UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 23, 1997

Dr. Stephan Brocoum
Assistant Manager for Suitability and Licensing
United States Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office
P. O. Box 98608
Las Vegas, Nevada 89193-8608

SUBJECT: COMMENTS ON THE DEPARTMENT OF ENERGY THERMOHYDROLOGY TESTING AND MODELING PROGRAM

Dear Dr. Brocoum:

The Nuclear Regulatory Commission staff has reviewed recent information on the Department of Energy's (DOE's) Thermohydrology Testing and Modeling Program. The objective of this review was to evaluate whether the program will provide the information necessary for the license application. Based on our review, we have no objections related to the program. However, we do have several comments about the program. First, we believe that an accelerated drift-scale heater test at thermal loads much higher than those expected at the repository poses a risk of masking potentially important phenomena and not providing the information necessary to differentiate among alternative conceptual models. Second, the applicability of neither the equivalent continuum model (ECM) approach nor alternative approaches to bound predictions of liquid flow to waste containers has been demonstrated. Finally, it is not clear that the testing and modeling strategy will observe and evaluate phenomena to determine the importance of thermal-hydrologic-chemical (THC) coupling. These comments are discussed in more detail in the following:

- Thermal Testing Strategy: The staff supports DOE's approach of phased thermal testing at various scales, including laboratory-scale testing, the Fran Ridge Large Block Test (LBT), the alcove-scale single heater test, and the drift-scale heater test. It is our belief that evaporation of water close to the heat source, condensation in cooler regions at some distance from the source, and potential gravity-influenced liquid water flow (mostly through fractures) towards the heat source are possible phenomena of significant interest, because they may determine the time and rate of wetting of the waste packages and, hence, their effectiveness in waste containment. Of the thermal tests to be conducted at various scales, the drift-scale heater test at the Exploratory Studies Facility (ESF) will probably provide the best source of data for differentiating among conceptual models. Using knowledge of the location and kinds of sensors used in the test, analyses should be conducted to check that the significantly higher heat load of the planned drift-scale heater test compared to the expected repository heat load will not mask potentially important phenomena. If DOE has already performed analyses to assess the occurrence and nature of gravity-driven refluxing, the staff would appreciate receiving the related reports.

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Such analyses can also help in modifying test designs to provide assurance that important heat and mass transfer phenomena will be observed.

- Adequacy of Conceptual Model: The influence of fractures on rates of water flow toward waste packages is a central question in estimating the life of waste containers. The proposed thermohydrology tests should distinguish among alternative conceptual models, including those that incorporate fractures and those that do not. Specifically, the proposed tests should be designed to discriminate among various conceptual models, such as the ECM's in which the fractures and porous rock are conceptualized as a single continuum in contrast to discrete fracture models or models that use the concept of multiple interacting continua. It needs to be demonstrated that the model selected for performance analyses will include the important processes that affect water flow and provide conservative bounds on water flow rates and subsequent effects on engineered barrier system performance.

- Effects of Thermal-Hydrologic-Chemical Coupling: The testing and modeling strategy should include means for bounding the effects of THC coupled processes on repository performance. Some NRC- and DOE-sponsored work indicates that this three-process coupling may lead to significant changes in the near-field environment and, thus, influence waste package performance. A suitable THC modeling strategy needs to be developed. The staff supports a phased approach in which a scoping analysis is first performed to demonstrate that THC bounding assumptions and analyses are conservative. If the THC bounding assumptions and analyses cannot be shown to be conservative, then THC coupled effects need to be evaluated using more robust THC models.

For this review, the staff depended mainly on the January 1996 report by the Peer Review Team (PRT) that was established by DOE to review its thermohydrology program, associated DOE responses, and PRT counter responses. In addition, the staff factored in information from previous DOE documents, as well as information gathered during an Appendix 7 meeting (July 1996) and NRC/DOE ESF videoconference (September 1996).

The enclosure provides a more detailed basis for these comments. Because the drift-scale heater test and the Fran Ridge LBT are expected to start in 1997, the staff comments are provided for your immediate consideration. A Technical Exchange or an Appendix 7 meeting on the thermohydrologic testing and modeling strategy may be useful to discuss and clarify these comments.

If you have any questions concerning this letter, please contact Jeffrey Pohle of my staff at (301) 415-6703, or via internet (jap2@nrc.gov).

Sincerely,

Original Signed By

Michael J. Bell, Chief
Engineering and Geosciences Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

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## NUCLEAR REGULATORY COMMISSION STAFF COMMENTS ON THE DEPARTMENT OF ENERGY THERMOHYDROLOGY TESTING AND MODELING PROGRAM

### COMMENT 1

A field-scale heater test at thermal loads much higher than those expected at the repository poses a risk of masking the phenomenon of gravity-driven liquid water flow toward the heaters, which might occur at the lower temperatures expected for the repository.

### BASIS

The Department of Energy (DOE) is pursuing a program of phased thermal testing at various scales-from laboratory-scale testing to the Fran Ridge Large Block Test (LBT) to the alcove-scale single heater test to the drift-scale heater test. Of these tests, the drift-scale heater test at the Exploratory Studies Facility (ESF) will probably provide the best source of data for evaluating conceptual models. Therefore, the ESF heater test should be designed so that it is able to: (i) discriminate among the candidate conceptual models, and (ii) observe phenomena that are expected to occur under conditions representative of the proposed repository. One way to ensure that phenomena expected at the repository are observed is to conduct the test under the thermal regime of the repository and at a site that is representative of the repository. It is the staff's understanding that DOE plans to conduct the drift-scale test at a heat load that is much higher than expected at the repository. Using higher heat loads may be able to accelerate the test; however, it raises the question of whether the test results can be scaled to repository conditions. If DOE chooses to conduct the test at a higher heat load, then DOE should perform analyses to show that the results can be scaled to repository conditions.

Previous field-scale heater tests at Climax, G-Tunnel, and near the Apache Leap Test Site (ALTS) experienced liquid water formation on the heater during the heating phase of the experiments. Gravity-driven refluxing is one likely mechanism that could lead to dripping and the deposition of water on the test heaters. Liquid water interacting with the waste package during the heating phase of the repository will contradict one of the hypotheses of the DOE Waste Containment and Isolation Strategy which relies on the waste package environment remaining dry for long periods of time. Therefore, field-scale heater tests should be designed to resolve whether water will be able to contact the waste package during the heating phase under repository heating conditions.

DOE stated during the July 1996 Appendix 7 meeting that wing heater temperatures during the drift-scale test would be high, possibly in excess of 400° C, to expedite the heating of a large mass of rock (i.e., 15,000 to 30,000 $m^3$) to temperatures above boiling within a 2-4 year time period. This would result in drift wall temperatures in excess of 200° C during the heating portion of the test. Scoping calculations indicate that drift wall temperatures in a repository with a thermal load of 80-85 MTU/acre will be approximately 120°-130° C, with a maximum of 150° C possible (Nuclear

Enclosure

Regulatory Commission, 1996). Heat and mass transport mechanisms, such as episodic gravity-driven refluxing and dripping, which could occur with drift wall temperatures less than 150° C, would be much less likely to occur if the drift wall temperatures exceed 200° C and highly unlikely for temperatures as high as 250° C. Therefore, the formation of liquid water on heaters observed during heater tests at Climax, G-Tunnel, and ALTS would likely not occur in a heater test conducted at the higher temperatures. The results of a heater test in which the drift walls attained temperatures excessively higher than those expected at the high level waste (HLW) repository could mask the phenomenon of gravity-driven refluxing and dripping from individual fractures. This masking could erroneously be interpreted to support the equivalent continuum model (ECM), because the ECM lacks the capability to represent this phenomenon.

Statements were made during the Appendix 7 meeting and the follow-up NRC/DOE ESF videoconference that gravity-driven refluxing and/or dripping can be observed during tests conducted at the higher temperatures either: (i) at some distance within the rock mass during the heating period of the test because of the high level of instrumentation; (ii) during the heating period in which the boiling isotherm has penetrated only a short distance past the drift wall and drift wall temperatures would not have exceeded 150° C; or (iii) during the cooling period when the drift wall temperature has decreased below the boiling isotherm.

In response to (i), the staff notes that the dripping phenomenon occurs when a quantity of liquid water episodically flows down fractures whose surface temperatures are cooled below the boiling temperatures experienced further within the adjacent rock mass (Phillips, 1994) and drips into the drift upon reaching the drift wall (or ceiling). It is doubtful that the DOE-planned instrumentation is capable of detecting this phenomenon within the rock mass far from a free surface. Additionally, the dripping phenomenon will only occur when episodic fracture flow occurs at the drift wall (or ceiling) and not within the rock mass. In response to (ii), it appears to the staff that the accelerated temperature ramp-up of the heater test will provide only a short period of time when the drift-wall temperatures are similar to those predicted for the HLW repository. It is not clear whether this limited period of time will allow for the formation of a zone of condensed water above the central drift area to initiate and maintain the refluxing/dripping phenomenon. In response to (iii), the staff observes that the single-drift design of the drift-scale experiment and the plan to uniformly heat the entire length of drift floor and wing heaters to high temperatures may more easily shed away condensed water from above the single drift, which would not be as easily shed from the multitude of drifts at a range of temperatures in the HLW repository. The excessively high temperatures of an accelerated thermal load single-drift heater test may drive the zone of condensed water sufficiently far from the drift wall so that water refluxing back to the single drift may not be detected during the limited term cool-down period of the heater test.

RECOMMENDATION

The ESF drift-scale heater test should be designed to provide the information necessary to discriminate among various conceptual models and be conducted such that either important phenomena expected to occur under repository conditions can be directly observed or that the characteristics of such phenomena can be inferred through application of suitable scaling relations. Numerical analyses should be performed prior to the test to assess the likelihood of meeting the test objectives. In addition, unless the phenomenon of gravity-driven liquid water flow towards the heaters is shown to be insignificant in the performance of the repository, DOE should conduct analyses to demonstrate that this phenomenon will not be masked during the conduct of the drift-scale heater test.

COMMENT 2

The applicability of either the ECM approach or alternative approaches to bound predictions of liquid flow to containers has not been demonstrated. The planned laboratory-scale studies, field-scale heater test, and related analyses may not provide information to discriminate among alternative conceptual models or to provide the basis for the selection of a bounding model.

BASIS

The DOE Waste Containment and Isolation Strategy relies on attributes of the unsaturated zone environment to provide a setting in which waste packages are expected to contain the waste for thousands of years. Prediction of two of these attributes, seepage and containment, are particularly dependent on the conceptual models used to predict thermally-driven flow of moisture through partially-saturated, fractured porous media. Prediction of seepage or containment using improper or inadequate conceptual models can lead to nonconservative assessment of the containment and isolation of waste at the geologic repository. DOE has stated its intention to use laboratory tests and available *in-situ* observations to bound sensitivity analyses, incorporate remaining uncertainties into process level models, and bring more geologic realism into the models "via inter-laboratory cooperation and through investigating the circumstances under which the ECM approximation is valid." In addition to the ECM, DOE analyses of the Fran Ridge LBT and the *in-situ* tests may also be predicated on alternative conceptual models.

Several aspects of the program to evaluate the validity of the ECM are not clear. In particular, it is not clear how remaining uncertainties will be identified or incorporated into process level models or how the validity of the ECM approximation will be investigated. Until the limitations of the ECM are identified, there remains the potential for over-reliance on results from models predicated on the ECM formulation. This over-reliance is demonstrated in the 1995 DOE total system performance assessment (TRW Environmental Safety Systems, Inc., 1995) and in the analysis of the proposed drift-scale thermal test (Buscheck and Nitao, 1995), both of which rely heavily on the ECM conceptualization. The ranges of conditions for which the ECM conceptualization is valid in these analyses have not been identified.

RECOMMENDATION

DOE should demonstrate that the model selected for performance analyses includes the important processes that will affect water flow and provide conservative bounds on water flow rates.

## COMMENT 3

An approach for obtaining conservative bounds for the effects of THC coupled processes has not been demonstrated.

## BASIS

Limited NRC- and DOE-sponsored work indicates thermal-hydrologic-chemical (THC) coupling processes may lead to significant changes in the near-field environment. For instance, at high thermal loads, significant concentrations of dissolved species, such as chloride and elevation of pH, can be expected to occur near the boiling front surrounding the repository (Nuclear Regulatory Commission, 1996). In addition, a two-dimensional calculation using a repository scale model with a single component that took into account reaction with quartz indicated changes in permeability due to THC coupled processes (Robinson, 1995).

The Peer Review Team (PRT) stated that because of the relatively limited amount of work related to THC processes, "...they could not assess how important these processes are to the overall performance of the repository system." The PRT noted, however, that "...simply lacking knowledge about the THC processes is not justification for assuming them to be unimportant." Finally they stated: "The PRT believes that there remain possibilities for significant 'surprises' associated with THC processes."

The PRT stated that for THC it "would prefer to see simple scoping calculations first, followed by numerical simulations at a scale that can be validated and calibrated by proposed laboratory and field tests. Another possible approach would be to try to apply thermochemical models, such as EQ3/6, to conditions anticipated to occur at the boiling front, rather than trying to fully couple TH flow models and HC transport models."

The DOE response was basically that it agreed with the PRT recommendations and "The coupled THC calculations remain only a small part of the program designed to understand rock-water reactions." DOE concluded: "... THC studies will continue to be centered around the use of EQ3/6 to examine possible rock-water reactions in detail, as recommended by the PRT."

Evaluation of THC coupled effects can be achieved with models that adequately couple THC processes. The current codes mentioned by the PRT and DOE for modeling TH processes (i.e., TOUGH, TOUGH2, VTOUGH, FEHM, and NUFT) do not include chemistry suitable for describing rock-water interactions and the effects on solution chemistry due to evaporation and condensation processes. An additional code mentioned in the DOE response, GIMRT/OS3D, is a fully saturated code that does not include two-phase fluid flow. The thermochemical code EQ3/6 does not include hydrologic processes.

## RECOMMENDATION

The staff supports a phased approach recommended by the PRT. DOE should demonstrate that THC bounding assumptions and analyses are conservative. If the THC bounding assumptions and analyses cannot be shown to be conservative, then THC coupled effects should be evaluated using coupled THC models. Serious consideration should also be given to including chemistry measurements in the drift-scale test to investigate the extent of this three-process coupling.

## REFERENCES


Buscheck, T.A., and J.J. Nitao, *Thermal-Hydrological Analysis of Large-Scale Thermal Tests in the Exploratory Studies Facility at Yucca Mountain*, UCRL-ID-121791, Livermore, CA: Lawrence National Laboratory, 1995.

Nuclear Regulatory Commission, *NRC High-Level Radioactive Waste Program Annual Progress Report Fiscal Year 1996*, NUREG/CR-6513, NO.1. Washington, DC, 1996.

Phillips, O.M., *Liquid Infiltration Through the Boiling-Point Isotherm in a Desiccating Fractured Rock Matrix. Proceedings of the Fifth International High-Level Waste Management Conference*, American Nuclear Society: 2,189-2,196, La Grange, llinois, 1994.

Robinson, B., *Status of Coupled Thermohydrologic/Geochemical Modeling*, Second Meeting of the Thermohydrologic Modeling and Testing Program Peer Review, Las Vegas, Nevada, August 21-24, 1995.

TRW Environmental Safety Systems, Inc., *Total System Performance Assessment—1995: An Evaluation of the Potential Yucca Mountain Repository*, B00000000-0171702200-00136, Rev. 01, Las Vegas, Nevada, 1995.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 22, 1997

MEMORANDUM TO: Michael Bell, Chief
ENGB/DWM/NMSS

FROM: Neil Coleman, Hydrogeologist
ENGB/DWM/NMSS

SUBJECT: TRIP REPORT: OBSERVATION OF THE DEPARTMENT OF ENERGY UNSATURATED ZONE FLOW TSPA-VA ABSTRACTION/TESTING WORKSHOP, ALBUQUERQUE, NEW MEXICO, DECEMBER 11-13, 1996

During the second week in December, I attended the subject workshop. This was an internal Department of Energy (DOE) workshop that was not open to the public. Therefore, I was solely an observer rather than a participant. This was the first of a series of ten abstraction workshops designed to bring together Yucca Mountain data collectors and modelers. The ultimate goal of the series is to develop a valid, defensible total system performance assessment and viability assessment (TSPA-VA) using the most current, available data.

The workshop consisted of four parts. First, the Sandia organizers gave an overview of the format, goals, ground rules, and a general summary of TSPA plans for the future. The second part of the workshop consisted of brief ten-minute talks by the key investigators. To ensure brevity, speakers were asked to use only two slides and to describe the most important issues in their areas of investigation. In the third part of the workshop, researchers split up into working groups and discussed ten key unsaturated zone issues and identified various subissues for each. Their key unsaturated zone issues included topics like infiltration, perched water, seepage into drifts, treatment of fracture properties, etc. Then the researchers split up into four working groups with the goal of prioritizing the ten key issues and their top four subissues under each. The following four principal issues for unsaturated flow were identified during the workshop:

- Lateral flow and perched water below the repository
- Flow channeling and seepage into the drifts
- Infiltration and future climate change
- Model calibration

In the fourth and final part of the workshop, participants wrote up technical proposals to address problem areas under the four principal issues. The proposals were to be discussed and prioritized after the workshop to determine which were most important and could be funded during the current fiscal year.

CONTACT: N. Coleman, ENGB
415-6615

Since returning from the workshop a question has arisen about DOE's schedule to finalize the various abstractions that will support TSPA-VA calculations. I spoke with Holly Dockery of Sandia on January 15th. The current plan is to finalize abstractions for the earliest workshops, such as the unsaturated zone workshops, by this summer. Abstractions for the later workshops would be finalized by this fall.

This workshop appeared to do a good job of setting the stage for two other planned workshops, i.e., thermohydrology and unsaturated zone transport. I suggest that the Nuclear Regulatory Commission send representatives to observe each of the abstraction workshops. Even though our staff are restricted to observer's roles, it is the best way to get an early understanding of how abstractions are being developed for the TSPA-VA work.

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