Peer Review of the Total System Performance Assessment-Viability Assessment

Final Report

February, 1999

Prepared by: ________ Date: 11 February 1999
Bob Budnitz

Prepared by: ________ Date: 11 February 1999
Rod Ewing

Prepared by: ________ Date: Feb. 11, 1999
Dade Moeller

Prepared by: ________ Date: Feb 11, 1999
Joe Payer

Prepared by: ________ Date: Feb 11, 1999
Chris Whipple

Prepared by: ________ Date: Feb. 11, 1999
Paul Witherspoon

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 issues where additional data and analyses could lead to improved understanding of the repository's performance. It has also been useful in identifying aspects that are comparatively unimportant to performance, for which additional data and analyses are not likely to be beneficial.

The Panel recognizes that substantial amounts of field and experimental data have been developed in support of the TSPA-VA; however, many elements of the analysis require additional data to be credible. These needs are of two types: fundamental data that are essential to the development and implementation of the models, and data sets designed to challenge conceptual models and test the coupled models used in the TSPA-VA. While it obviously is not feasible to test the full TSPA-VA, it is feasible to test many of the individual component models experimentally. We note that many experiments are planned or in progress that should be useful in confirming, calibrating, or invalidating models developed for, or applied to, analyses of conditions at the proposed repository. Sensitivity analyses, although of value, cannot substitute for such experiments, because the sensitivity analyses used in the TSPA-VA often do not directly address the uncertainties associated with the experimental database or the selection of a conceptual model.

To be credible, it would have been necessary for the TSPA-VA to have included: (1) component subsystem models that capture the important and relevant phenomena; (2) databases that are adequate and substantially complete, where possible; (3) a proper and demonstrable description of the coupling between the subsystem models; and (4) adequate tests and evaluations of the modeled behavior. Although the TSPA-VA offers many examples of partial, even substantial, success in each of these four areas, the Panel observed examples of important deficiencies in each. Concerning items (1) and (2), the final positive estimates of performance described in the TSPA-VA rest in large part on potentially optimistic, or at least undemonstrated, assumptions about the behavior of certain barriers in the system, for example, the performance of the cladding and the waste package. Concerning item (3), the Panel believes that it may be beyond the capabilities of current analytical methodologies to analyze systems of such complexity and covering such spatial and temporal scales. For this reason, we believe that the effects of coupled processes can best be dealt with through a combination of bounding analyses and engineered features designed to minimize the effects of such processes. Concerning item (4), the TSPA-VA does not contain the convincing direct measurements or confirmation of the modeled behavior of components or subsystems even where such testing is feasible. This type of testing should be a part of the analysis of such a complicated system.

As noted above, the assigned objective for the TSPA-VA was to assess the probable behavior of the repository. In contrast, the objective for the TSPA-LA will be to determine whether it can be shown with reasonable assurance that the repository will comply with the applicable regulatory limits. These are significantly different objectives, and recognition of this distinction should be an important element of the path forward to the TSPA-LA. This issue is discussed in more detail in Section III.

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.

D. Future Actions to Improve the TSPA

As the Panel has observed in its review, the objectives for the TSPA-LA differ significantly from those for the TSPA-VA. Recognition of this distinction should be an important element of the path forward to the TSPA-LA.

For cases in which it is feasible to improve either the component models or their underlying data, the Panel recommends that primary attention be directed to those changes that will affect the overall assessment of the proposed repository. Where conservative bounding analyses do not result in an unduly pessimistic estimate of total system performance, it may not be cost-effective to refine the assessment in an attempt to make it more realistic. For those systems and events for which, by virtue of their complexity, it is not feasible to produce realistic models supported by data, the Panel recommends that, if possible, a combination of bounding analyses and design changes be applied.

There are some aspects of the analysis for which additional data collection and modeling will produce only small reductions in uncertainty. If certain aspects of the complex coupled phenomena can be ignored or treated one-dimensionally, the overall analysis will be vastly simplified. At the same time, however, care is needed to ensure that the use of bounding analyses does not result in unacceptably conservative projections of the performance of the proposed repository. In such cases, we recommend that, where it is possible, the project staff demonstrate, either in the TSPA-VA reference design or in a revised design, that a specific group of uncertainties have only limited consequences with respect to the overall repository performance.

Although the Panel cannot predict what will be necessary if the project reaches the stage of submitting a licensing application, it is almost certain that the U.S. Nuclear Regulatory Commission will require a documented understanding of the underlying processes, assumptions, and analyses that goes well beyond that which was presented in the TSPA-VA. To accomplish these goals and to achieve the required degree of confidence, the Panel recommends that the project staff begin in its future efforts with a simpler set of analyses, and then evaluate the more complex issues through either sensitivity studies or bounding evaluations.

Since the projection of the performance of the proposed repository by the TSPA-VA is conditioned largely on the effectiveness of the waste package and cladding, particular attention needs to be directed to these components of the proposed barrier system. Important examples of key issues include the possibilities that the buildup of corrosion products from the outer carbon steel layer could cause early failure of the inner corrosion-resistant layer of the waste packages, and that the credit taken for spent fuel cladding may be optimistic, considering the potential effects of hydrogen embrittlement. Although the TSPA-VA contains many useful sensitivity analyses that illuminate the behavior of certain components and systems within the proposed repository, those analyses taken as a whole do not provide sufficient insights to overcome these deficiencies and uncertainties. Where such analyses produce results that are inconsistent with intuitive judgments, the underlying models and parameters should be examined to ensure that uncertainties in the performance of the proposed repository are appropriately represented.

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 corresponding fraction of packages that are wetted were determined from a random sampling of a response surface obtained from a detailed analysis of the seepage into an individual drift. This probabilistic approach reflects the uncertainty in the capillary and flow properties of the fractures at the drift scale. The percolation flux is a direct reflection of the average infiltration flux above the repository.

The approach used in the analysis of seepage into the drifts, which the Panel considers to be both novel and informative, was based on an assumed steady-state flow in a fracture continuum, in which seepage commences where conditions exist for the drift surface to become fully saturated. A percolation flux threshold is estimated; below this threshold, seepage is assumed not to occur. However, because estimates of the percolation flux depend on the permeability and capillary structure of the fracture continuum in the immediate neighborhood of the drifts, these estimates are subject to the large uncertainty in the knowledge of the heterogeneity, spatial correlation, and anisotropy of these properties. During the period of the thermal pulse, thermomechanical and thermochemical effects may alter both the permeability and capillary structure of the fracture network and the seepage patterns as a function of time. This raises the possibility that seep locations will shift with time. The present analysis assumes that dry waste packages remain dry and wet packages remain wet as long as the climate remains constant. If, instead, the seep locations shift, more waste packages would be expected to experience liquid water, but with less frequency for some. During the dry periods, the corrosion rates would be reduced. The possible development of a precipitation cap may reduce the amount of seepage in drifts over which such a cap forms. It is not surprising, therefore, that the assessment of seepage and of the number of waste packages that will experience water drips is highly uncertain. For these reasons, it is not clear to the Panel that the present approach correctly captures the seepage behavior of an individual drift.

The large uncertainty in the seepage analysis is unfortunate, because seepage into the drifts is one of the most sensitive parameters in the dose estimates presented in the TSPA-VA. Given the uncertainties described above, the long term effect of the percolation rate on seepage cannot be calculated with a reasonable degree of accuracy. In addition, the percolation rate is itself uncertain due in part to uncertainties in long-term climate predictions.

Key Role of the Waste Package

Based on the TSPA-VA results, the TSPA analysts have judged that the rate of waste package degradation is a principal determinant of overall repository performance. The integrity of the waste package as a barrier is important to the performance of the repository as projected within the TSPA-VA for each of the time periods considered: 10,000, 100,000 and 1,000,000 years.

The waste package contributes to the containment strategy in two ways: first, it provides complete isolation until such time as the package is fully penetrated and, second, it provides subsequent retardation of the egress of radionuclides from the penetrated package. The Panel concluded that the conceptual description and analysis of the corrosion of waste packages are well underway and the needs are well defined. The Panel notes, however, that the understanding and treatment of how corrosion damage of a waste package evolves over time are not well developed. There is a need for improvements in 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.

4. Corrosion of steel beneath corrosion-resistant metal. For a waste package design with outer corrosion-resistant metal and inner steel barriers, the TSPA-VA analysis was likely highly conservative for steel, i.e., it overstated the corrosion rate.
5. Incomplete status of the analysis of stress corrosion cracking of C-22 and other Ni-Cr-Mo alloys. The performance of such alloys is a function of the corrosive environment, metallurgical condition, and tensile stress state. Further analysis and experimental data are needed in support of the assessments of these effects.

The Panel notes that there are insufficient data and analyses at this time to support fully or to discard any of the options being considered for a final waste package design. A rationale, backed up by analysis and data, is required for the specification of metals (both sequence and thickness) for the waste packages. The analyses for the TSPA-VA were performed using the waste package degradation (WAPDEG) model, which provided an understanding of the corrosion behavior of the waste packages. The analyses, however, were developed to a level of complexity that extended well beyond the data that were available. This complexity may be useful for the anticipated LA phase if sufficient data on key parameters become available. If not, the Panel believes that attempts to apply the WAPDEG model may compromise the transparency of the treatment. Necessary changes include an updating and/or revision of the model, including better integration of the multitude of process models used for analyzing various degradation modes or engineering enhancements, and the development of a more rational and stronger case to confirm the linkage between the process models and their abstractions.

At this time, the experimental data available to the TSPA staff are insufficient for determining (1) the performance of various alloys under anticipated conditions within the repository, and (2) the composition of the water that will interact with the waste packages. For this reason, the TSPA-VA staff depended to a large extent on expert elicitation. While these estimations were useful at this stage, the Panel concluded that significant improvements may be required for the anticipated TSPA-LA phase. The Panel also believes that it should be possible to resolve these deficiencies at reasonable cost and within a reasonable time.

Disruptive Events

The Panel reviewed five categories of events that could potentially disrupt the proposed repository. These were earthquakes, volcanism, criticality, human intrusion, and climate change. Highlights of our review are as follows:

Earthquakes

The primary seismic concerns were exemplified by various scenarios in which postulated rockfalls might damage a waste package. For other seismic effects, including flowfield disruption, effects of fault displacement, and groundwater-level rise, the TSPA-VA staff asserted with plausibility arguments that the impacts would be minor. The Panel concurs with these findings.

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 discussed in Sections II and IV of the Panel's final report. The soil buildup issue is summarized here to illustrate some of the concerns of the Panel.

Buildup of Radionuclides in Surface Soil

For calculation of doses that might be experienced after contaminated groundwater has reached the Amargosa Valley, it was assumed that residents pump water for consumption and for irrigation. With continuing irrigation, the concentrations in the soil would increase with time, eventually reaching a steady-state condition in which the annual additions to the soil will be equal to the annual losses. Losses of radionuclides from the soil can occur by wind or water erosion. Radionuclides can transfer to crops that are subsequently harvested, or weather down into the soil below the crop root zone. The effects of using contaminated groundwater were calculated using the GENII-S model, which permits the analysts to specify the length of time that irrigation water is deposited on the soil prior to the assumed period of intake. In the TSPA-VA model analyses, the time period for irrigation was assumed to be one year. If, in reality, some locations are irrigated for hundreds or thousands of years, the Panel has concluded that this assumption could lead to sizable underestimates of radionuclide concentrations in the soil, the amount depending on the particular radionuclide. Since the concentrations of radionuclides in plant roots depend on the concentrations in the soil, this will, in turn, lead to underestimates of the radionuclide uptake by root crops and to an underestimation of doses to exposed groups that consume these crops.

Data and Research Needs

Two types of data are needed: (1) fundamental data that are essential to the development and implementation of the models; and (2) data sets that are designed to challenge the conceptual models and to test the success of the coupled models. In developing the TSPA-VA, the project staff devoted considerable effort to meeting these needs, both through measurements in the field and experiments in the laboratory. The success of any future phases of the project, however, will depend on the continued direction of a substantial amount of effort to these needs. This will be especially important if more sophisticated models are incorporated into the analyses.

At the present time, there are several important areas in which the need for data has not been met. This is one of the reasons that a substantial part of the knowledge base in certain key areas presently rests on expert elicitations. Such areas include flow in the unsaturated zone, the near-field environment, waste package degradation, waste form degradation, radionuclide mobilization, and flow and transport in the saturated zone. In a similar manner, solubility limit distributions for several of the key radionuclides come from a limited experimental database; many are based on reanalysis of data from previous experiments. If there is any area amenable to experimental study, it should be the determination of concentration-limits in relevant solution compositions.

In addition, the experimental data needs associated with waste package design and assessment, noted above, include the determination of the critical temperature for alloy 22 in anticipated chemical environments and the measurement of corrosion rates of waste package materials and Zircaloy cladding when they are experiencing corrosive conditions.

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.