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

March 15, 1999

MEMORANDUM TO: James L. Blaha, Assistant for Operations
Office of the Executive Director for Operations

FROM: Carl J. Paperiello, Director
Office of Nuclear Material Safety and Safeguards

SUBJECT: PEER REVIEW PANEL REPORT ON U.S. DEPARTMENT OF ENERGY'S TOTAL SYSTEM PERFORMANCE ASSESSMENT - VIABILITY ASSESSMENT

Please forward the following information to the Commission. The Total System Performance Assessment - Viability Assessment (TSPA-VA) Peer Review Panel (hereafter referred to as the Panel) was formed to provide the U.S. Department of Energy (DOE) with a formal, independent evaluation and critique of the TSPA-VA for the proposed repository at Yucca Mountain. The objectives of the Panel were to describe the technical strengths and weaknesses of the TSPA-VA and to provide suggestions for its improvement in preparation for a possible license application. On February 11, 1999, the Panel published its final report on TSPA-VA. The Executive Summary of the Panel's report is attached.

Generally, the Panel's report expressed skepticism that the TSPA-VA represents the "probable" behavior of the repository. They described the basis for their skepticism as: 1) the difficulty of assessing repository performance over long time periods; 2) use of several component models which are likely conservative and others which are likely non-conservative; 3) lack of sufficient site-specific data to evaluate and confirm the models; and 4) performance estimates rely in large part on potentially optimistic, or at least undemonstrated, assumptions about the behavior of certain barriers of the system (e.g., performance of cladding and the waste package). Despite these limitations, the Panel also noted that the TSPA-VA was a useful step and produced valuable insights into the performance of the repository, helping to identify data and analysis needs. Further, the Panel recommended that: 1) the required degree of confidence in performance assessment, that could be necessary in the license application, could be obtained through the use of a simpler set of analyses; and 2) evaluation of the more complex issues be carried out through either sensitivity studies or bounding evaluations.

The majority of technical comments raised by the Panel have been raised previously by U.S. Nuclear Regulatory Commission (NRC) staff and others. However, NRC staff does not agree with the Panel's summary conclusion, which implies that the evaluation of the repository is an insurmountable task. NRC staff contacted two members of the Panel (Chris Whipple and Robert Budnitz) to discuss the basis for the strong statements regarding estimating repository performance. NRC staff learned that the Panel interpreted the language of the Energy Policy Act of 1992 (i.e., to assess the probable behavior of the repository) to require in the TSPA-VA a

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determination of the most likely behavior of the repository. Thus, conservative as well as non-conservative assumptions made in the TSPA-VA are construed as detracting from the representation of the results as the "probable" behavior of the repository. The Panel also noted in its report that it considered the license application (LA) an easier objective for performance assessment, because the LA requires only a demonstration of reasonable assurance that the repository will comply with the applicable regulatory limits (e.g., conservative or bounding analyses are reasonable ways for demonstrating compliance but not for estimating probable behavior). NRC staff believes the Panel has misinterpreted the Congressional intent in requiring an estimate of the probable behavior of the proposed repository at Yucca Mountain.

The Panel's report also identifies data and research needs essential to the development, implementation, and testing of the performance assessment models. NRC staff, in its review of the VA, have similar views and have identified areas where additional data are needed. The Commission will be briefed on the staff's review of the VA on March 16, 1999. One area of difference between the Panel and the NRC staff involves the analysis of potential impacts of volcanism on repository performance. The Panel believes the TSPA-VA supports a conclusion that volcanism is not an important contributor to dose to offsite populations. NRC staff considers that additional information is needed on the consequences of volcanism to support such a conclusion.

The panel will present the results of their final report to DOE in an open meeting in Las Vegas, Nevada on March 17, 1999. NRC and Center staff plan to attend the presentation.

Attachment: As stated

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FINAL REPORT

TOTAL SYSTEM PERFORMANCE ASSESSMENT

PEER REVIEW PANEL

February 11, 1999

Attachment

Peer Review of the
Total System Performance Assessment-Viability Assessment

Final Report

February, 1999

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Date: 11 February 1999

Prepared by: R. C. Ewing
Rod Ewing
Date: 11 February 1999

Prepared by: Dade W. Moeller
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Prepared by: Paul A. Witherspoon
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Date: Feb. 11, 1999

EXECUTIVE SUMMARY

A. Introduction

The TSPA-VA Peer Review Panel (the Panel) was formed to provide the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) with a formal, independent evaluation and critique of the Total System Performance Assessment - Viability Assessment (TSPA-VA) for the proposed high-level waste repository at Yucca Mountain. The objectives of the Panel were to describe the technical strengths and weaknesses of the TSPA-VA and to provide suggestions for its improvement, as the TSPA staff moves ahead to prepare documentation in support of a possible license application (LA).

The Panel issued three interim reports prior to the completion of the TSPA-VA. These were based on draft documents supplemented by formal and informal meetings and interactions with the TSPA-VA staff. The comments in this final report were based on documented work, namely, the completed TSPA-VA (CRWMS M&O, 1998d) and its supporting Technical Basis Documents (CRWMS M&O, 1998c) and on other documents cited as references to this report.

B. Key Findings

The objective that Congress defined for the TSPA-VA was to assess "the probable behavior of the repository." Judged on that basis, the Panel finds that a number of the components of the TSPA-VA analysis were not supported by adequate evidence that they are representative of the systems, components, and processes they were designed to simulate. In addition, several of the component models are likely to be conservative and others non-conservative, as described in this report. For these reasons, it is unlikely that the TSPA-VA, taken as a whole, describes the long-term probable behavior of the proposed repository. In recognition of its limitations, decisions based on the TSPA-VA should be made cautiously.

With the benefit of hindsight, the Panel finds that, at the present time, an assessment of the future probable behavior of the proposed repository may be beyond the analytical capabilities of any scientific and engineering team. This is due to the complexity of the system and the nature of the data that now exist or that could be obtained within a reasonable time and cost. The TSPA-VA team has performed well, has developed numerous analytical innovations, and has produced technical reports of exemplary clarity. The failure of the TSPA-VA to capture the probable future behavior of the proposed repository system is due in large part to the difficulty of the problem, including the long time scales over which performance is to be described and the large and heterogeneous physical setting that is addressed by the analysis. This difficulty was compounded by a failure, in many elements of the analyses, to initiate and complete the necessary research, develop the appropriate models, and collect and apply the needed data and information.

The TSPA-VA was a necessary and useful step in the evolving understanding of how a repository could be expected to perform at Yucca Mountain. It has produced valuable insights into the performance of various repository components, and has helped identify

C. TSPA-VA Methodology

On the basis of its review, the Panel concluded that certain portions of the TSPA-VA were well done; the Panel also concluded that serious questions remain as to the adequacy and acceptability of other portions of the analyses. On the positive side, the Panel noted that the overall performance assessment framework and the approach used in developing the TSPA-VA were sound and followed accepted methods. The Panel also observed that certain of the technical complexities and uncertainties associated with the analysis were unusual, if not unique. Prominent among these were the unprecedented time periods over which the performance of the proposed repository is to be assessed; the heterogeneity of the site; the multitude of the paths through which radionuclides could be transported and ultimately come into contact with offsite groups; and the complexity of the processes that interact to affect hydrological and chemical conditions within the proposed repository and its environment.

The Panel readily acknowledges that many of these technical complexities are difficult to analyze. In general, such a complex analysis may incorporate significant errors if the wrong deterministic model for specific phenomena is selected, or if an incorrect analytical solution for the model or an incomplete description of the system to be modeled is used. For the TSPA-VA analysis, the evolution of groundwater compositions over time is especially difficult to estimate, as are the phase assemblages formed during the alteration and weathering of spent fuel. Another complicating factor is that several groups of phenomena within the proposed repository involve complex coupled processes. These include phenomena in the unsaturated zone above and near the repository that govern the environment surrounding the waste packages; phenomena that control waste degradation inside the packages after package degradation has begun; and the behavior of radionuclides in the unsaturated zone and saturated zone environments. Sufficiently detailed coupled models have not been developed in the TSPA-VA to permit an integrated analysis to be performed in either of the first two cases.

The lack of an adequate theoretical basis for certain of the models was a major contributor to the analytical difficulties in the TSPA-VA. Exacerbating the problem was a lack of sufficient site-specific data to evaluate and confirm the models. Although in some cases, this lack was confirmed by independent reviews by Panel members, in other cases these efforts showed that additional data existed that could have been used. An important point to recognize is that in such circumstances, elicited expert opinion should not be used as a first option for filling such needs. If data can be obtained through measurements in the laboratory or field, in a reasonable time and at a reasonable cost, this should always be the preferred approach Because of the inherent complexity of the proposed repository and the number of phenomena that need to be analyzed, the TSPA-VA analysts used a simplified form of the detailed process-level models to reduce the associated computational requirements. These simplified models were referred to as model abstractions. The Panel agrees that this approach is sound in principle. However, some issues remain, such as the exact basis for the abstracted models. An abstraction should be a simplification of a more fundamental process-based model, and it should provide results consistent with such models over the same range of parameter and input values that can be taken into consideration in the more complicated approach.

E. Specific Technical Observations and Findings

Advances and Improvements in the TSPA-VA Analysis

The TSPA-VA contains many substantial advances and improvements over earlier similar reports. Perhaps the most dramatic change has been in the approach used to assess the rate of infiltration of water into the mountain. On the basis of this change, the maximum assumed rate has been revised upwards by an order of magnitude. This is consistent with the recent discovery of fast flow paths within the site, as evidenced by the findings of the ^{36}Cl studies. One direct result of the use of this refined analysis is a shift in the project team's concept of the way flow and transport occurs from predominantly matrix flow-dominated regimes to fracture flow-dominated regimes. The revised interpretation of infiltration has also led to a more realistic representation of the fracture-matrix interaction, although it is still far from complete, and to an improved characterization of the hydrologic properties of the geologic setting. Another significant development was the incorporation, for the first time, of a model for analyzing seepage in the drifts. The hydrology of the near-field environment is now modeled at a much smaller scale. Outcomes of the Drift Scale Test and related investigations in the engineered barrier system will be useful in testing these models.

The project team has also incorporated a dramatic and needed improvement in numerical modeling in the area of transport in the saturated zone, where they have abandoned the previous finite-difference model in favor of a streamtube-based approach. Although the adoption of a streamtube approach based on an overall dilution factor is less desirable than a more detailed treatment of dispersion, it is appropriate given the limitations in the data concerning the saturated zone. This model is not physically representative of the saturated zone transport for isolated waste package failures. Nonetheless, sensitivity analyses indicate it overestimates dilution for such cases by perhaps a factor of three. If this is accepted as being an indication of the actual situation, this factor is small in comparison to the other uncertainties in the saturated zone assessment.

The TSPA-VA staff has made a concerted effort to study the complex interaction problems resulting from the thermal pulse, as described in the published literature. Of particular significance are the analyses of coupled thermohydrological, thermochemical, and thermomechanical effects. The work on thermal hydrology has progressed significantly since the TSPA-95, but work on thermochemical effects is still lacking. The staff is now linking hydrology at the drift scale to processes at the site scale, at least during the thermal period, and to thermohydrological, thermochemical, and thermomechanical processes. Also worthy of note are published results of sensitivity analysis of the saturated zone; the introduction of geostatistics for assessing flow, transport and retardation in the unsaturated zone; and the analyses of the various tests currently under way, including the single heater test, the large block test, and the drift scale test.

Key Role of Infiltration and Seeps Analysis

According to the TSPA-VA, "limited water contacting waste packages" is one of the four basic attributes of the proposed repository. Infiltration and seepage into the drifts are the main factors controlling such contact. Within the TSPA-VA, the seepage rates and the

the conceptual description, in the approach to the problem, and in the completion of the necessary experimental work. Once these improvements have been accomplished, the next step will be to complete the necessary analytical analyses.

The largest and most realistic threats to waste package performance are localized corrosion processes such as pitting, crevice corrosion, and stress corrosion cracking. Therefore, it is prudent and sound engineering practice to emphasize corrosion resistance in the design of the waste packages and in the selection of materials to be used in them. In general, the key issues and processes, as well as the corrosion performance of various candidate materials, are reasonably well understood. It is primarily the specifics in applying this knowledge to an analysis of the proposed repository, and the validation of this analysis with relevant data, that are still being developed and need further work.

The ambient waters at Yucca Mountain are innocuous to corrosion-resistant metals. From the standpoint of the proposed corrosion-resistant layer of the waste package, any chemical changes in these waters that occur as a result of thermal hydrological effects at the drift wall and in the surrounding rock are relatively unimportant; the waters will remain innocuous. What is important are the chemical changes that may occur through processes taking place at the waste package surface. This being the case, what needs to be determined and properly considered are any chemical changes that occur as the incoming water interacts within the engineered barrier system and, in particular, those changes that occur on or very near the waste package surfaces

Reactions at the metal surface, under deposits and in crevices will significantly change the water composition. Of most concern are metal-nonmetal crevices with corrosion products, deposits, rock and debris, and metal-metal crevices involving C-22/steel, C-22/C-22, and C-22/Ti.

The Panel identified several physical events and processes that affect the waste packages that were not considered or not sufficiently covered within the TSPA-VA. All of these are deemed to be important to the determination of waste package performance:

1. Expansion due to the formation of iron oxide corrosion products. The resulting expansion in volume (up to a factor of two) due to the corrosion of steel was not analyzed in the TSPA-VA. Such expansion can spall coatings and deform materials in contact with steel.
2. Treatment of waste package fabrication, transport, and emplacement. This adds to uncertainty. Procedures used in welding, heat-shrink fitting in assembling the canisters, in supporting the canisters on pedestals, and associated fabrication activities can have significant effects on corrosion and performance.
3. Corrosion processes in moist sand/particulate matter. After an initial period, waste packages are likely to be covered with particulate matter, e.g., intentional backfill, debris, and corrosion products, rather than remaining clean. Corrosion under these conditions was not evaluated within the TSPA-VA either through analysis or experiments. For steel, corrosion rates are likely to be significantly higher under these conditions, as contrasted to the situation for immersion. For corrosion-resistant metal, the effects on localized corrosion are uncertain.

Volcanism

On the basis of extensive analyses of the direct-release volcano scenario, the information in the TSPA-VA concludes that this pathway is not an important contributor to doses to offsite population groups. The Panel concurs.

Criticality

Based on a detailed analysis of one specific spent-fuel in-canister scenario assumed to occur at 15,000 years, the TSPA-VA analysts estimated that potential criticalities were highly improbable and would, in any event, produce only modest increases in doses offsite. Other criticality scenarios appeared to be less likely than the in-canister scenario. The Panel finds these results to be reasonable.

Human Intrusion

It is assumed in the TSPA-VA analysis that an inadvertent intruder, in seeking to obtain groundwater, drills a single borehole at the repository site. The Panel concluded that the selected scenario is unrealistic, principally because of the extremely conservative assumption that all of the impacted waste goes downward to the saturated zone, rather than being pulled to the surface, and because of the potentially non-conservative modeling of transport in the saturated zone.

Climate Change

The effect of climate change on projections of repository performance is significant. However, predictions of climate change are difficult to make and impossible to confirm. Based on the existing state-of-knowledge, climate-change experts believe that the current interglacial period, which has lasted for several thousand years, will inevitably end. When this occurs the projected glaciation would probably not reach as far south as Yucca Mountain, based on past ice ages. Nonetheless, there would be substantial cooling and increased precipitation. The TSPA-VA projections are that the infiltration rate through Yucca Mountain will increase from the estimated present-day annual value of 7 mm to a long-term average of about 40 mm. This, as noted elsewhere in the report of the Panel, would have a pronounced effect on repository performance.

Overall, the Panel believes that the approach taken by the TSPA-VA staff to examine the future time at which a change in climate may occur is reasonable. Whether the accompanying analysis of the infiltration that would accompany an increase in precipitation is reasonable is less clear; the projections were disputed by a recently published review from the U.S. Geological Survey (USGS, 1998).

Potentially Non-Conservative Approaches

In the course of its review, the Panel identified several issues for which the assumptions made by the project staff in developing the TSPA-VA may be unduly optimistic. An example is the long-term performance of Zircaloy cladding on spent fuel. Another non-conservative assumption, used in the biosphere analysis, pertained to the buildup of radionuclides in soil irrigated with contaminated groundwater. Both of these issues are

An experimental program can advance the spent fuel corrosion model beyond its present empirical representation that is based on a regression analysis. Since over ninety percent of the radioactive waste that is intended to be disposed in the repository is spent fuel, a considerable knowledge of spent fuel corrosion is needed.

Although laboratory studies can serve as a source for some of these data, in other cases the needs can better be met through additional characterization of the site. In terms of the latter effort, there is a broad area along the projected saturated zone flow path from Fortymile Wash to the Amargosa Valley, 10 km or more in length, in which no boreholes have been drilled. In essence, site characterization has not been completed for over half of the projected length of the saturated zone flow path. The resulting voids include data on key subjects, such as subsurface geology, watertable configuration, and hydraulic parameters.