Sandia - for action

Department of Energy

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QA: N/A

JUL 14 1997

OVERNIGHT MAIL

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U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO U.S. NUCLEAR REGULATORY COMMISSION (NRC) COMMENTS ON DOE'S THERMOHYDROLOGY TESTING AND MODELING PROGRAM

Reference: Ltr, Bell to Brocoum, dtd 1/23/97

In your letter dated January 23, 1997, "Comments on the Department of Energy Thermohydrology Testing and Modeling Program," you provided three comments. These comments were related to: (1) our plans to use temperature profiles that risk potentially masking the phenomenon of gravity-driven liquid water flow; (2) the applicability of either the Equivalent Continuum Model (ECM) approach or alternative approaches to bound predictions of liquid flow; and (3) our demonstration of an approach for obtaining conservative bounds for the effects of thermal-hydrologic-chemical (THC) coupled processes. This letter provides our response to the staff's comments; additional information on our thermohydrology testing and modeling program is contained in Enclosure 1.

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.*

Your primary concern, as expressed in the January 23, 1997, letter (and the only major concern expressed for all thermal testing in your Comment 10 of the General Accounting Office (GAO) report titled "NUCLEAR WASTE Impediments to Completing the Yucca Mountain Repository Project" (GAO/RCED-97-30), is that compared to repository conditions, the peak temperatures in the Drift Scale Test are high and are reached in a relatively short period of time. You suggest that such high temperatures have the potential of masking important phenomena and associated observations that could be useful in discriminating among alternative conceptual models.

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Although the Drift Scale Test is a major part of our thermal testing strategy, the test is not

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expected to address the issues with respect to heat-driven near field processes by itself. The repository thermal load and the Drift Scale Test thermal load are not directly comparable, due to the extreme differences in their time scales. Therefore, we must use the Drift Scale Test to study phenomena, rather than for it to act as a replica of the repository. It would be centuries before some of the expected phenomena manifest themselves in a repository. In this context, it is unavoidable that the heating rate in field-scale thermal tests will have to be accelerated substantially relative to repository conditions in order for the test to be of use in the licensing process. Nevertheless, because of your concerns, we have modified the test hardware to provide for more flexibility in setting and changing the heater outputs, to allow us to conduct the test at lower heating rates and temperatures.

Peak temperatures are predicted to occur only locally around the wing heaters (possibly as high as 350°C to 400°C based on a worst case (hottest), conduction-only, zero flux model) and are largely a function of the low thermal conductivity of the matrix of the repository rock (Topopah Spring Tuff). This same low thermal conductivity means that the effect is localized, as shown in Figure 1 (enclosed).

The Drift Scale Test has many goals, including investigating large scale and critical phenomena. For example, an important goal of the test is to heat a large enough volume of rock and water to induce large scale phenomena. Heating a meaningful volume of rock to above 100°C in a realistic time-frame may require the drift-wall temperature in the test to be greater than any expected repository temperature. Another controlling factor for the test is to investigate critical phenomena, such as refluxing. In the repository, the cooling of the rock will be slow and gradual, as the applied heat (from the waste) decays and heat in the rock dissipates. In the Drift Scale Test, as the heaters are turned off at some point in time, the cooling will be relatively rapid. One of the motivations of accelerating the heating is to minimize the time required to reach the critical post-boiling period when condensate drainage into the drift is most likely.

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.*

Although ECM, or some variation, has been employed extensively in the past in examining and analyzing fluid flow in the unsaturated porous media of Yucca Mountain, Nevada, both in the ambient and thermally-perturbed regimes, the ECM is not being relied upon exclusively to analyze the response of the rock during the field-scale thermal tests. Both the ECM and dual permeability models have been implemented in modeling the Single Heater Test and the Drift Scale Test, and will be used in analyses of test results from both.

It is entirely possible that the planned tests and analyses will not conclusively discriminate among various models of repository performance because of the great differences in time and size between a repository and a meaningful test program. Nevertheless, we believe the currently planned tests and analyses are sufficient to provide a reasonable understanding of coupled processes for use in the licensing process. This is particularly so when it is realized, as was acknowledged in your Comment 10 on the GAO report, that "the thermal testing data that will be available at DOE's current planned date of license application will be limited and will need to be confirmed by additional data collected durinng performance confirmation."

Comment 3: *An approach for obtaining conservative bounds for the effects of THC coupled processes has not been demonstrated.*

We agree that interaction between THC processes can have a significant effect on the near field environment. This position is based on a synergistic analysis of the results of laboratory experiments, modeling calculations, and natural analogue studies. Conservative bounds can be placed on the effects of THC processes only by considering all three of these perspectives. Modeling alone, in the absence of experimental, field-based, and natural analogue studies, would be insufficient to establish conservative bounds on these effects.

The field testing component of the thermal testing program has been designed to ensure that THC phenomena are observed, monitored, and sampled. This requires heating schedules of sufficient intensity and duration to overcome the sluggish kinetics of rock-water interactions. This is another motivation for the accelerated heating and higher temperatures in the Drift Scale Test. The test design includes monitoring water chemistry during the test and changes in rock chemistry caused by the heating and cooling. Analyses of advecting water and gas samples during the test are planned as are analyses of pore waters before and after the test. Because of the presence of introduced materials such as tunnel supports (concrete and steel), samples of water and gas will be analyzed for the effects of these introduced materials as well as those of the natural materials.

We are using results from testing and monitoring activities to improve our thermal testing and modeling plans. We have focussed our program, and it is clear from your letter that we need to keep you better informed about the improvements in the program and the various analyses supporting these improvements. To this end, a list of recent, relevant reports/documents is provided in the Reference List at the end of Enclosure 1. If there are any you do not have, please let us know and we will transmit them to you. In addition, we agree with your suggestion about future meetings about thermal testing issues, particularly meetings that are aimed at resolution of the issues.

In conclusion, we are aware of your concerns, and have made changes in the test hardware and are considering changes in the test operations from those currently planned, to address your concerns. The DOE is confident that the planned tests and analyses will provide an understanding of thermally driven coupled processes sufficient for a reasonable assurance standard for the licensing process. This is particularly so because the test results will ultimately be used in conjunction with the results from a performance confirmation program. Further detailed discussion of each of the three comments and responses are provided in Enclosure 1. If you have questions about any aspects of this package, please contact William J. Boyle at (702) 794-5506 or April V. Gil at (702) 794-5578.

Stephan J. Brocoum
Assistant Manager for Licensing

AML:AVG-1440

Enclosures:
1. Response to NRC comments on DOE Thermohydrology Testing and Modeling Program
2. List of recent, relevant reports/documents

cc w/encls:
L. H. Barrett, DOE/HQ (RW-1) FORS
R. A. Milner, DOE/HQ (RW-40) FORS
A. B. Brownstein, DOE/HQ (RW-52) FORS
C. E. Einberg, DOE/HQ (RW-52) FORS
Nancy Slater, DOE/HQ (RW-52) FORS
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Tammy Manzini, Lander County, Austin, NV
Jason Pitts, Lincoln County, Pioche, NV
V. E. Poe, Mineral County, Hawthorne, NV
L. W. Bradshaw, Nye County, Tonopah, NV
Wayne Cameron, White Pine County, Ely, NV
P. A. Niedzielski-Eichner, Nye County, Chantilly, VA
R. I. Holden, National Congress of American Indians, Washington, DC
Tom Burton, Nevada Indian Environmental Coalition, Reno, NV
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ENCLOSURE 1

NRC 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."

RESPONSE

The thermal testing strategy is multifaceted: laboratory testing; progressively, more complex, larger, and longer duration field thermal tests; modeling analyses; natural analog studies; and performance confirmation monitoring play important, interrelated roles in the strategy. The Drift Scale Test (DST) is expected to provide the major bases for site specific data on heat-driven near-field processes in the license application time frame. As discussed in Section 5.2.2 of the Test Design Report (CRWMS M&O, 1996), the data will be utilized for discriminating between various conceptual models representing these processes, and in refining and confirming the conceptual models representing the processes, with a goal to increase the confidence in these models to an acceptable level.

An adequate evaluation of the applicability/usefulness of the alternative conceptual models requires an understanding of the dominant thermohydrologic flow regimes and processes, and the effect of the interactions between the thermohydrologic, thermochemical, and thermomechanical processes, especially in the near field. Buscheck and Nitao (1995) discuss how the objectives of the DST have influenced its design. Table 2 (enclosed) of Buscheck and Nitao, 1995 summarizes the major issues relative to thermal-hydrologic-mechanical-chemical behavior, and the approximate length of time needed during the DST for these issues to be resolved. A major consideration in establishing the heating configuration and heating rates of the DST is to provide information for resolving the issues listed in Table 2 in a timely fashion, namely two to four years for most of the issues. This corresponds well with the philosophy of having a robust license application.

The DST was designed to accentuate the manifestation of potentially important heat-driven phenomena such as heat pipes, buoyant gas-phase convection, coupled thermo-hydrologic-chemical and thermo-hydrologic-mechanical processes. It was also designed to maximize the sensitivity of measured temperature, relative humidity and liquid saturation to percolation flux and to address the question of the effect of percolation flux on the coupled thermal-hydrologic-mechanical-chemical processes in the near field in a time frame compatible with the license application.

ENCLOSURE 1

The nominal plan for heating of the DST, which is being reexamined, utilizes uniform heating conditions within the heater drift and a uniform step-function heating in the wing heater arrays to ensure that the effect of geologic heterogeneity on thermohydrologic behavior can be observed. We need to make it clear that this "uniform" heating involves three substantially different heating regimes: the canister heaters, the inner wing heaters and outer wing heaters. The thermal load in the DST will, therefore, be non-uniform. Any attempt to mimic the non-uniform heating conditions of the current (point-load) repository design will severely conflict with the ability to discriminate the influence of natural system variability. The effect of variability in the heating conditions on the drift-scale model of the repository can be readily quantified and accounted for at this time, while the effect on thermohydrologic behavior can be monitored during performance confirmation monitoring. It is far more difficult at present to quantify with confidence the natural system heterogeneities with respect to their effect on thermohydrologic behavior. Nevertheless, we are making every effort to characterize the rock in the DST area before heating. It is more important to address the issue of whether and how the natural system heterogeneities influence the thermohydrologic behavior around the drifts than to demonstrate the ability to model the consequences of an imposed heterogeneous heating system. Moreover, it has not yet been determined whether the point-load approach or the more axially uniform line-load approach will be adopted for the repository thermal load design; therefore, picking a repository heating load for the DST is problematic.

Backup information to your first comment states that 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. Various conceptual models have been utilized in the design analysis of the drift scale test." Several of these conceptual models, such as the dual permeability model (DKM) and the stochastic DKM have undergone considerable development and refinement since the early model calculations conducted in support of the DST design (Buscheck and Nitao, 1995). The effective continuum model (ECM) has been used extensively in the past; however, with improvements to the computational efficiency of the DKM and stochastic DKM, it is now feasible to substantially reduce the extent to which the ECM will be utilized in future analyses. In order to assess the usefulness of alternative conceptual models, it is imperative to determine the dominant thermal-hydrologic regimes and processes, as well as the critically important coupling between geochemistry and thermohydrologic behavior, and geomechanics and thermohydrologic behavior. Several of the major thermohydrologic objectives of the DST, which have influenced its design, are described in Buscheck and Nitao (1995). These major thermohydrologic objectives are to determine:

- the dominant mode(s) of heat flow;
- the dominant thermohydrologic flow regime(s) and processes, such as vapor diffusion, that govern the magnitude and direction of vapor and condensate flow;

- the significance of coupling geochemical and geomechanical phenomena to thermohydrologic behavior;

- the influence of natural system heterogeneities and their distributions and of flow conditions on the flow of heat, vapor, and condensate.

There are at least two more major objectives of the DST:

- thermohydrologic behavior in the DST would be sensitive to percolation flux just as it is in the post-emplacement repository. Measurements of temperature, liquid saturation, and relative humidity should be able to discriminate the magnitude of percolation flux;

- to be able to observe the influence of nonequilibrium liquid-phase flow, in particular, nonequilibrium condensate shedding around and below the boiling zone.

These questions are to be addressed for thermal loading conditions that are relevant to repository conditions. They would be addressed in the time frame of the license application for construction authorization and the license amendment to receive waste. Table 2 (enclosed) of Buscheck and Nitao (1995) summarizes the major issues concerning thermohydrologic and thermal-hydrologic-mechanical-chemical behavior (which are included in the primary objectives listed above) and the approximate duration of time required during the DST for these issues to be resolved. A major consideration in establishing the configuration and capacity of the heating system of the drift scale test is to provide information for resolving the issues listed in Table 2.

Another major consideration in selecting the heating of the DST is that the volume of rock perturbed by heat be sufficiently large compared to the scale of heterogeneity of the fracture networks. Based on analyses, it was judged that a vertical thickness of 10 m of rock should be dried out to meet the objective of testing a large volume of rock. The relationship between peak drift-wall temperature $T_{dw,peak}$ and dry out zone thickness DZ of the DST is given in Fig. 8 (attached) of Buscheck and Nitao (1995). For a heated area of 1475 m^2, $T_{dw,peak}$ = 150°C results in DZ = 6 m (which is only slightly larger than the heater drift diameter), while $T_{dw,peak}$ = 200°C results in DZ = 12 m. It is important to note the impact of the finite size of the DST and the resulting edge-cooling effect on thermohydrologic behavior, even with the wing heaters. Because of the finite size of the DST, $T_{dw,peak}$ must be considerably higher (than in the repository) to compensate for the lateral heat loss in the DST. Therefore, because of the high lateral heat loss associated with the DST, it is inappropriate to compare the areal power density (APD) of the DST to the APD of the repository as a measure of whether the DST is representative of repository conditions.

We understand that your primary concern is that peak temperatures in the DST are high relative to repository conditions. Drift-scale thermo-hydrologic behavior in the repository requires:

(1) approximately 30 years to attain peak drift-wall temperatures, (2) 30-50 years to begin to coalesce the boiling zones between neighboring drifts, (3) 200-300 years to attain the maximum vertical length of the heat-pipe zone, and (4) 500-700 years to attain the maximum spatial extent of boiling conditions. It is inescapable that any thermal test conducted within the license application time frame will have to be significantly accelerated relative to repository conditions. It is important that the DST result in coupled thermal-hydrologic-mechanical-chemical phenomena that are relevant to a much longer time frame. An important issue for the reference thermal load of 83 MTU/acre is the consequence of an extensive boiling zone that will eventually coalesce between drifts and extend more than 300 m vertically. The following points clarify the rationale for the current DST design:

- The current thermal goal for the maximum repository drift-wall temperature is 200°C. While the point-load design results a peak drift-wall temperature range of 110-160°C, the line-load design, which is being considered as a design alternative, results in a peak drift-wall temperature range of 180-210°C for 83 MTU/acre, which is comparable to the peak drift-wall temperature being considered for the DST. As mentioned above, because of the finite size of the DST, it is necessary to drive the peak drift-wall temperature to 200°C to dry out a large enough volume of rock, with respect to the fracture heterogeneity, in a meaningful time in the licensing process.

- Analyses of drift-scale thermohydrologic behavior in the repository (NFER, 1996) indicates that the most vulnerable period for heat-driven, liquid-phase flow entering the emplacement drift is the period immediately following the boiling period. Because the DST has an accelerated cooldown period, the likelihood that post-boiling condensate drainage may enter the drift is enhanced relative to the much more gradual cooldown period under repository conditions. One of the primary motivations for accelerating the DST heat-up schedule is to minimize the time required to get to the critically important post-boiling period when condensate drainage into the drift is most likely. The heating distribution in the wing heater arrays was selected to minimize condensate shedding around the boiling region and to maximize the potential for post-boiling condensate drainage into the heater drift.

- As is shown in Fig. 26 (attached) of Buscheck and Nitao (1995), the temperature distribution is highly diagnostic of the occurrence of refluxing in the heat pipes, with areas of high liquid-phase flow not rising above the nominal boiling point. Note that the liquid-phase flux in the calculated heat-pipe zone above the DST was on the order of 1 m/yr, which is well in excess of any assumptions about percolation flux (steady or episodic) applicable to the DST area. In general, if the local liquid-phase flux can overwhelm the local evaporative capacity of the heated rock, this should be clearly indicated by a depression in the temperature distribution, which will be determined by approximately 3000 separate sensors. Therefore, the important phenomenon of (1) liquid-phase flux overwhelming the dry-out zone, (2) refluxing in fractures, and (3) dripping into the heater drift will be clearly detected during the DST, regardless of whether it occurs in the vicinity of the heater drift or well out in the rock.

ENCLOSURE 1

In addition, the approximately 50 packed-off sections of the 12 hydrology holes used for permeability tests and the approximately 90 SEAMIST pads in the 10 chemistry holes provide opportunities to observe and obtain liquid water. Finally, with respect to drips in the drift, we will have an infrared camera and two video cameras on rails photographing essentially the entire inside of the drift periodically; more importantly, unless the drips are pure distilled water, they should leave behind observable evidence, especially on the canister heater surfaces.

- The outer half of the wing-heater arrays are specified to have an areal power density that is 50 percent greater than either the inner half of the wing heaters or the region inside of the wing heaters (i.e., the immediate vicinity of the heated drift). The purpose of this heating configuration is to minimize condensate shedding around the wing heaters and to drive condensate towards the heater drift, thereby enhancing the likelihood of condensate entering the drift. By minimizing condensate shedding around the wing heaters, the tendency for the development of a heat-pipe zone is maximized. This configuration also maximizes the sensitivity of the DST to percolation flux.

- The peak predicted rock temperature of 382°C occurs at the outer half of the wing-heater array, which is well away (about 7 meters) from the heated drift wall. Note that 382°C was determined with the use of a conduction-only model and a value of thermal conductivity (K_{th} = 1.67W/m°C) that is probably low for the DST area. With the use of a thermal-hydrological model and a percolation flux of 0.05 mm/yr, a peak rock temperature of 312°C is predicted for the hottest portion of the wing-heater array. If a percolation flux of 5 mm/yr is assumed, the peak temperature is only 222°C. Therefore, the higher temperatures at the wing heaters reported earlier are worst case scenarios. The relatively high temperatures around the wing heaters (as compared to the vicinity of the heated drift) are the result of: (1) attempting to drive condensate from the outer boiling region towards the heater drift and (2) the small diameter of the wing-heater boreholes. The relatively high temperatures are only applicable to the rock in the immediate vicinity of the outer wing heaters, which is well removed from the heated drift.

- Note that the preliminary DST calculations were done with constant heater outputs (the canister heaters, inner wing heaters and outer wing heaters have different heat outputs) during the heat-up period. We are now conducting additional calculations in which the heater output is cut back once a thermal goal (such as 200°C at the heater drift wall) is achieved. It should therefore be feasible to achieve the desired accelerated heat-up schedule without driving the peak drift-wall temperature to above 200°C. Recent T-H calculations for the DST (that assume a percolation flux of 5 mm/yr and K_{th} = 2.1W/m°C) attained $T_{dw,peak}$ = 196°C after 4 yr of full-power heating, which is 150°C less than that calculated by the conduction-only model with K_{th} = 1.67W/m°C. Therefore, if a high percolation flux is applicable to the DST area, it may not be necessary to throttle the heating rate for the DST. We are well aware of the benefits and limitations of model predictions. It is a certainty that the test measurements will differ from the predictions. But such differences will allow us to gain insight into the phenomena.

- For repository heating conditions, thermohydrologic behavior (temperature, relative humidity, and liquid saturation) around the drifts is relatively insensitive to percolation flux during the first 50-100 years. After 50-100 years, thermohydrologic behavior becomes progressively more sensitive to percolation flux. Before the license application, it is impossible to conduct a test at repository conditions because to observe the effect of percolation flux the test would have to last 50 to 100 years. Therefore, the DST has been designed to be heated more quickly than a repository so that measurements that will result in useful information, can be made in a meaningful time frame. Measurements of temperature, liquid saturation, and relative humidity are highly indicative of the magnitude of percolation flux in the DST area.

ENCLOSURE 1

NRC COMMENT 2

"The applicability of the 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 test, and related analyses may not provide the information to discriminate among alternative conceptual models or to provide the basis for the selection of a bounding model."

RESPONSE

The ESF thermal testing program does not rely on the Effective Continuum Model (ECM) alone to analyze the thermohydrological response of the formation to the heater tests and waste emplacement. Both the ECM and dual permeability models have been implemented in modeling the Single Heater Test (Birkholzer and Tsang, 1996). In addition, both the dual permeability model (DKM) and the stochastic DKM have undergone considerable development and refinement since the preliminary calculations in support of the DST design (Buscheck and Nitao, 1995).

It is anticipated that these and other alternative conceptual models will be employed in the prediction and analyses of the test results from the Drift Scale Test. A preliminary report for drift-scale seepage using interpenetrating fracture and matrix continua with spatially-correlated log-normal distributions of conductivity, was recently completed for ambient conditions, using the NUFT code (Nitao, 1996).

The competition between gravity drainage of condensate through connected fracture networks and imbibition into the partially saturated matrix is at the heart of the issue of whether equivalent continuum models, some variation of interacting continua, or discrete fracture models are applicable to the evolution of the future unsaturated hydrologic system at Yucca Mountain. How well the different conceptual and numerical models can interpret the thermal test data on the test scale will certainly contribute to the reduction of model uncertainty in the prediction of the thermal hydrological behavior of the repository. In addition to the model uncertainty, the parameter uncertainty must be accounted for. Therefore, as much as possible, ambient site characterization data for each test will be used to constrain the parameter values. The ambient data will include thermal, mechanical and hydrological properties from core samples from the boreholes in the ESF thermal alcove, and in situ cross hole air permeability tests which characterize the permeability values and the connectivity of the fracture network in the Large Block Test, Single Heater Test and Drift Scale Test. In addition, gas tracer tests are being designed for the Drift Scale Test to be performed both prior to and during heating to further constrain the estimates on the spatial distribution of parameters responsible for vapor movement.

The importance of water flow into drifts to contact waste containers is well recognized by the program and the FY97 work scopes reflect this. Detailed planning of our FY 97 program took into account the January 1996 Thermohydrology Peer Review Report. The planned work is focused directly on the issues raised in the NRC staff comments. While we do not expect to have answers to all the questions on the impact of THC processes on repository performance, we anticipate having supportable bounds on some effects, and clear definition of future confirmatory work needed, in time to be incorporated in the VA.

In particular, we would like to call attention to the following two analysis plans which deal specifically with the bounding calculations on water flow into drifts that may contact waste containers. These plans were developed as a result of two Total System Performance Assessment--Viability Assessment Abstraction /Testing workshops. (CRWMS M&O, 1997a) One plan is entitled "Flow Seepage into Drifts under Pre-Waste Emplacement Conditions," and came out of the Unsaturated Flow Workshop; the other is entitled "Thermal-Hydrological Modeling of Seepage into Drifts," and is a result of the Thermohydrology workshop. The objective of the latter testing plans is to determine the probability of water dripping onto waste containers and the distribution of flow rates in response to the thermal loading of the repository. One focus of these modeling efforts is to evaluate the model and parameter uncertainties for the conditions of seepage into the drift, and to develop bounds on the changes in seepage flux with time after emplacement. If you want more information on the plans, please let us know.

ENCLOSURE 1

NRC COMMENT 3

"An approach for obtaining conservative bounds for the effects of thermal-hydrologic-chemical (THC) coupled processes has not been demonstrated."

RESPONSE

We agree that thermal-hydrologic-chemical coupled processes may have significant effects in the near-field environment. This conclusion is based on (1) experiments in which changes in hydrological properties of fractured tuff were modified by chemical processes, (2) simulations using a variety of computer codes (EQ3/6, OS3D/GIMRT, FEHM, NUFT) that demonstrate significant transport of mass near the boiling front, during fracture flow, and associated with water interaction with materials emplaced in drifts, and (3) natural analogue studies in which modification of rock properties was documented where processes similar to those expected in the near-field and altered zones occurred in rocks chemically and mineralogically identical to those that compose the potential repository (NFER 1996). It is thought that conservative bounds can be placed on the effects of the THC processes only by considering all three of these perspectives. Modeling alone, in the absence of rigorous experimental, field-based, and natural analogue studies would be insufficient to establish conservative bounds on these effects. This is based on the fact that currently there is not an adequate computational platform or numerical modeling capability to satisfy all of the computational challenges imposed by THC coupling.

We also recognize that the codes currently employed for evaluating thermal-hydrologic-chemical coupling each have limitations. It is for this reason that a staged approach is developed to evaluate these effects, which is consistent with the recommendations of the Peer Review Team. Simple, bounding calculations have been performed for a wide range of effects (e.g., salt and silicate deposition during evaporation at temperature, silica transport, dissolution and precipitation effects on matrix porosity, fracture aperture modification during dissolution and/or precipitation, dehydration of hydrous minerals, etc.), using a variety of codes. Since each code is a unique formulation of a conceptualized model of the THC processes, use of different codes provides some measure of conservatism, by considering a range of methods for numerically describing the THC processes.

The results of the simplified simulations are being followed by more complex simulations, considering additional processes. In addition, the sensitivity of the results to variations in parameters of the system are also considered, thus identifying particular sensitivities within the THC spectrum of processes.

Simultaneously, field-based and laboratory-based experiments and natural analogue studies have been and are being conducted to evaluate the application and limitations of the bounding calculations. The field testing component of the Thermal Testing program (i.e. Large Block Test, Single Heater Test, and Drift Scale Test), for example, was designed to ensure that THC phenomena would be observed, monitored, and sampled. This includes heating schedules sufficient to overcome the sluggish kinetics of water-rock interaction. The design of the tests also includes the capability to monitor changes in rock chemistry before and after the tests, and monitor water chemistry during the tests. In addition, some chemical and isotopic characteristics of advecting water have been measured in the Single Heater Test, and pore water chemistry will be determined before and after the Drift Scale Test. Sampling of advecting water and gas during the Drift Scale Test is also planned. This will be complemented by pre-test predictions of water chemistry and gas phase chemistry. There is also a detailed THC modeling effort that includes pre-test scoping and predictive calculations, as well as modeling in conjunction with data analysis and interpretation.

It is believed that significant surprises can only be avoided by taking a multi-pronged approach to the problem of THC processes. Modeling using a variety of numerical conceptualizations, complemented by a focused field and laboratory-based experimental program, provides the most conservative approach to evaluating THC coupling effects.

ENCLOSURE 1

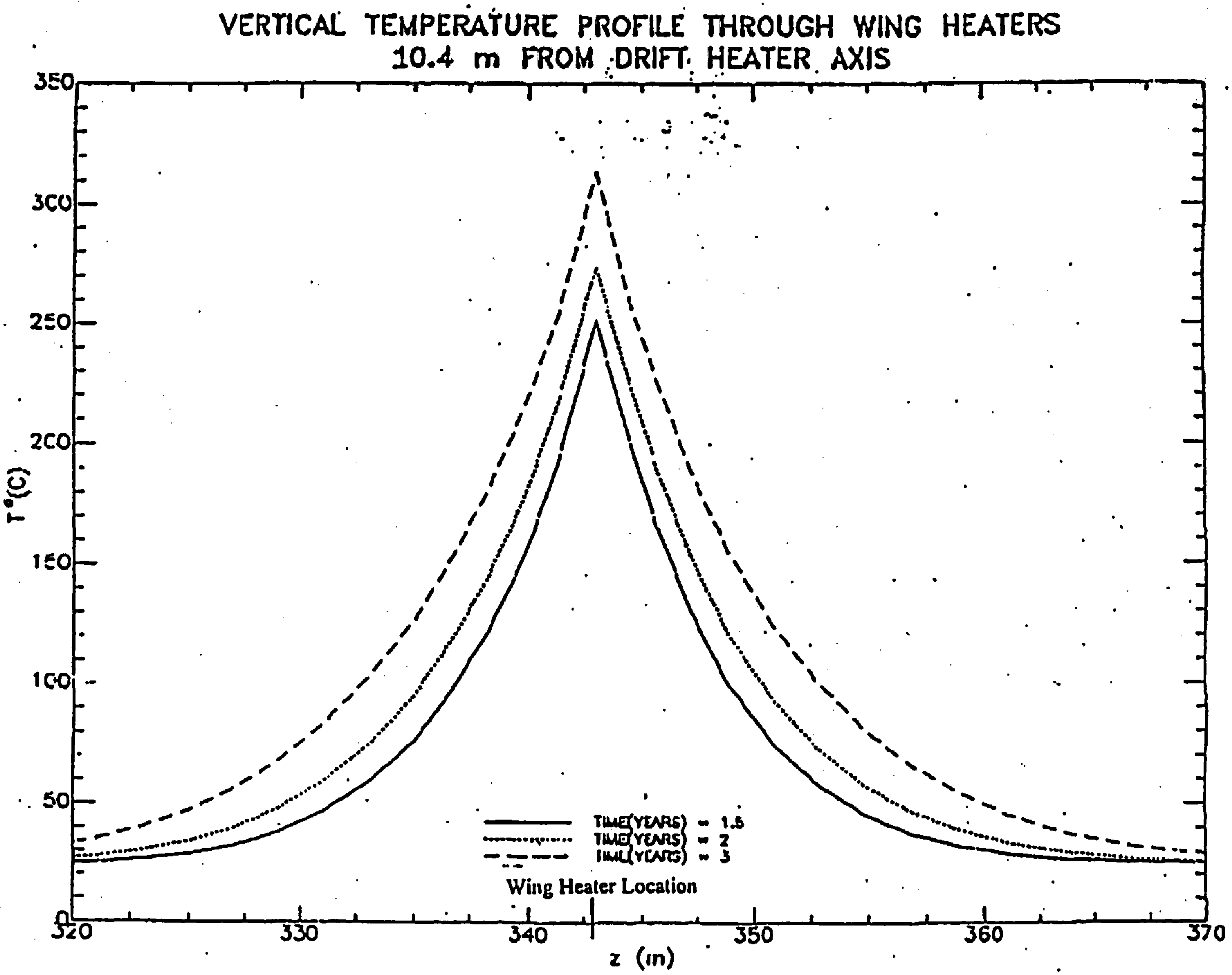

Figure 1

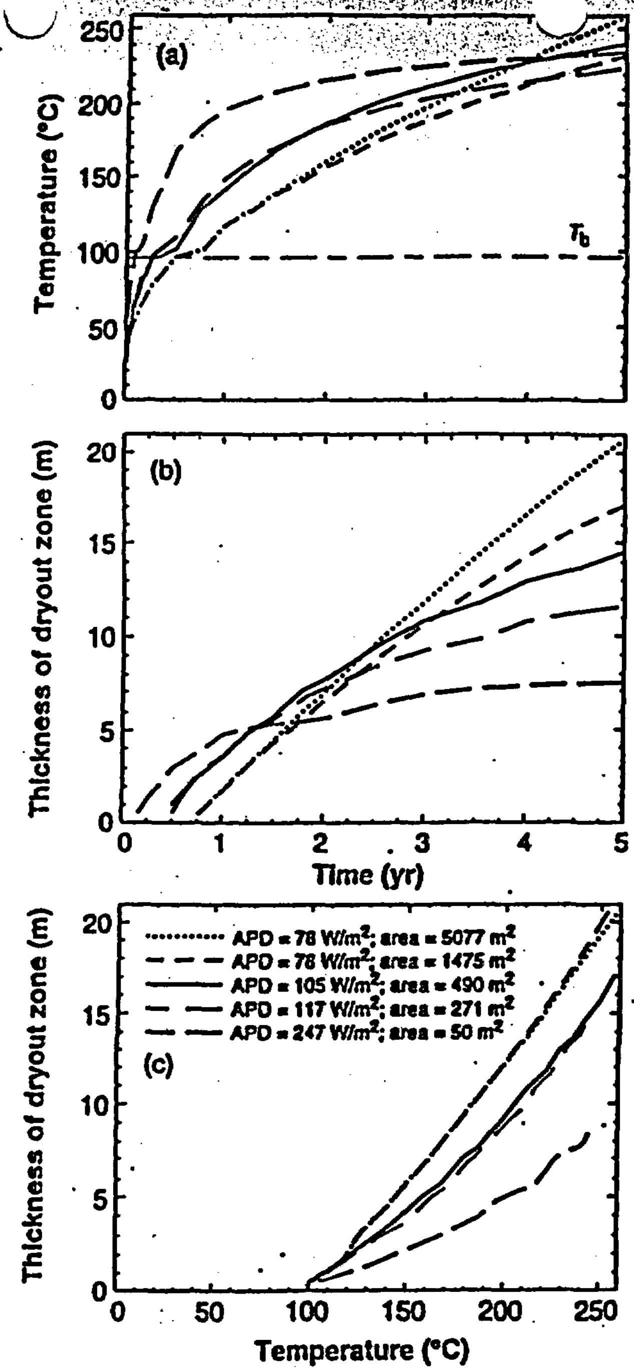

Figure 8. Results of heating at full power for 5 yr. (a) Temperature and (b) vertical dryout zone thickness at the center of an array of horizontal-borehole-emplaced heaters heating a disk-shaped area for various combinations of APD and heated area. The APD is averaged over the listed areas. (c) Vertical dryout zone thickness vs temperature at the center of the heater array. Bulk permeability $k_b = 280$ millidarcy and vapor diffusion tortuosity factor $\tau_{eff} = 0.2$.

Figure 8 From Buscheck and Nitao, 1995

ENCLOSURE 1

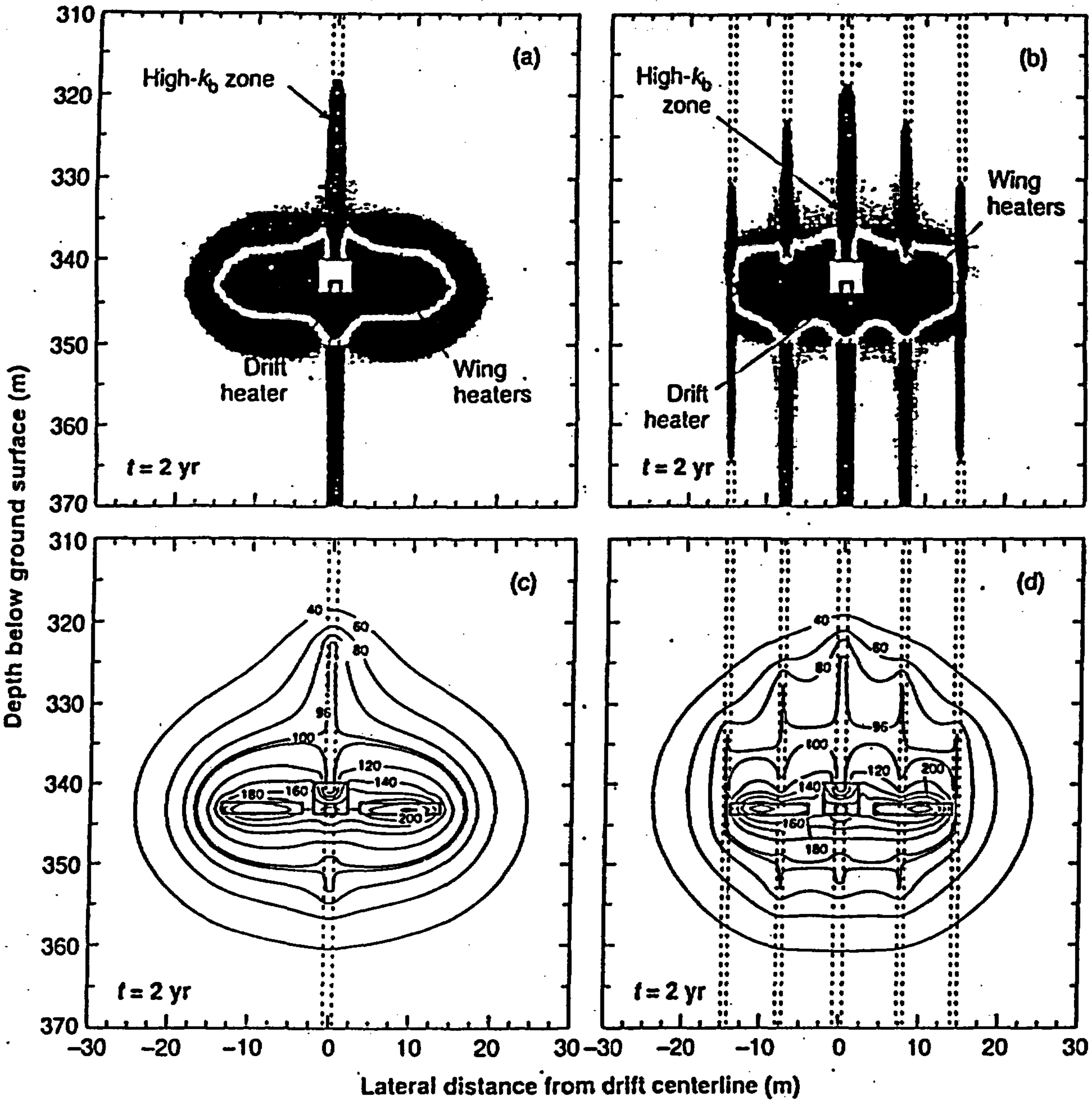

Figure 26. (a, b) Dimensionless liquid saturation distribution and (c, d) temperature distribution orthogonal to a row of drift-emplaced, large-WP-sized heaters generating a lineal heat load of 0.8 kW/m and flanked by two horizontal-borehole-emplaced wing heater arrays. The heater arrays are generating an APD of 105 W/m^2 over the interval $4 < |x| < 9$ m and 157.5 W/m^2 over the interval $9 < |x| < 14$ m from the drift centerline. The heterogeneous bulk permeability k_b distribution consists of 84-darcy high-k_b zones separated by 1-millidarcy nominal-k_b zones. Vapor diffusion tortuosity factor $\tau_{eff} = 0.2$. The medium-shaded area surrounding the heater array corresponds to regions that are drier than ambient liquid saturation (dryout zone). The dark-shaded areas correspond to regions that are wetter than ambient liquid saturation (condensation zone). The light shading surrounding the dark-shaded area corresponds to a small rise in liquid saturation (outer edges of the condensation zone). No shading indicates no change in liquid saturation.

Figure 26 From Buscheck and Nitao, 1995

ENCLOSURE 1

Table 2. Time requirements for diagnosing various T-H-M-C effects.

T-H regimes and processes, T-H-C processes, and the influence of rock heterogeneity	Minimum required full-power heating period	Time at which diagnosis is possible	Supporting figure numbers
1. Significant heat-pipe zones develop	1–2 yr	1–2 yr	Figs. 3, 4, 12, 14, 17, 19, 20, 27
2. Throttled advective rock dryout	1–2 yr	1–2 yr	Figs. 19, 22
3. Unthrottled nonbuoyant rock dryout	1–2 yr	1–2 yr	Figs. 3, 4, 12, 19, 20, 22
4. Buoyant gas-phase convection dominates vapor flow	1–2 yr	1–2 yr	Figs. 3, 4, 12, 20, 22
5. Buoyant gas-phase convection dominates heat flow	1–2 yr	1–2 yr	Figs. 3, 4, 12, 20, 21
6. Degree of vapor diffusion enhancement	2–4 yr	4–6 yr	Fig. 22
7. Reflux-driven geochemical alteration of flow and transport properties	4 yr	4 yr	Fig. 25
8. Rock heterogeneity dominates vapor and condensate flow	1–2 yr	1–2 yr	Fig. 26
9. Heat conduction overwhelms effects of heterogeneity-dominated vapor and condensate flow*	6+ yr	6+ yr	Fig. 27

*Is only applicable if item 8 was found to be important.

Table 2 From Buscheck and Nitao, 1995

ENCLOSURE 2

References

CRWMS M&O, 1996. Test Design, Plans and Layout Report for the ESF Thermal Test, M&O Report BAB000000-01717-4600-0025, September 20, 1996, Yucca Mountain Site Characterization Project, TRW Environmental Safety Systems, Las Vegas, Nevada.

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

Birkholzer, J.T and Tsang, Y.W, 1996. Forecast of Thermal-Hydrological Conditions and Air Injection Test Results of the Single Heater Test, Level 4 Milestone SP918M4, Yucca Mountain Project, Ernest Orlando Lawrence Berkeley National Laboratory, Earth Sciences Division, Berkeley, California.

NFER 1996, Near-Field and Altered-Zone Environment Report, Volume II, 1996. UCRL-LR-124998. Livermore, California: Lawrence Livermore National Laboratory.

Nitao, John J.,1996. Preliminary Bounds for Drift-Scale Distribution of Percolation and Seepage at the Repository Level under Pre-Emplacement Conditions, Lawrence Livermore Laboratory Deliverable SPLB1M4, December, 1966.

CRWMS M&O, 1997. Single Heater Test Interim Report, M&O Report BABEAF000-01717-6900-0001, February 1997, Yucca Mountain Project, TRW Environmental Safety Systems, Las Vegas, Nevada.

CRWMS M&O, 1997a. Thermohydrology Abstraction/Testing Workshop Results. M&O Report B00000000-01717-2200-00184, March 1997, Yucca Mountain Project, TRW Environmental Safety Systems, Las Vegas, Nevada.