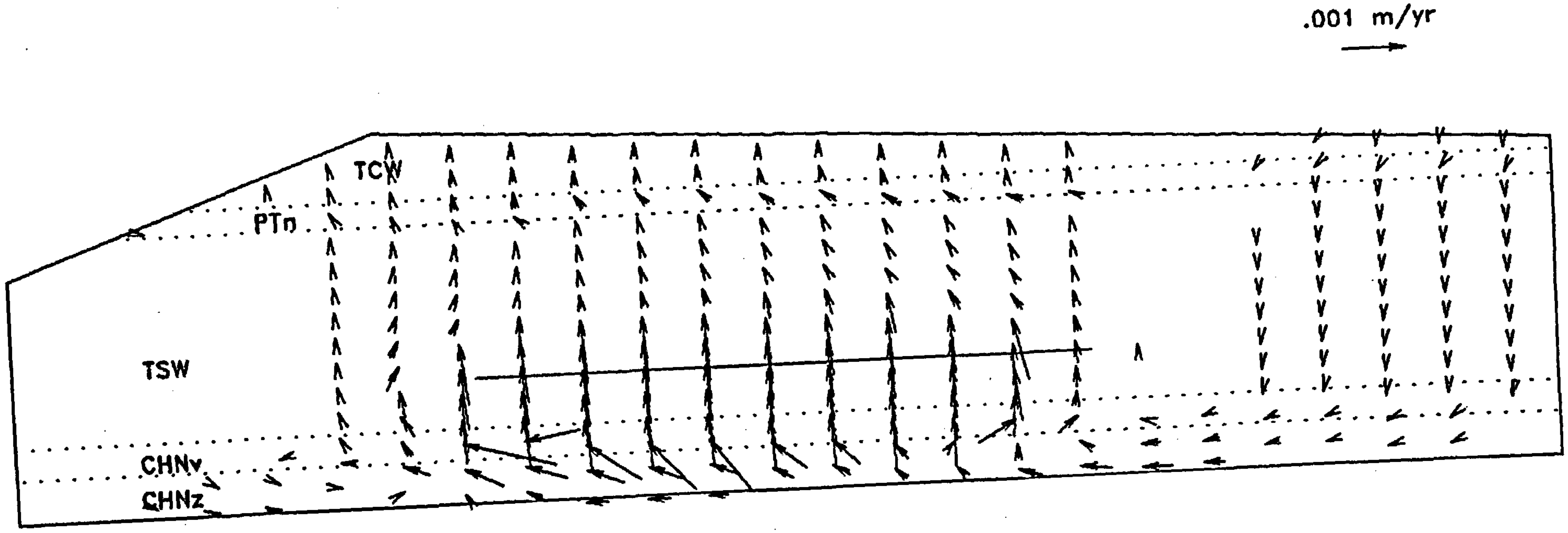


TYPICAL X-SECTION   10,000 YRS



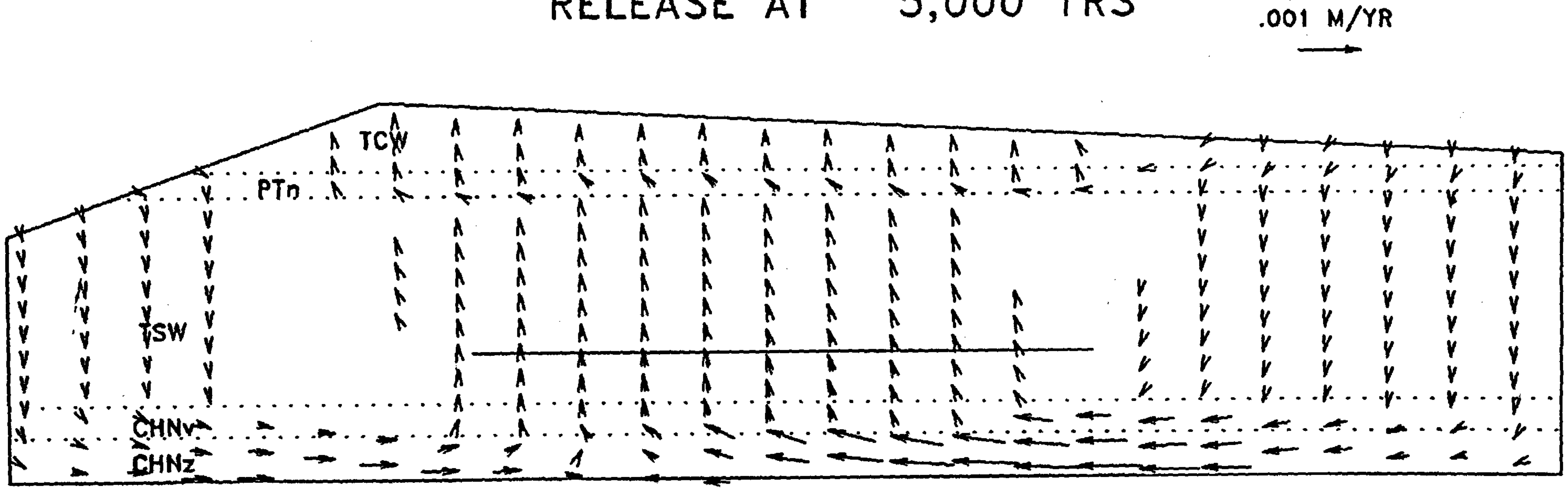
TYPICAL X-SECTION 114 KW/YR

RELEASE AT 500 YRS



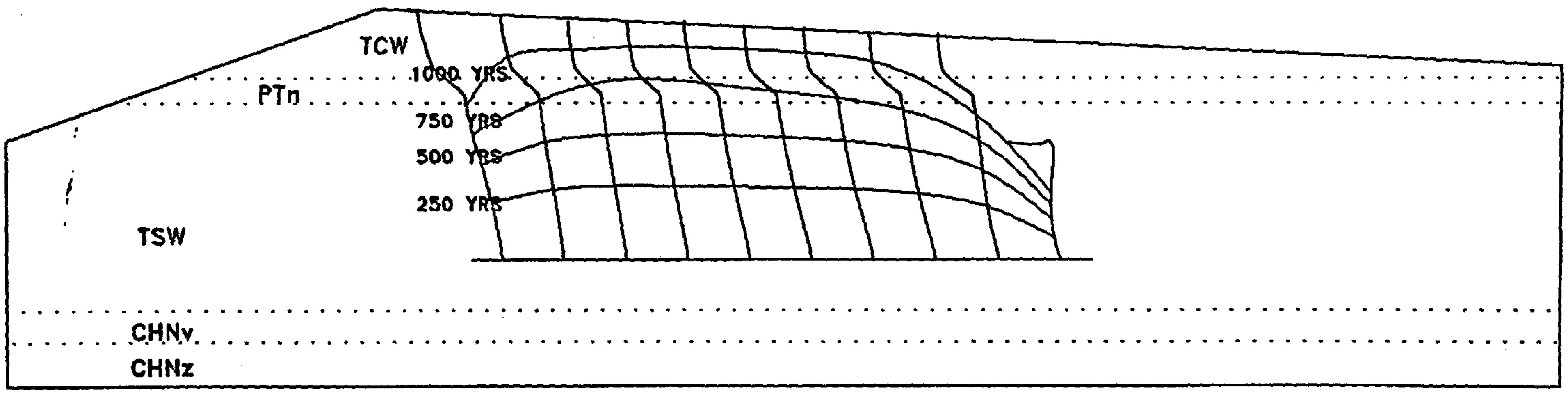
TYPICAL X-SECTION 114 KW/AC

RELEASE AT 5,000 YRS



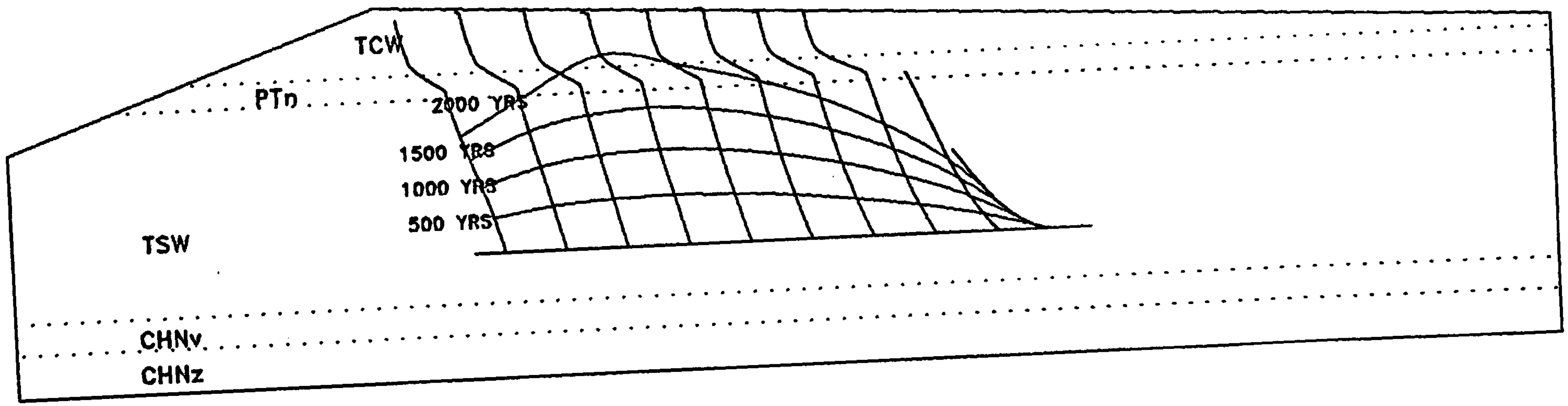
TYPICAL X-SECTION 57 KW/YR

RELEASE AT 500 YRS



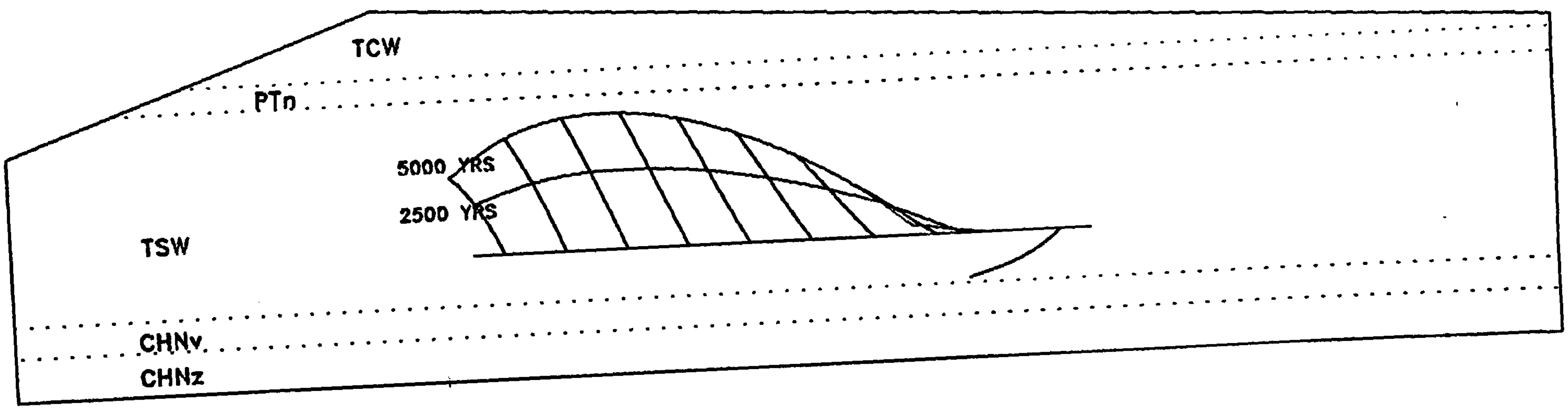
TYPICAL X-SECTION 57 KW/AC

RELEASE AT 5000 YRS



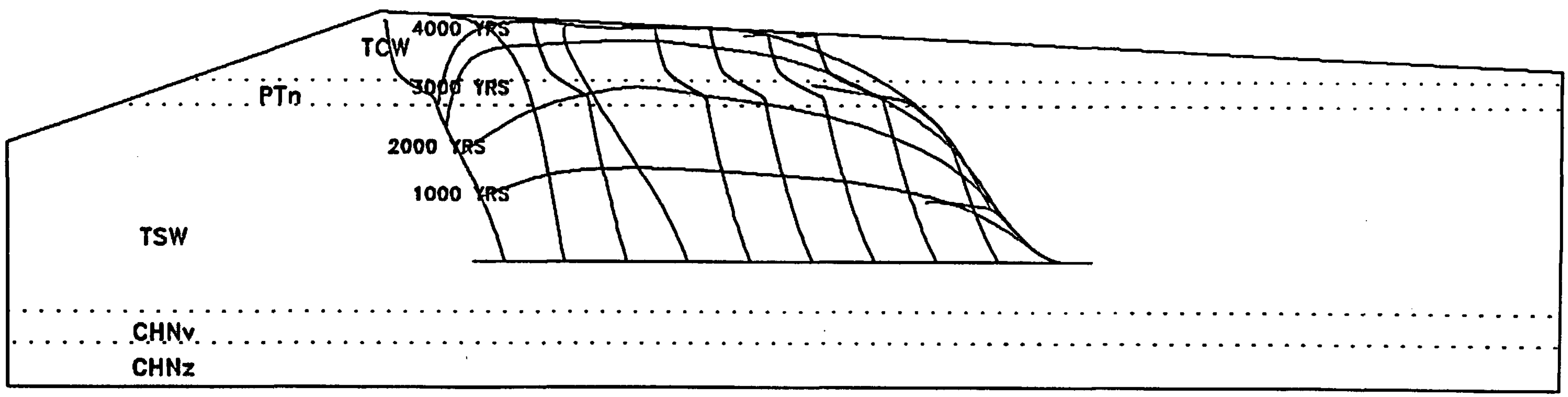
TYPICAL X-SECTION 28.5 KW/AC

RELEASE AT 5,000 YRS



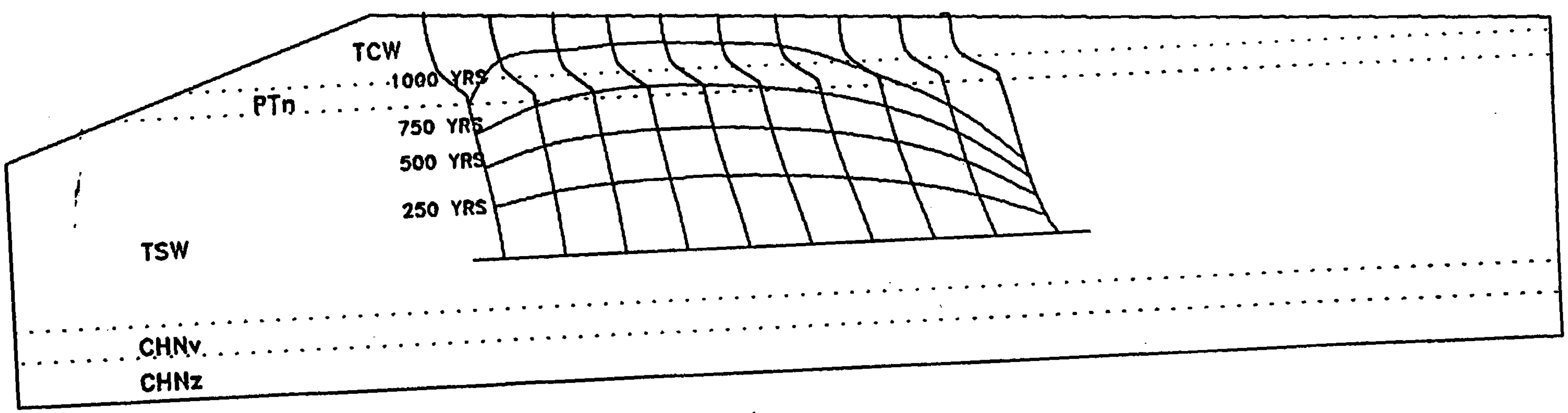
TYPICAL X-SECTION 28.5 KW/AC

RELEASE AT 500 YRS



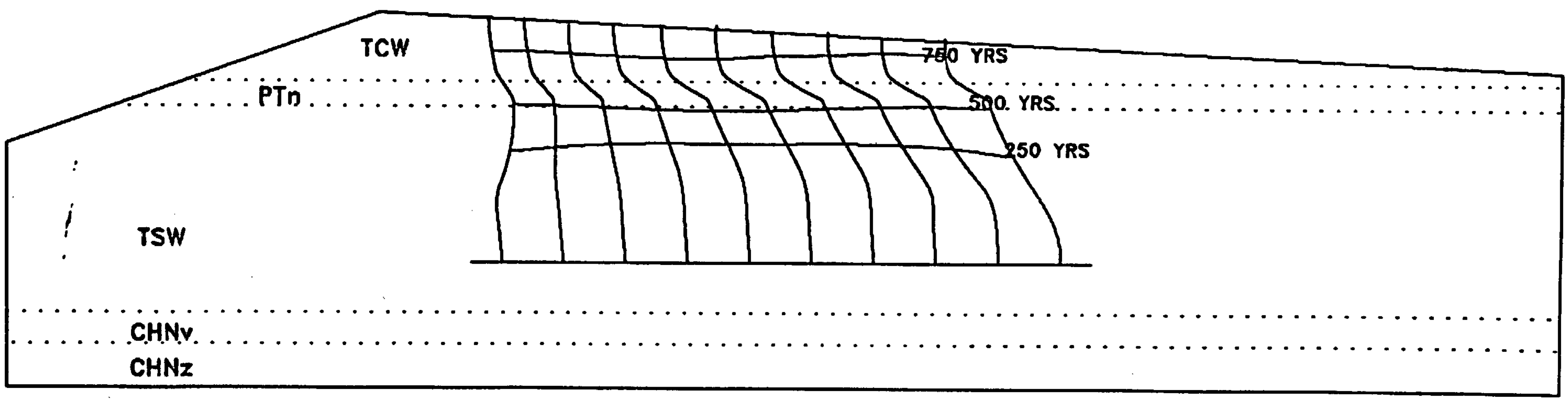
TYPICAL X-SECTION 114 KW/AC

RELEASE AT 5,000 YRS



TYPICAL X–SECTION 114 KW/YR

RELEASE AT 500 YRS



Performance Assessment Considerations for the Vapor Phase in Yucca Mountain

DOE/NRC Technical Exchange
Albuquerque NM March 18, 1992

Richard Codell (301)-504-2408
U.S. Nuclear Regulatory Commission
Washington D.C. 20555

1. Geochemical C-14 Model

2. C-14 Source Term

3. Disruptive Releases for C-14 and other Volatile Radionuclides.

1-D Convection / Dispersion with Retardation R_d

$$\frac{\partial}{\partial t}(R_d C) = u\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} - \lambda R_d C$$

If $R_d = f(T)$ and $T = f(t)$

$$\frac{\partial (R_d C)}{\partial t} = R_d \frac{\partial C}{\partial t} + \boxed{C\frac{\partial R_d}{\partial t}}$$

Source Term

Geochemical transport Modeling of C-14

- In context of a research model to explain interaction of C-14 with carbonate, water and bicarbonate $R_d = f(T, \varepsilon a)$
- 5 balance equations for carbon:
  - water and carbon dioxide
  - carbonate, and bicarbonate
  - water disociation
  - charge balance
  - conservation of carbon dioxide
- nonlinear iterative solution for a closed system using Newton-Raphson
- Include in a one-dimensional transient PDE that includes temperature dependence of equilibria

ESSENTIAL CARBON SYSTEM CHEMICAL REACTIONS

$H_2O(l) + CO_2(aq) \Leftrightarrow H^+ + HCO_3^-$ $\quad K_{HCO_3^-} = \frac{a_{H^+}\, a_{HCO_3^-}}{a_{H_2O}\, a_{CO_2(aq)}}$ (1)

$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$ $\quad K_{CO_3^{2-}} = \frac{a_{H^+}\, a_{CO_3^{2-}}}{a_{HCO_3^-}}$ (2)

$H^+ + OH^- \Leftrightarrow H_2O$ $\quad K_{H_2O(l)} = \frac{a_{H_2O(l)}}{a_{H^+}\, a_{OH^-}}$ (3)

$H_2O(g) \Leftrightarrow H_2O(l)$ $\quad K_{H_2O(g)} = \frac{a_{H_2O(l)}}{f_{H_2O(g)}/f^{\circ}_{H_2O}}$ (4)

$CO_2(g) \Leftrightarrow CO_2(aq)$ $\quad K_{CO_2} = \frac{a_{CO_2(l)}}{f_{CO_2(g)}/f^{\circ}_{CO_2}}$ (5)

$CaCO_3(cc) + H^+ \Leftrightarrow Ca^{2+} + HCO_3^-$ $\quad K_{cc} = \frac{a_{HCO_3^-}\, a_{Ca^{2+}}}{a_{CaCO_3(cc)}\, a_{H^+}}$ (6)

Chemical Constraints for Local Equilibrium

1. Essential Carbon System Chemical Reactions Are in Local Equilibrium.
2. Aqueous Solution Is in Local Electroneutrality.
3. Mass of Carbon Is Conserved among Solid, Liquid and Gas Phases.
4. Calcium Is Conserved among Liquid Phase and Calcite.
5. Calcite is Absent if the Solution is Undersaturated (and Equation (6) is eliminated).
6. Activity Coefficients Are Calculated Using an Extended Debye-Huckel Equation.
7. CO_2 Fugacity Is Related to the Moles of CO_2 in the Gas by Dalton's Law.

Geochemical Model for Total Carbon

- Calculate chemical equilibrium in each tank
- Determine output from tank to next tank in gaseous phase (no water moves)
- Sum new inventories of carbon and recompute coefficients
  - Eq. Coefficients function of T
  - Activity coefficients function of T and ionic strength
- Repeat calculation of chemical equilibrium for next time step

Chemical Equilibrium Model
for
Total Carbon

Mass Action Equations

$$[H_2O + CO_2(aq) \rightleftharpoons H^+ + HCO_3^-]$$

$$\beta_1 = 0 = \log a_{H^+} + \log a_{HCO_3^-} - \log a_{CO_2}(aq.) - \log k_{HCO_3^-} \quad (1)$$

$$[HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}]$$

$$\beta_2 = 0 = \log a_{H^+} + \log a_{CO_3^{2-}} - \log a_{HCO_3^-} - \log k_{CO_3^{2-}} \quad (2)$$

$$[H^+ + OH^- \rightleftharpoons H_2O]$$

$$\beta_3 = 0 = \log a_{H^+} + \log a_{OH^-} + \log k_{H_2O} \quad (3)$$

where a = activity of species,
γ = activity coefficient, and
k = equilibrium coefficient.

$\gamma = f(T)$ and Ionic Strength
$k = f(T)$

Charge Balance in Aqueous Phase

$$\beta_4 = 0 = -\frac{a_{H^+}}{\gamma_{H^+}} - \frac{a_{Na^+}}{\gamma_{Na^+}} - \frac{2a_{Ca^{2+}}}{\gamma_{Ca^{2+}}} + \frac{a_{HCO_3^-}}{\gamma_{HCO_3^-}} + \frac{2a_{CO_3^{2-}}}{\gamma_{CO_3^{2-}}} + \frac{a_{OH^-}}{\gamma_{OH^-}} \qquad (4)$$

Conservation of Carbon in Water and Gas

$$\beta_5 = 0 = \frac{f^0_{CO_2}(aq.)}{k_{CO_2}\,\chi_{CO_2}} \frac{P_T \phi \;(1-S)\,V_T}{R\,T} \times 100$$

$$+ W_{H_2O}\left(\frac{a_{CO_2}}{\gamma_{CO_2}(aq.)} + \frac{a_{HCO_3^-}}{\gamma_{HCO_3^-}} + \frac{a_{CO_3^{2-}}}{\gamma_{CO_3^{2-}}}\right) - n_{CTot} + n_{CaCO_3} \qquad (5)$$

If Calcite Present:

Mass Action Equation for Calcite

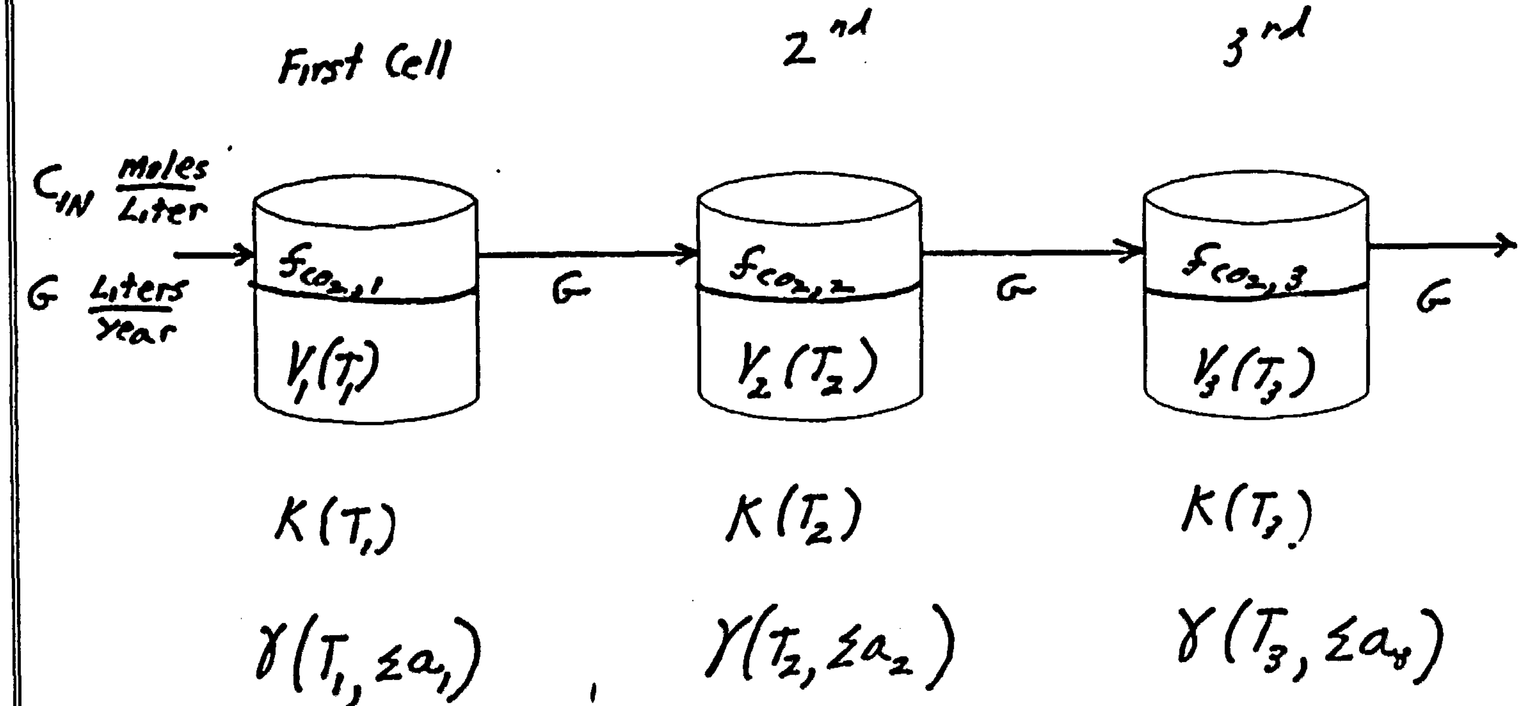
$$[CaCO_3(solid) + H^+ \leftrightarrow Ca^{2+} + HCO_3^-]$$

$$\beta_6 = \log a_{Ca^{2+}} + \log a_{HCO_3^-} - \log a_{H^+} - \log k_{CaCO_3} = 0 \qquad (6)$$

Mass Balance Equation for Calcium

$$\beta_7 = 0 = n_{CaCO_3} + W_{H_2O}\frac{a_{Ca}}{\gamma_{Ca}} - n_{Ca} \qquad (7)$$

Mass Transfer Model for TOTAL C



Mass Transfer Model for Total Carbon

Carbon entering first tank

$$Q_{in,1}^{t+\Delta t} = C_{C14,0}^{t+\Delta t}\, G_1^{t+\Delta t}\, \Delta t \qquad (8)$$

Carbon leaving tank i and entering tank i+1

$$Q_{in,i+1}^{t+\Delta t} = f_{CO_2,i}^{t}\, \frac{100\, G_{i+1}^{t+\Delta t}\, \Delta t}{R\, \chi_{CO_2}\, T_i^{t+\Delta t}} \qquad (9)$$

Moles of carbon in tank i at time t

$$M_{CT}^{t} = \left[\left(\frac{1}{\gamma_{CO_2}} + \eta\right) a_{CO_2}^{t} + \frac{a_{HCO_3^-}^{t}}{\gamma_{HCO_3^-}} + \frac{a_{CO_3^{2-}}^{t}}{\gamma_{CO_3^{2-}}}\right] W_{H_2O}^{t} + M_{CTS}^{t} \qquad (10)$$

where M_{CTS} = moles of solid calcite in tank i, and

$$\eta = \frac{V_T\, \phi^t\, (1-S) \times 100\; f_{CO_2}^{\circ}}{W_{H_2O}^{t}\, R\, T^t\, k_{CO_2}^{t}\, \chi_{CO_2}} \qquad (11)$$

Total moles of carbon in tank i at time t + Δt

$$M_{CT,i}^{t+\Delta t} = M_{CT,i}^{t} + Q_{in,i}^{t+\Delta t} - Q_{in,i+1}^{t+\Delta t} \qquad (12)$$

C-14 Transport Model

- Trace quantities of C-14
  - does not affect bulk chemistry
- Transfer rates of carbon between inventories used as transfer rate for C-14
- C-14 enters at repository level
- Radioactive decay of all C-14 inventories at end of each time step
- Calcite contaminated with C-14 well-mixed but separate from uncontaminated calcite

C-14 entering first tank in gas stream

$$Q_{C14,1}^{t+\Delta t} = C_{C14,in}^{t+\Delta t} \times G_{in}^{t+\Delta t} \qquad (13)$$

C-14 leaving ith tank in gas and entering (i+1)th tank

$$Q_{C14,i+1}^{t+\Delta t} = \frac{M_{C14,sl}^{t}}{M_{CT,sl}^{t+\Delta t}} \times f_{CO_2,i}^{t} \times 100\ G_{i+1}^{t+\Delta t} \frac{\Delta t}{R\ \chi_{CO_2}\ T_i^t} \qquad (14)$$

C-14 "affected" calcite inventory

$$\Delta M_{CTS} = M_{CTS}^{t+\Delta t} - M_{CTS}^{t} \qquad (15)$$

$$M_{CRS}^{t+\Delta t} = M_{CRS}^{t} + \Delta M_{CTS}, \quad M_{CRS}^{t+\Delta t} \geq 0 \qquad (16)$$

Removal of C14 in gas/liquid to calcite

If $\Delta M_{CTS} > 0$,

$$\Delta M_{C14,gl}^{t+\Delta t} = M_{C14,gl}^{t+\Delta t} \frac{\Delta M_{CTS}}{M_{CRS}^{t+\Delta t}} \qquad (17)$$

Input of C14 into gas/liquid from calcite

if $\Delta M_{CTS} < 0$,

$$\Delta M_{C14,gl}^{t+\Delta t} = \Delta M_{CTS} \frac{M_{C14S}^{t}}{M_{CRS}^{t}} \le M_{C14S}^{t} \qquad (18)$$

Radioactive decay of All C-14 inventories (19)

Elements of the Flow and Transport Model

1. **Uniform One-Dimensional Flow Is Vertically Upward.**

2. **Time Dependent Flow Rate and Temperature Are Taken from a 2-D Single Phase Gas Flow and Analytical 2-D Repository Heat Flow Model.**

3. **The Temperature-Saturation Relation Is Derived from a Regression of Computed Values in a Two-Phase, 2-D Model of Heat and Mass Transfer in Tuff (Nitao, 1988).**

4. **Diffusion Between Representative Volumes in Gas and Liquid Phases Is Neglected.**

5. **Liquid Flow Between Representative Volumes Is Neglected.**

6. **At Each Time Step, Carbon is Distributed Among the Solid, Liquid, and Gas Phases According to the Local Equilibrium Model.**

7. **14C Is Introduced as a Pulse at the Repository Location.**

8. 14C Is Transported as a Trace Constituent in Proportion to C Transport (No Isotopic Fractionation).

9. 14C Is Distributed Homogeneously in Calcite Precipitated from 14C Contaminated Solutions; It Is Not Distributed in Calcite Precipitated from Uncontaminated Solutions.

10. 14C Contaminated Calcite Dissolves Before Uncontaminated Calcite.

11. Radioactive Decay of 14C is Accounted.

12. Retardation of 14C Transport at a Point (Instantaneous Local Retardation) Is Given by

$$R_n = \frac{(\text{Seepage Velocity of the Gas})}{(\text{Average Velocity of 14C})}$$

Average Velocity of 14C =

$$(\text{Seepage Velocity of the Gas}) * \frac{(\text{Moles of 14C in the Gas})}{(\text{Total Moles of 14C})}$$

$$R_n = \frac{(\text{Total Moles of 14C})}{(\text{Moles of 14C in the Gas})}$$

FLOW AND TRANSPORT MODEL

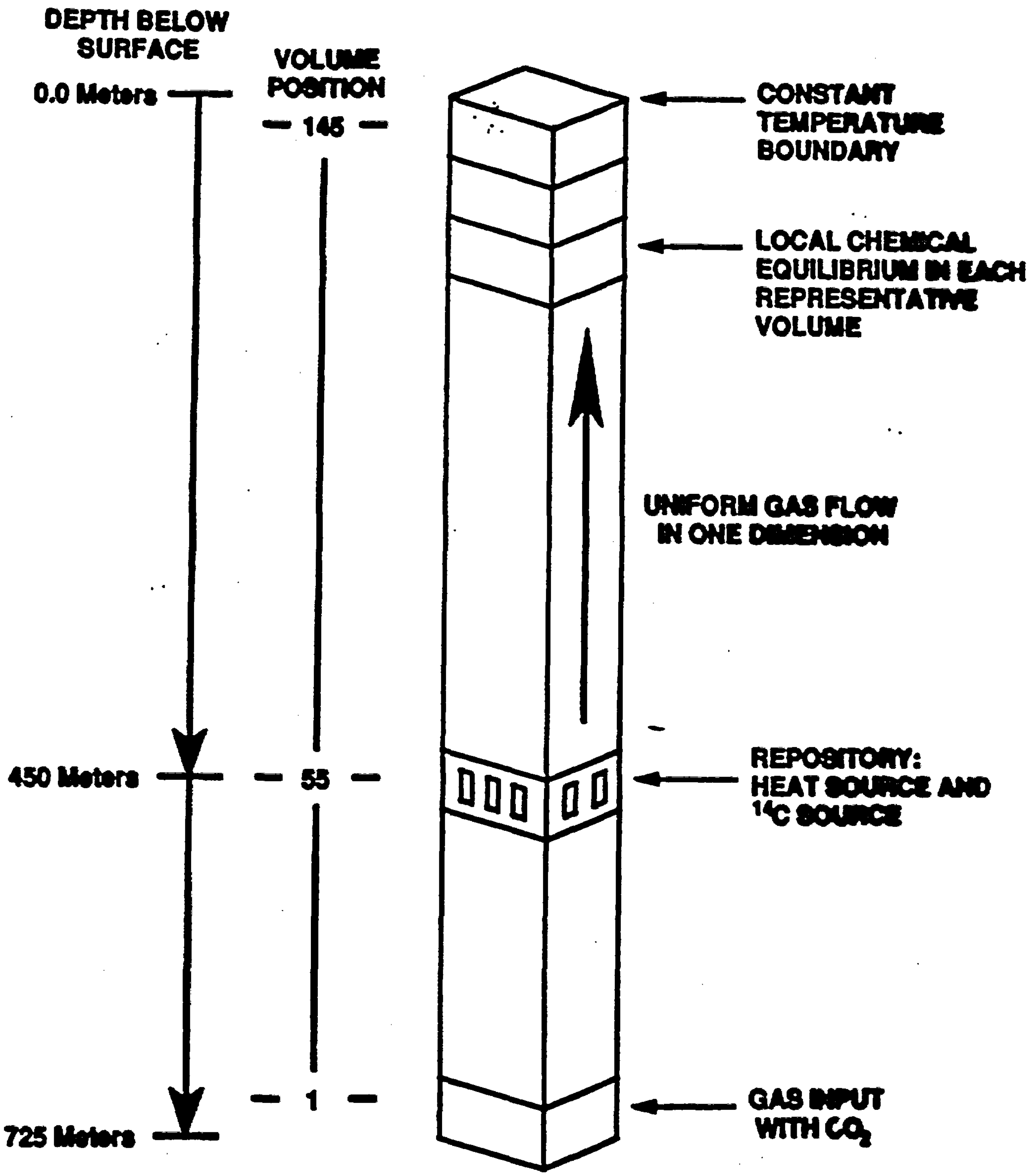


Figure 1 - One-dimensional Flow and Transport Model

Parameter	Value
Cell cross section	2 cm^2
Cell spacing	5 m
Volume of cell	6.25 m^3
Porosity	.2
Initial saturation	.8
Initial C/cell	.00202 mole/l
Na/cell	.001 mole/l
Ca/cell	.0004 mole/l
CO_2 input gas	2.53E-4 mole/l

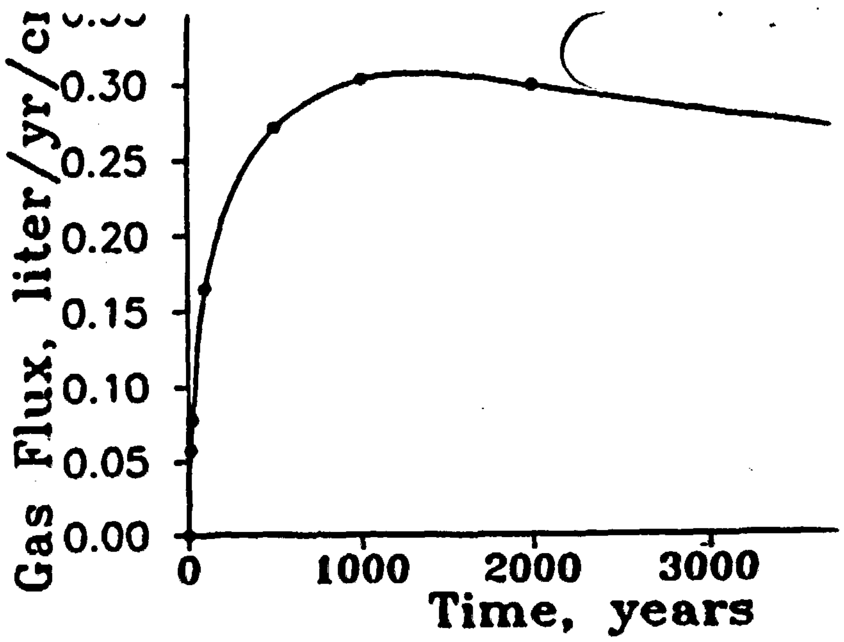
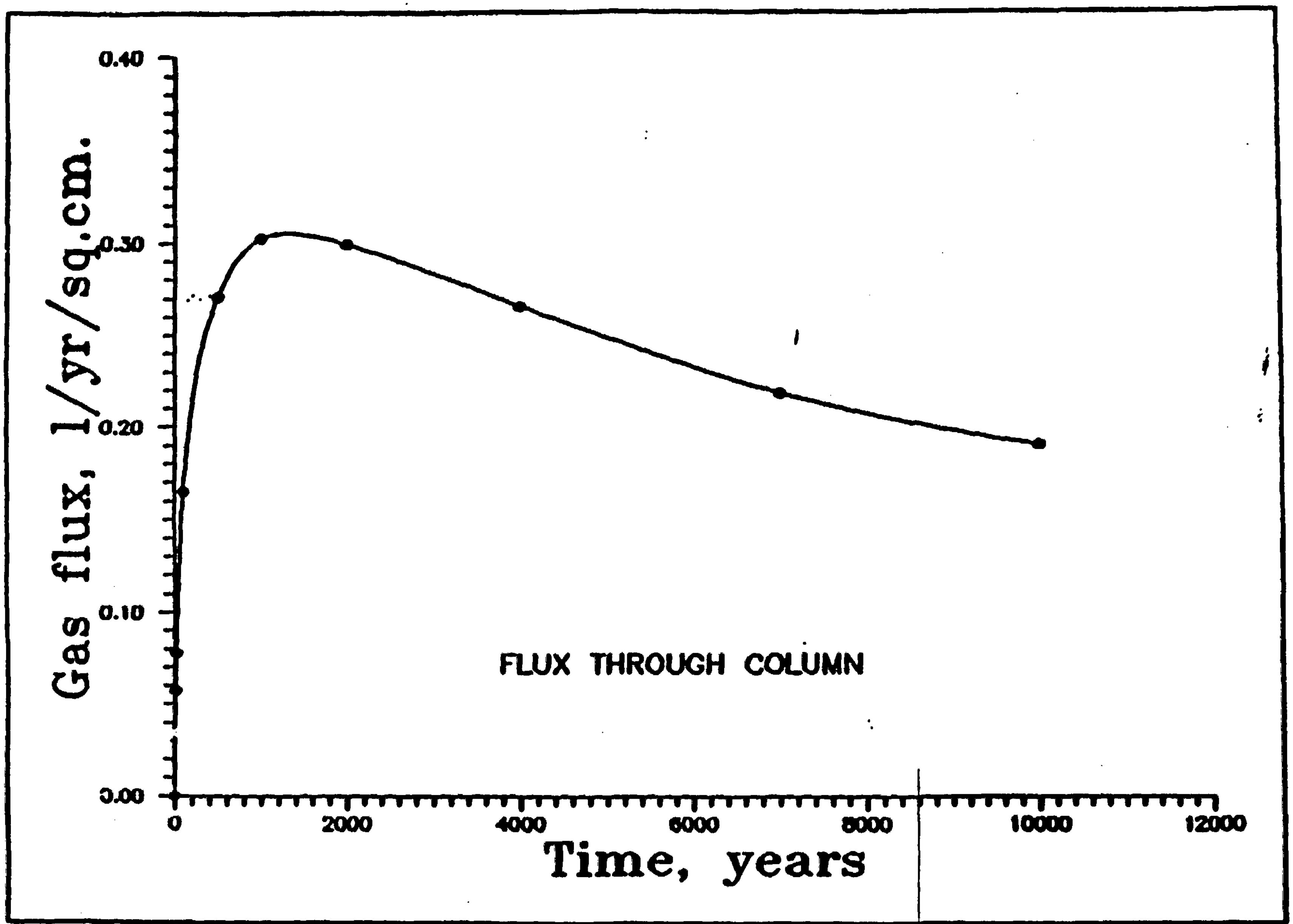
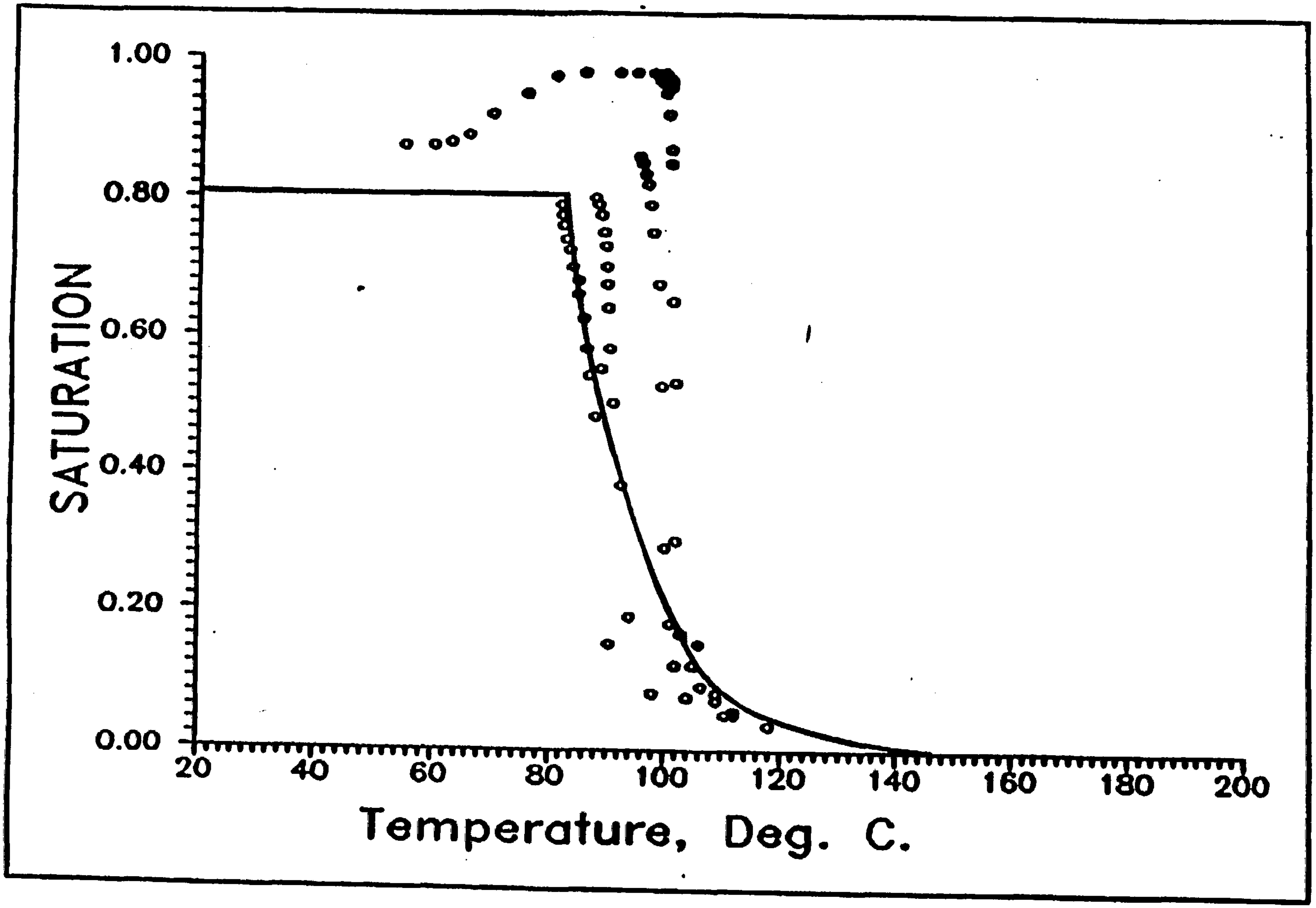
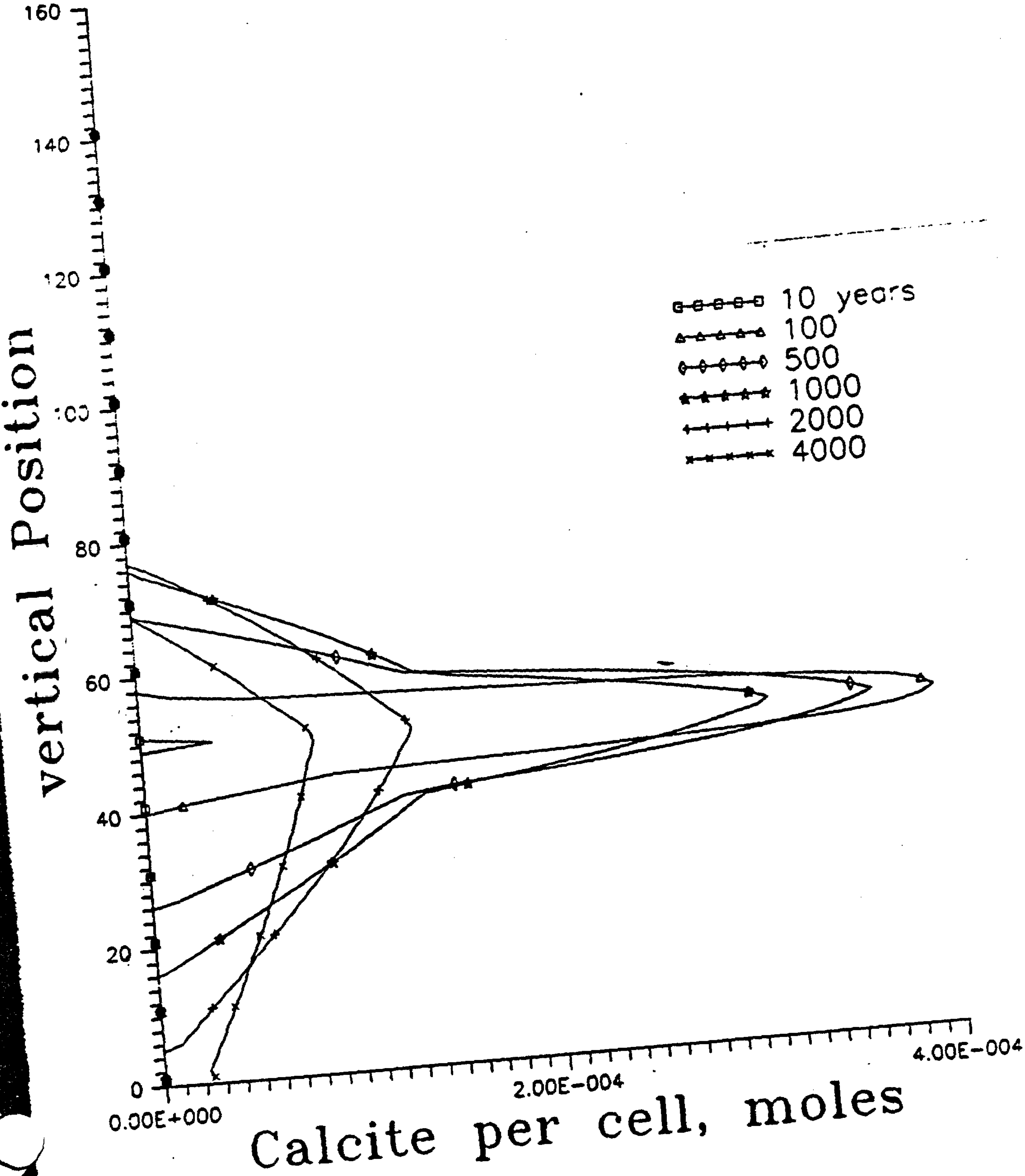


Figure 3 - Gas Flux for Example


Gas flux, l/yr/sq.cm.
0.40
0.30
0.20
0.10
0.00
0
2000
4000
6000
8000
10000
12000
Time, years
FLUX THROUGH COLUMN


1.00
0.80
0.60
0.40
0.20
0.00
SATURATION
20
40
60
80
100
120
140
160
180
200
Temperature, Deg. C.



vertical Position
160
140
120
100
80
60
40
20
0
0.00E+000
2.00E-004
4.00E-004
Calcite per cell, moles
10 years
100
500
1000
2000
4000

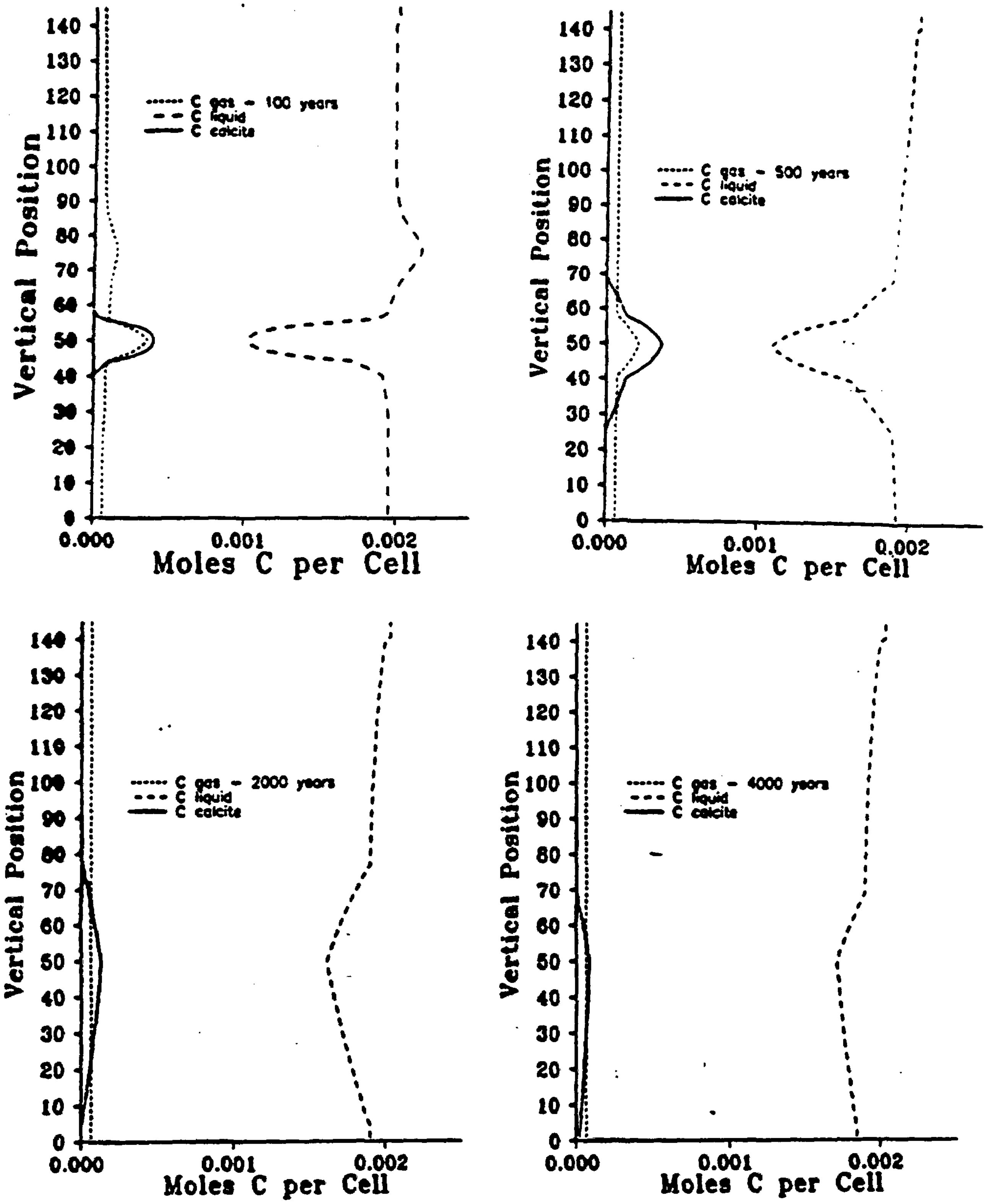


Figure 5 - Carbon content of gas, liquid and solid phases

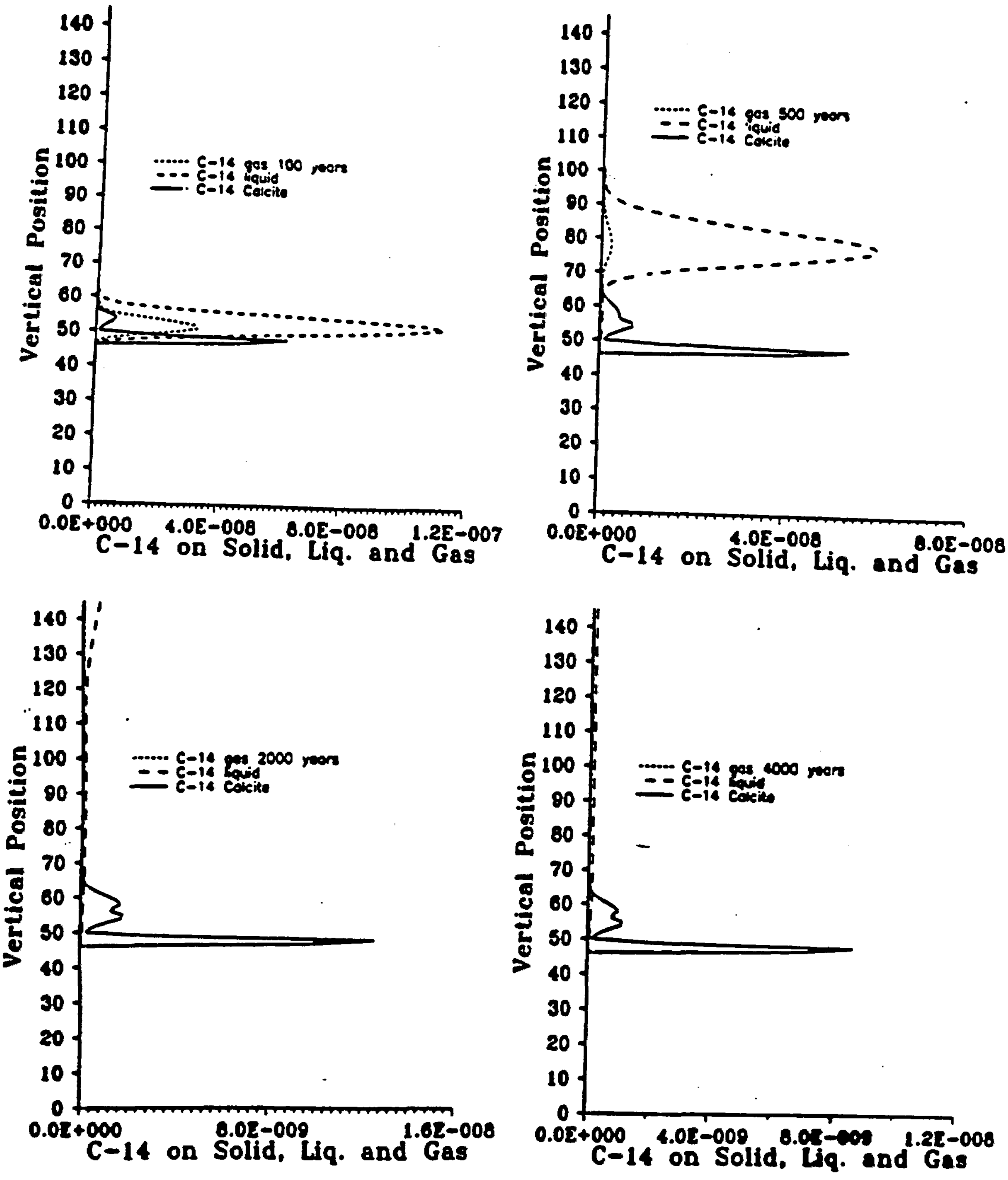


Figure 6 - ^{14}C content of gas, liquid and solid phases
(NOTE: scales change)

...ons. These ... 7.2, moder- ... with the Q/K ... out 0.2 and par- ... 0.006 bar, de-

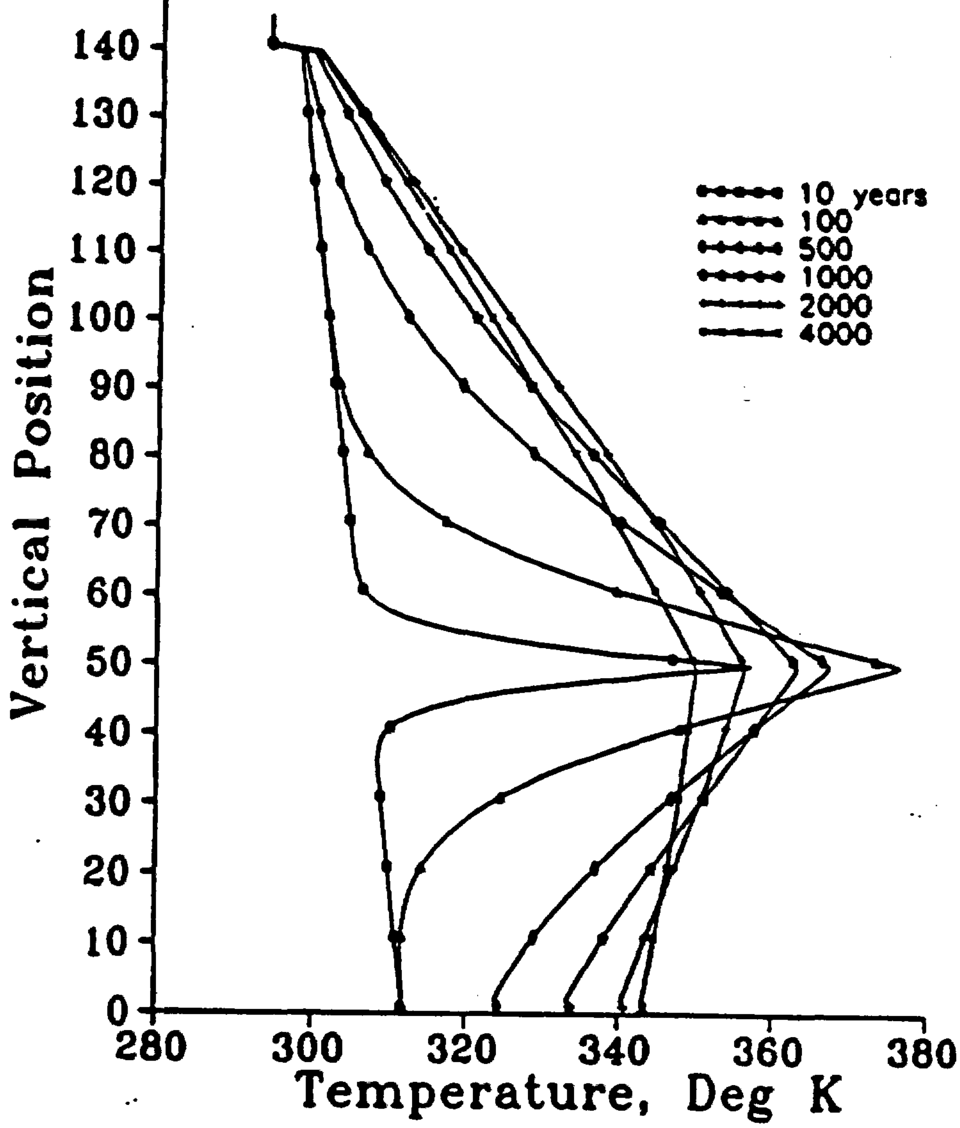
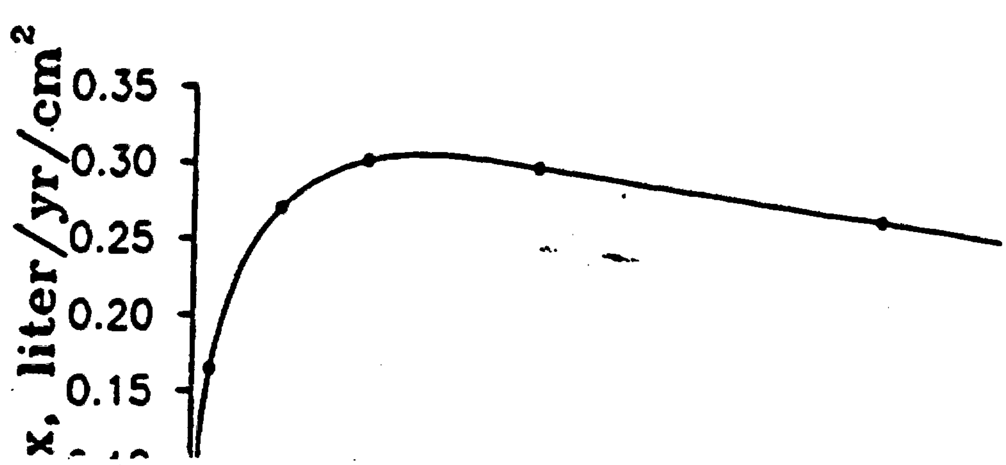
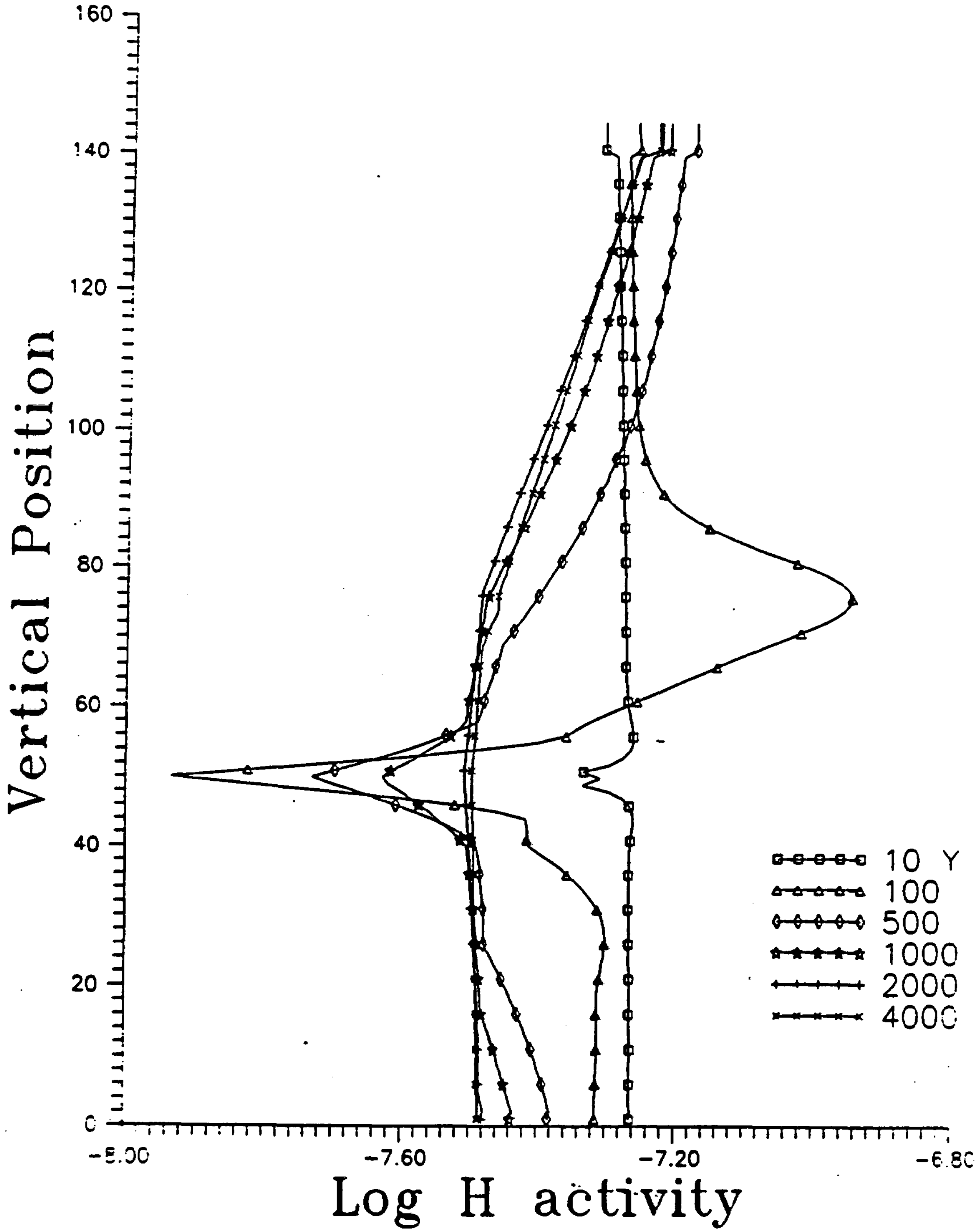


Figure 2 - Temperature Profiles for Example

... and





Vertical Position
160
140
120
100
80
60
40
20
0
-8.00
-7.60
-7.20
-6.80
Log H activity
10 Y
100
500
1000
2000
4000

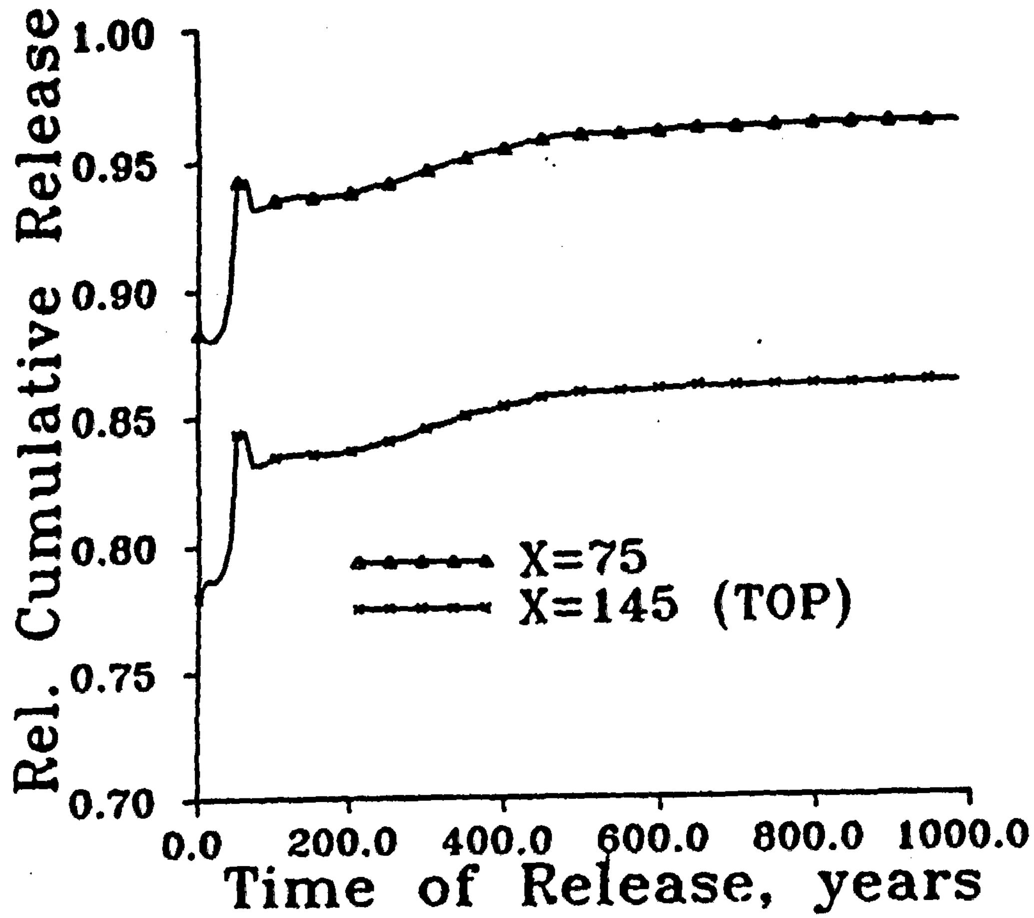


Figure 7 - Cumulative release by 1500 years as a function of when ^{14}C was released

fixed for a long period before repository cooling leads to redissolution of the calcite.

Although [illegible]

References

1. S. Ampter, B. Ross, "Simulation of gas fl Yucca Mountain, Nevada with a model based o ter head", Proceedings of the Symposium on W agement, Tucson, AZ, 2, 915 (1990)

2. W.B. Light, T.H. Pigford, P.L. Chambre, a Lee "Analytical models for C-14 transport in a pa saturated, fractured, porous media". FOCUS 89, ings, Nuclear Waste Isolation in the Unsaturated American Nuclear Society, Lagrange Park, Illino

3. R.B. Knapp, "An approximate calculation tive gas-phase transport of ^{14}C at Yucca Mounta da", J.Contaminant Hydrology, 5, 133 (1990)

4. J.J. Nitao, "Numerical modeling of the the hydrological environment around a nuclear waste using the equivalent continuum approximation: H Emplacement", UCID-21444, Lawrence Livermore Laboratory (1990)

Conclusions

- Distribution of Carbon in Yucca Mountain affected by repository induced heating and gas flow
- Calcite will probably precipitate within a few tens of meters of repository horizon and redissolve slowly
- As the repository cools, carbon introduced to the system as gas will be consumed. Depleted gas will migrate upward, affecting the pH above.
- C-14 released early will be partially incorporated in calcite, and trapped for thousands of years
- C-14 released later will be retarded less, and further from fuel.
- Model results depend strongly on initial conditions of water chemistry and other parameters.

Effects of Gas Phase on Release and Transport

Volatile radionuclides can be released and transported in gas phase

- C-14
- I-129
- Compounds of Se, Tc, Cs

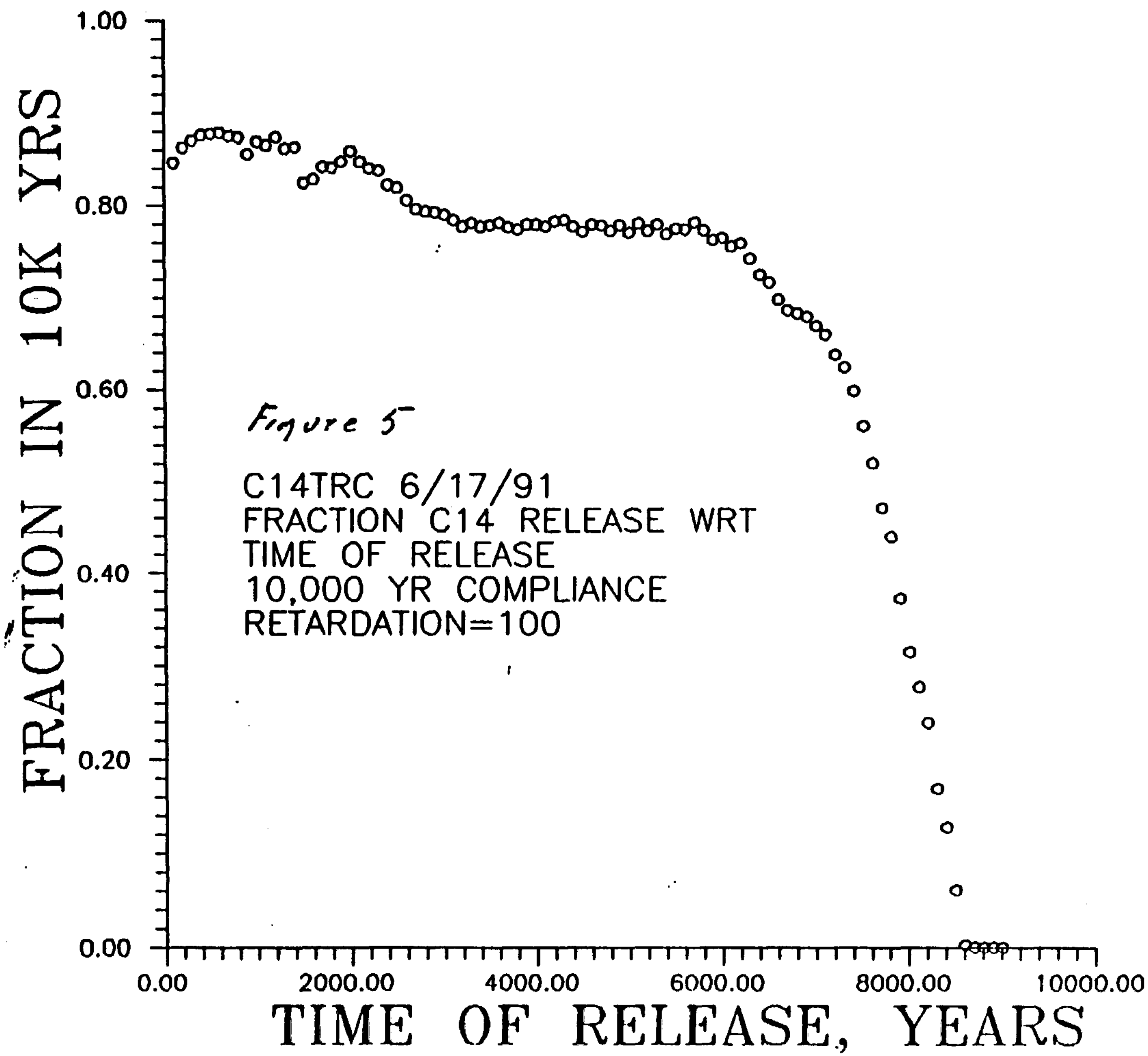
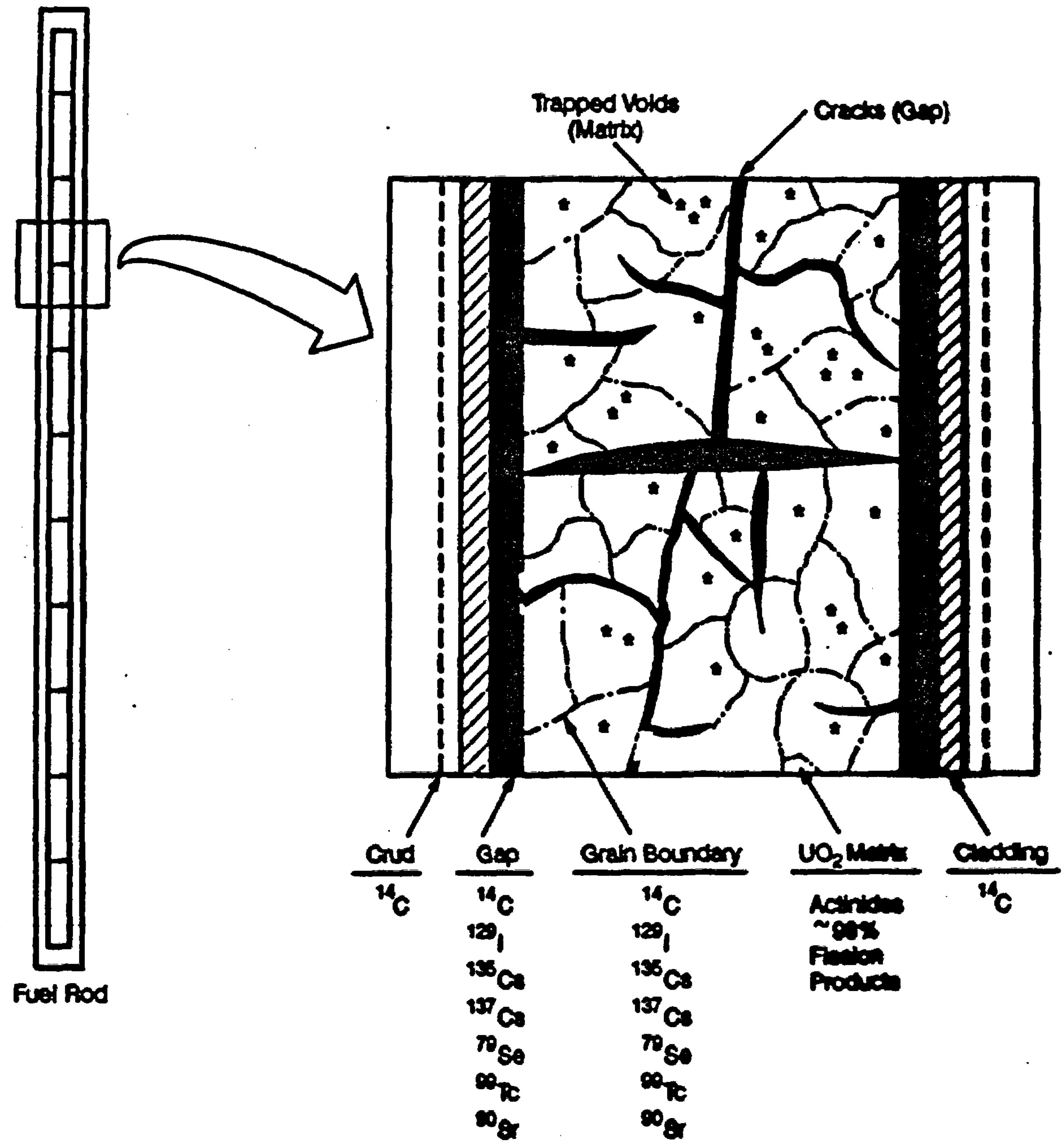


Figure 5
C14TRC 6/17/91
FRACTION C14 RELEASE WRT
TIME OF RELEASE
10,000 YR COMPLIANCE
RETARDATION=100
FRACTION IN 10K YRS
1.00
0.80
0.60
0.40
0.20
0.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
TIME OF RELEASE, YEARS



Location of Radionuclides in Spent Fuel and Potential Releases of C-14
(Apted, et. al., 1989)

Effects of Gas Phase on Radionuclide Source Term

Presence of air makes environment oxidizing, Leading to oxidation of canister metal and Uranium dioxide fuel

Volatile radionuclides can escape from canister in the air phase:

- internal pressure
- molecular diffusion
- barometric pumping

Last item, barometric pumping, would depend on the transport through the rock of pressure

Oxidation of Fuel Matrix

- Uranium dioxide unstable
- Oxygen available upon W.P. failure
- Oxidation rate will depend on:
  - temperature (and hence time of failure)
  - protection of cladding
- Oxidized fuel will be more soluble
- Oxidized fuel will be more porous

Cladding

- Very thin zircalloy or stainless steel
- Small fraction of fuel rods have defects
- Generally neglected as protection
- Some radionuclides tend to collect in or on cladding (esp. C-14)

NRC Phase 1 Model for C-14 Release from Fuel

1. Quick release - from outer layer of crud on cladding

2. Release from Grain and Gap on Cladding Failure

3. Oxidation of Cladding

$$L = \int_{t_f}^{t} 3.68 \times 10^{8} \exp\left(\frac{-15810}{T(t)}\right) dt \quad , \text{mm}$$

t_f = failure time, years
t = time, years
T = temperature, K

For T from 320 C - 110 C over 10 K years:
L = 0.0162 mm = 3% of cladding thickness
Most occurs within 100 years

$$\log t_s = (0.78E{-}4/T) - 13.01 \quad (1)$$

$$\log t_s = (1.03E{-}4/T) - 15.9 \quad (2)$$

t_s = spallation time, years
T = temperature, °K

e. Release rate of C-14 = $\lambda_s = 1/t_s$

f. Sample from range of Eqs. 1 and 2

g. Integrate λ_s over time:

$$M = M_0 \int_{t_f}^{t} \lambda_s e^{-(\lambda_s + \lambda_R)} dt$$

λ_R = rad decay
t_f = failure time

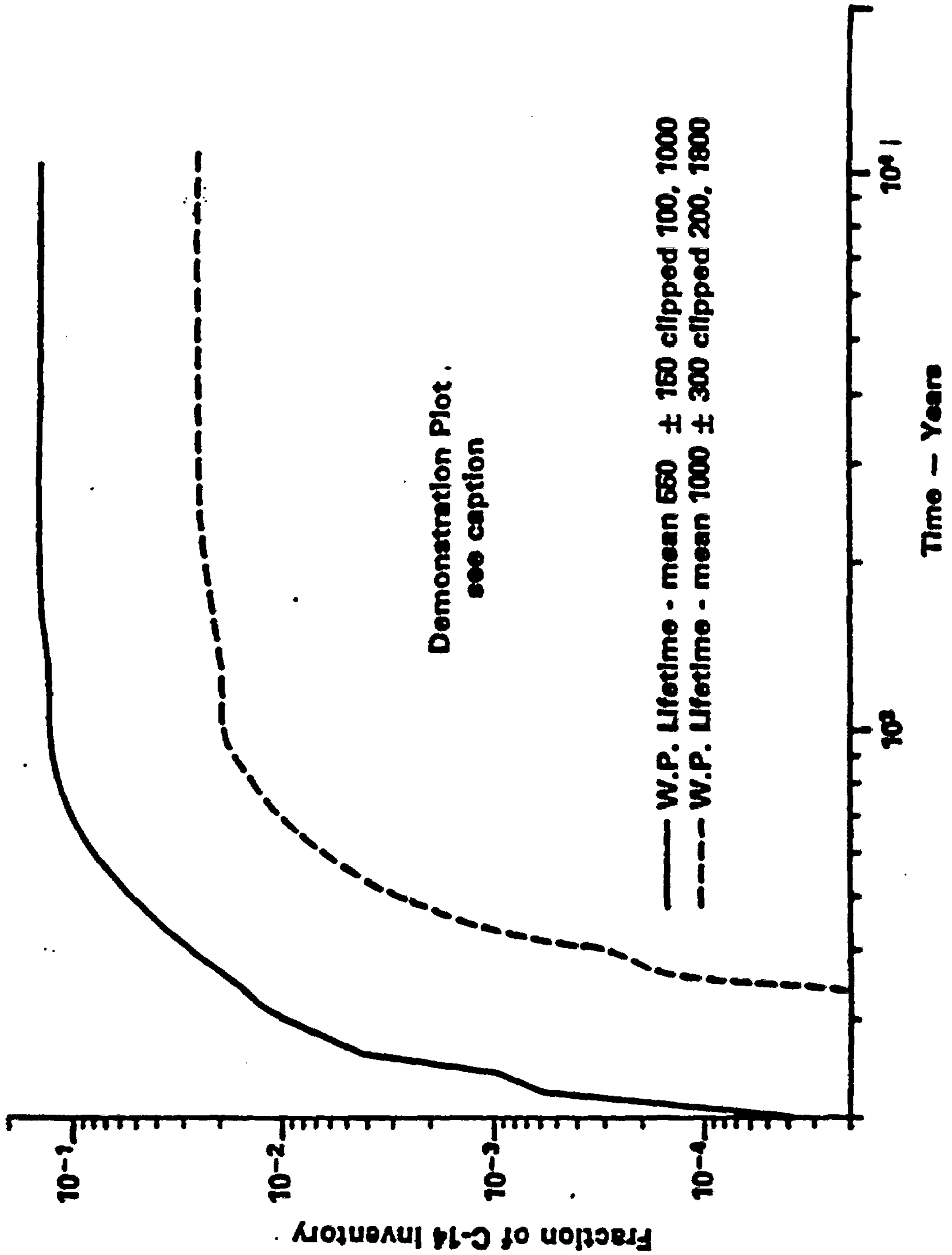


Figure D-1 Release of C-14 Inventory. This graph presents results from an initial demonstration of staff capability to conduct a performance assessment. The graph, like the demonstration, is limited by the use of many simplifying assumptions and sparse data.

Figure 2
A. Lerman

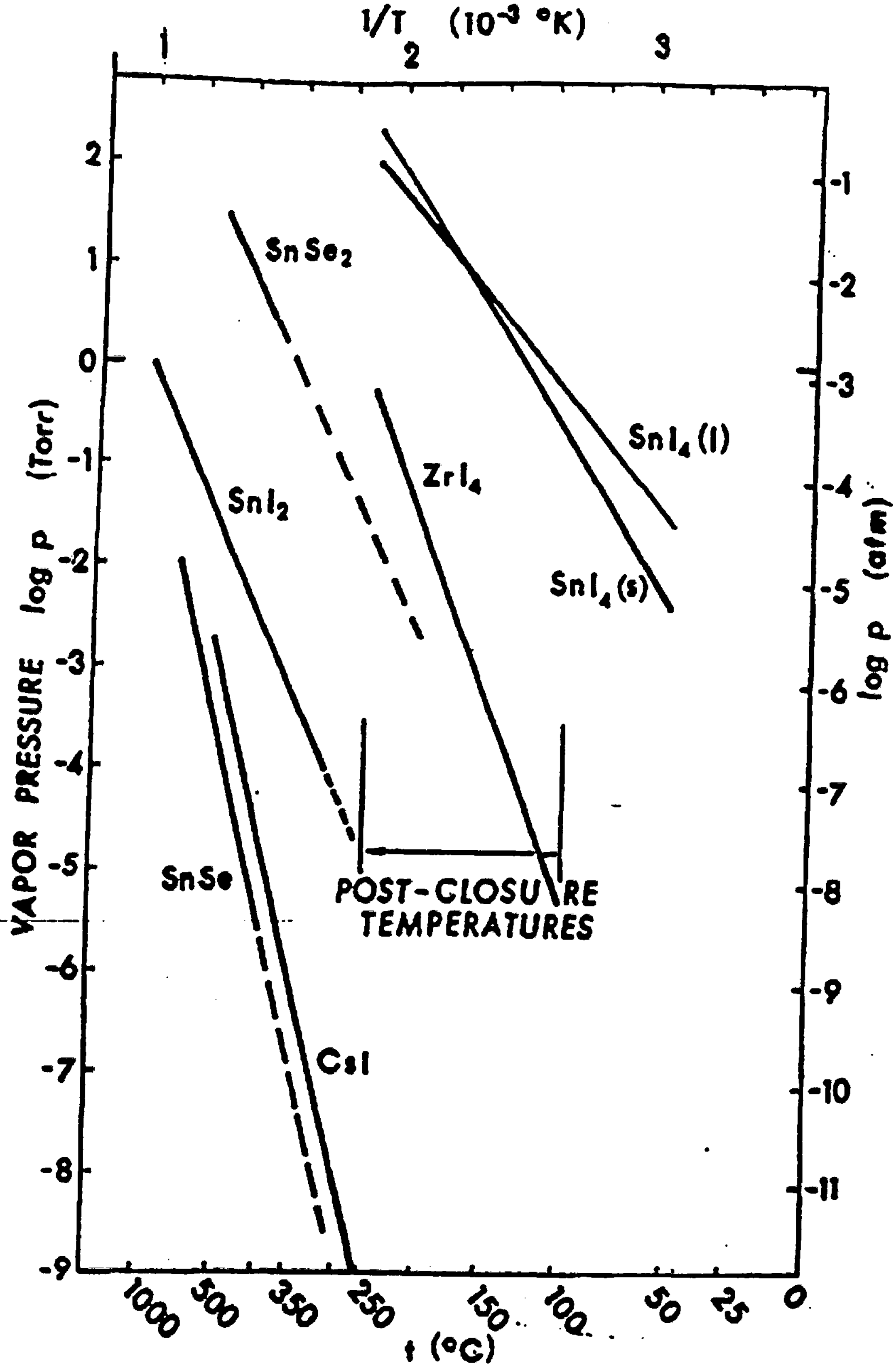
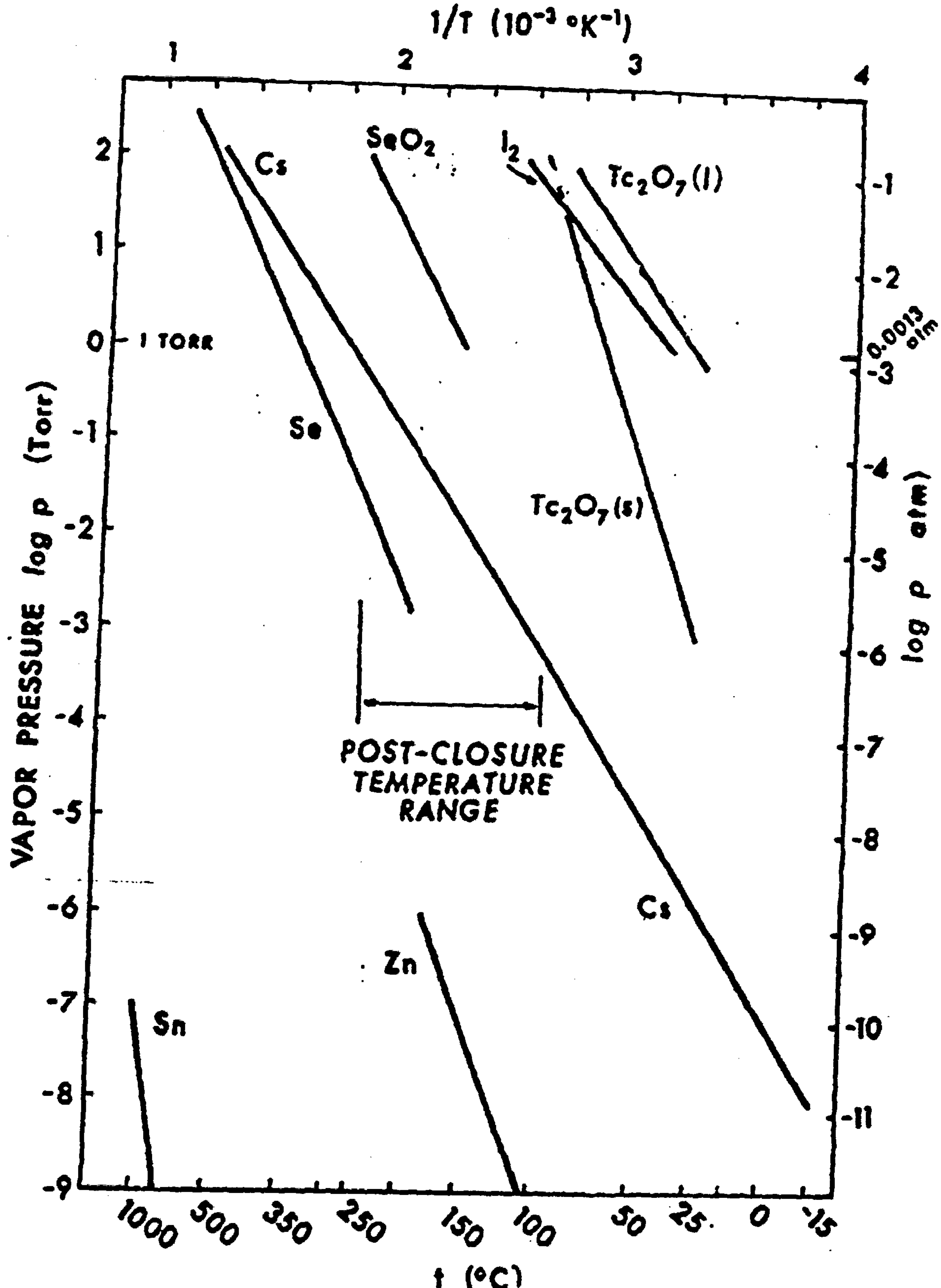


Figure 1


1/T (10^{-3} °K^{-1})
VAPOR PRESSURE log p (Torr)
log p atm
1 TORR
0.0013 atm
Cs
SeO2
I2
Tc2O7(l)
Se
Tc2O7(s)
POST-CLOSURE TEMPERATURE RANGE
Cs
Zn
Sn
t (°C)
1000
500
350
250
150
100
50
25
0
-15

VAPOR PRESSURES

SPECIES	VAPOR PRESSURE (ATMOSPHERES)	
	100°C	200°C
CO_2	> 2,000	> 12,000
I_2	6×10^{-2}	3.7
SeO_2	9.1×10^{-4}	5.4×10^{-2}
Tc_2O_7	1.2×10^{-4}	3.7×10^{-2}

(FROM LANGE'S HANDBOOK OF CHEMISTRY, 13TH EDITION, 1986)

COMPARISON OF INVENTORY TO CURRENT EPA 10,000-YEAR CUMULATIVE RELEASE LIMIT AT ACCESSIBLE ENVIRONMENT AND NRC 10CFR60.113 MAXIMUM RELEASE RATES FROM THE ENGINEERED BARRIER SYSTEM*

GASEOUS RADIONUCLIDES	INVENTORY AT 1,000 YEARS (CI)	EPA 10,000-YEAR CUMULATIVE RELEASE LIMIT, CI (ANNUAL AVG. CI/YR)	NRC POST-CONTAINMENT PERIOD RELEASE LIMIT FROM EBS (CI/YR)
^{14}C	62,000	6,200 (0.62)	**1.07
^{129}I	1,950	6,200 (0.62)	**1.07
SEMI-VOLATILE RADIONUCLIDES			
^{79}Se	25,050	62,000 (6.2)	**1.07
^{99}Tc	806,000	620,000 (6.2)	8.06
^{135}Cs	21,390	62,000 (6.2)	**1.07

*BASED ON [illegible] MTHM SPENT FUEL
**NUCLIDES FOR WHICH THE MAXIMUM RELEASE RATE IS GREATER THAN 1 X 10^{-5} PER YEAR INVENTORY BECAUSE OF THEIR SMALL INVENTORIES

(Park, 1991)

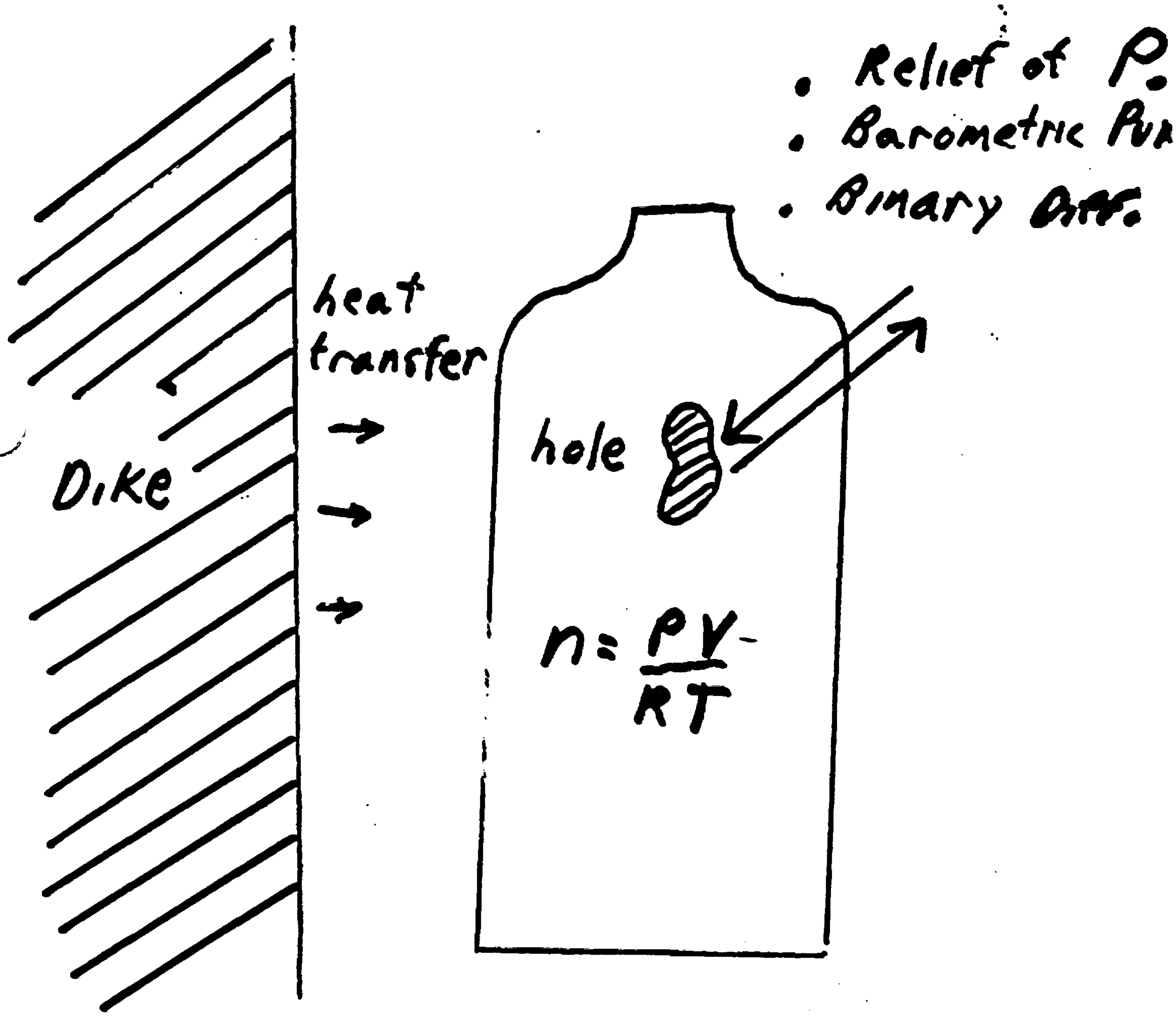
WOULD THESE POTENTIALLY GASEOUS RADIONUCLIDES ACTUALLY BE PRESENT IN THEIR VOLATILE FORMS ?

NUCLIDE	PROBABLE LOCATION & FORM IN SPENT FUEL	HIGH VAPOR PRESSURE FORM	COULD HIGH VAPOR PRESSURE FORM BE PRESENT UNDER OXIDIZING CONDITIONS?
^{14}C	FUEL ROD SURFACES, BULK CLAD, BULK UO_2, ELEMENT, CARBIDE	CO_2	YES
^{79}Se	BULK UO_2	SeO_2	YES
^{99}Tc	BULK UO_2	Tc_2O_7	YES
^{129}I	FUEL-CLAD GAP AND BULK UO_2, CsI	I_2	ONLY IN SMALL AMOUNTS
^{135}Cs	FUEL-CLAD GAP & BULK UO_2, Cs_2O, Cs_2UO_4, Cs_2MoO_4, CsI, Cs	Cs	NO

SUMMARY - ^{135}Cs WOULD NOT. ^{129}I COULD BE TO ONLY A SMALL EXTENT. THE OTHERS COULD BE, WHEN THEY ESCAPE THE SPENT FUEL

(Park, 1991)

Volcanic Intrusive Scenario with release of Volatiles



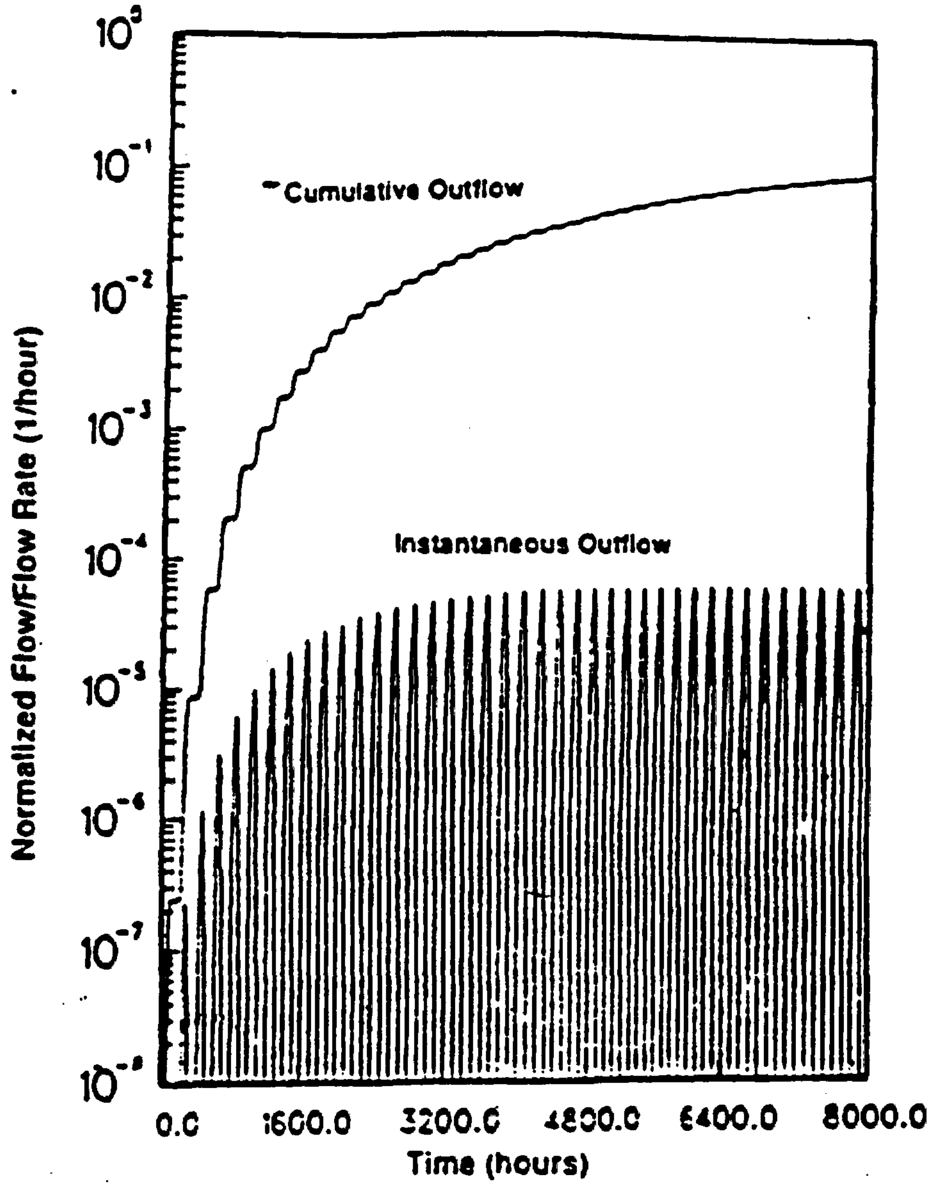


Figure 4. Instantaneous and cumulative outflow of contaminated gases expressed as a fraction of the total amount initially present.

Two distinct domains of time are apparent in the calculated histories of contaminant outflow. In the early-time *filtering regime*, the outflow of contaminant is greatly retarded by a filtering process in which most of the contaminant in the rising gas streams is transferred by molecular diffusion into the

ı differen-
a sole-
:cess tubes
o ning the
ated
t the land
arometer.
in figure
fluctua-
using the

and nonwe..oeu-... ....
than the silica-flour columns adjacent to the welded-tuff intervals. The combined effect of these differences probably resulted in the differences in trends detected between the probes placed adjacent to the two rock-type intervals. The HDP adjacent to the alluvium and nonwelded tuff probably have reached equilibrium with the formation. However, the HDP in the welded-tuff interval only recently have begun to indicate the movement of water from the formation into the silica flour; this condition is inferred from reversal of the trend from the deeper HDP-8A, HDP-9A, HDP-11A, HDP-13A, and HDP-15A. In conclusion,

and HDP in
by the ef-
aterial in
brate with
accurate
d before,
sand and
illed with
.e round
it s wet-
for the water
from low to
and for the
would be from
e created
s expected to
The drier
to absorb
re, to attain
m.

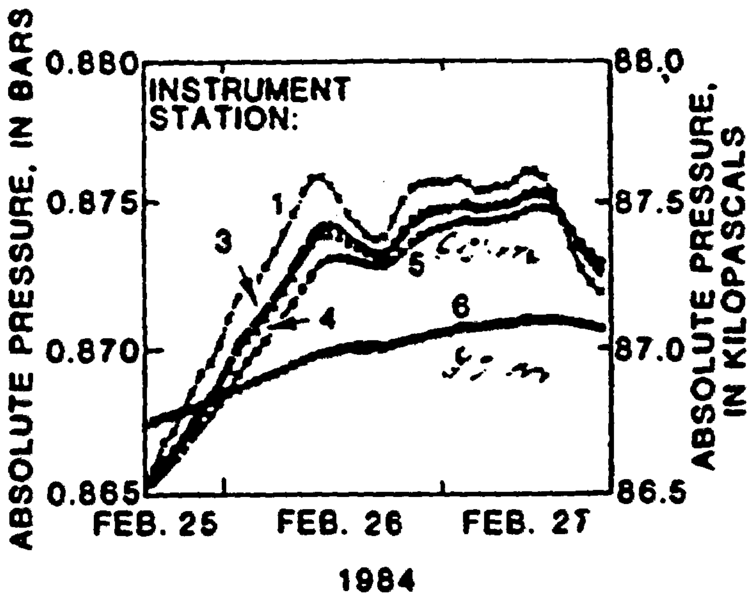


Fig. 6. Adjusted downhole-pressure variations in test borehole USW UZ-1. Differential pressures, measured with land surface transducers, were added to the calculated pneumatic-gravitational potential.

UZ-1

Conclusions

- Vapor phase considerations potentially important to a repository in unsaturated fractured rock
  - water flux
  - transport of volatile radionuclides
  - release of volatile radionuclides from source
- Present models for vapor phase flow release and transport based on inadequate data

NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT
DUE TO THERMAL GRADIENTS

STATE OF NEVADA COMMENTS

A comment by the State of Nevada on the process of technical exchanges was presented in its closing remarks. The protocol of the technical exchanges is a free and open exchange of technical views by all parties with no positions or agreements reached. The objective is an exchange of information on activities, data gathering, results, interpretations, and conclusions obtained to date. The meeting summary prepared subsequent to the exchange documents for the public record the purpose of the technical exchange, the agenda, the participants, and the information presented. At the March 18, 1992, technical exchange, some parties for reasons not expressed chose not to submit their information for the public record. As conceived by the Nuclear Waste Policy Act and confirmed in the NRC's 10 CFR Part 60 regulations, the repository program is a public process program. The public has the right to any information discussed between the applicant and the regulator. To insure the "public's right to know," the State requests that all information presented in technical exchanges as visual aids or reports be incorporated in the public record of the technical exchange.

ENCLOSURE 3

NRC STAFF SUMMARY OF THE NRC/DOE TECHNICAL EXCHANGE ON AIR AND VAPOR MOVEMENT DUE TO THERMAL GRADIENTS

On March 18, 1992, staff from the Nuclear Regulatory Commission, the U.S. Department of Energy (DOE), the State of Nevada, and DOE program participants attended a technical exchange, to discuss technical and regulatory issues related to evaluating gas transport and moisture redistribution caused by repository-induced thermal gradients. The technical exchange focused on gas flow in Yucca Mountain, Nevada, both natural and induced by repository thermal loads, and its potential for transporting gaseous radionuclides, especially carbon-14.

The first presenter was Ed Weeks, of the U.S. Geological Survey, who described the background on naturally occurring air flow at Yucca Mountain. Much of the gas flow observed in the unsaturated zone (UZ) boreholes comes from layers below the surface, at least 10 meters deep. There are several factors that affect the air flow at the site: wind, density difference, and barometric pumping. Wind is an important factor in driving the air flows, both because of its direct impact on the flanks of the mountain, and the Bernoulli effect as the air flows over the raised airfoil shape of the mountain, causing reduced barometric pressure at the top of the mountain. Weeks showed correlations of gas flow with wind speed and direction. Wind impacting on the bluffs of Solitario Canyon has the greatest correlation with air flow in the UZ boreholes. Barometric pumping has little effect on transport of gas from deep within the mountain, because there is no net flow out during a typical pressure variation of a few hours or days, but it does lead to mixing of gases inside the mountain.

The results of measurements of carbon dioxide (CO_2) in the UZ were also presented. Weeks postulated that CO_2 comes from the root zone in plants and is always discharging at the surface. The concentration of CO_2 generally decreases with depth, except for anomalously high concentrations thought to be caused by remnants of drilling fluid. The decrease with depth is thought to be caused by diffusion from the surface zone through the rock. CO_2 at depth is very old and hence depleted in radioactive carbon-14. Another explanation for the depletion is precipitation of calcite, which would require a source of calcium ions. In spite of the large air flows observed in Yucca Mountain, deep carbon-14 is below pre-bomb testing levels, indicating that it must be very old. In the circulation near Tiva Canyon, however, there is evidence of post-bomb levels, because of the circulation from the flanks of the mountain and the fractured nature of some of the exposed rock units.

The next speaker was Karsten Preuss of Lawrence Berkeley Laboratories, who is the developer of the TOUGH code used widely for two-phase heat and mass transfer. Preuss presented a table of characteristic propagation times (for 100m propagation), as shown below (reconstructed from the notes of the NRC staff):

	Topopah Springs	Calico Hills
Heat Conduction	299 yrs.	511 yrs.
Liquid Flow	2347 yrs.	1.76 yrs.(?)
Gas Flow	49.6 hrs.(?)	1.27 yrs.
Vapor Diffusion	14.8 yrs.	14.8 yrs.
Air Diffusion	846 yrs.	846 yrs.

The scale of the model was regional, with blocks too big to show the effects of heat immediately near waste packages, but did show the circulation patterns, in a gross sense. Preuss demonstrated that the effects of vapor-air diffusion were of the same order as those from buoyancy. Without diffusion, the model showed a distinct circulation pattern caused by the heat. With molecular diffusion turned on, the diffusion destroyed the circulation pattern. This conflicts with the model study of Ben Ross (of Disposal Systems, Inc. (DSI)) and the model chosen by the NRC staff in "Phase 2" of its Iterative Performance Assessment effort. One explanation for this observation is that the permeabilities NRC chose were several orders of magnitude larger than those chosen by Preuss, which favors convective effects over diffusion. Even with the lower permeabilities, Preuss predicts air travel times at Yucca Mountain on the order of several hundred years.

Tom Buscheck of Lawrence Livermore National Laboratories presented a talk on two-phase modeling at Yucca Mountain. Model focused on the near-field phenomena in the vicinity of the waste packages, using an adaptation of the TOUGH code called V-TOUGH. Buscheck's model took advantage of radial symmetry to show a three-dimensional picture of heat and mass transfer around waste packages. This model was intended to demonstrate the effects of heat loading on repository performance. Buscheck's models considered the range of 20 to 114 kilowatt (kw)/acre initial heat loading. The reference heat loading in the 1988 Site Characterization Plan was 57 kw/acre. At the higher heat loads, the models show that temperatures might remain above boiling for 10,000 years. Larger permeability leads to higher heat convection by latent heat and a larger dryout zone. If fractures are present and permeability is large, there will be significant dryout. Without fractures, the matrix permeability is small, which leads to a build-up of pressure and less vaporization of water. The temperature calculations are fairly insensitive to permeability, however. One very important observation of his modeling efforts is that the reflux rate -- the amount of water circulating in the near field as the result of heat transfer -- is several centimeters to tens of centimeters per year, far in excess of the amount of meteoric water likely to recharge the site. The consequences of this thermally driven reflux are not clear, however, since there does not appear to be a well-understood mechanism to bring the water back into contact with the rock or the waste. For this reason, Buscheck speculated that the high heat loading condition might be advantageous for the repository, since it would keep the canisters dry for an extended period. He did not consider, however, the possible deleterious effects of sustained high temperatures on the waste.

There was a comment on the possible flow-back of water driven above the repository by the heat, which would condense later and drip down onto the canisters. For this eventuality, Buscheck suggested that backfilling the tunnels with crushed tuff (possibly a highly sorptive variety) would eliminate any dripping, by wicking away the water. Another attendee commented about the collection of water near the heater experiment in G-Tunnel. Buscheck replied that there was no evidence, however, that the collected water ever came back into contact with the heater itself. Martin Mifflin, representing the State of Nevada, asked about innate water of hydration on minerals. The reply was that this was probably insignificant, compared to the amount of free water in the rock. Mifflin also commented that he had calculated the volume of water (matrix) within the 95°C contour determined by TOUGH and could not fit it into the available fracture porosity outside of the 95°C contour.

The next speaker was Ben Ross of DSI, a contractor to Sandia National Laboratories. Ross spoke of the TGIF model for gas flow at Yucca Mountain. As noted earlier, this model was the basis of the model developed by the NRC staff. It is significantly simpler than the two-phase models presented by Buscheck and Preuss, but captures many of the same phenomena. The significant differences are that it deals explicitly only with the gas phase and not the liquid phase, and is incapable of showing some of the important near-field phenomena such as drying-out and thermally induced reflux. One further distinction between the models is that Ross used significantly larger permeabilities, which were derived from pressure measurements, rather than measured directly. Consequently Ross' results show higher gas flow rates. Weeks commented that permeability data derived from pressure measurements may be of questionable reliability.

Ross spoke briefly of his latest development efforts to take latent heat transfer effects into account. The heat transfer parts of the calculations for both TGIF and the NRC models rely on heat conduction, only. Ross is funded at only a very low level, to continue the work, but initial results are positive.

Mike Wilson of Sandia National Laboratories (SNL) spoke briefly about the efforts to include carbon-14 modeling into its performance assessments. SNL will be using the carbon-14 travel time distributions, determined by the TGIF model, coupled with a source term model for carbon-14 emanations from the waste. As best as the NRC staff could determine, the carbon-14 gaseous-release model predicts release at the rate for all other dissolved radionuclide releases -- that is the prompt release fraction and slower release at the rate of fuel disintegration in water. Richard Van Konynenburg of Lawrence Livermore National Laboratories pointed out to Wilson that his model does not include dry oxidation, and that corrosion could be rapid in a wet steam environment. Nevertheless, Wilson claims that the model has many conservative assumptions.