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AUDIT REVIEW OF

An Evaluation of the Potential Yucca Mountain Repository

Andrews et al. 1994. *An Evaluation of the Potential Yucca Mountain Repository*. B00000000-01717-2200-00099-Rev. 1. Las Vegas: Intera, Inc.

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ABSTRACT

An audit review was conducted of *An Evaluation of the Potential Yucca Mountain Repository*, B00000000-01717-2200-00099-Rev. 01 in accordance with requirements specified by the Nuclear Regulatory Commission. The aforementioned report is one of two Total-System Performance Assessments conducted in 1993 by the U.S. Department of Energy for the proposed high-level radioactive waste repository at Yucca Mountain, NV; the other Total-System Performance Assessments was carried out by Sandia National Laboratories, and its review is documented elsewhere. Both of these TSPAs constitute the second iteration of the U.S. Department of Energy TSPA program for Yucca Mountain. The review described in this report focused on the following areas: (i) comparison to previous Total-System Performance Assessments, (ii) issues identified in the review of previous Total-System Performance Assessments that remain unresolved, (iii) identification of new issues in the current Total-System Performance Assessments, and (iv) suggestions for in-depth analyses. The review also includes an assessment of the extent to which the stated objectives of the subject Total-System Performance Assessments were achieved.

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1 INTRODUCTION

An audit review was conducted of the report entitled *An Evaluation of the Potential Yucca Mountain Repository*, B00000000-01717-2200-00099-Rev. 01 by Andrews et al. (1994). This review was conducted in accordance with requirements specified by the Nuclear Regulatory Commission (NRC) (see McCartin, 1994).

Andrews et al. (1994) describe a Total-System Performance Assessment (TSPA) conducted by the U.S. Department of Energy (DOE) for the proposed high-level radioactive waste (HLW) repository at Yucca Mountain. This TSPA was one of two conducted by the DOE in 1993 for Yucca Mountain; the other was conducted by the Sandia National Laboratories (SNL) (Wilson et al., 1994). The TSPAs carried out in 1993 constitute the second iteration of TSPAs performed for the DOE. As previously mentioned, the review discussed in this report only pertains to the Andrews et al. report; the review of the SNL 1993 TSPA is discussed elsewhere (see Gureghian et al., 1994). For simplicity, the TSPA discussed by Andrews et al. is hereinafter referred to as "TSPA-93."

In accordance with directions from the NRC to the Center for Nuclear Waste Regulatory Analyses, the review of TSPA-93 focused on the following areas:

- Comparison of TSPA-93 to TSPA-91 (Barnard et al., 1992)
- Identification of issues highlighted in the review of TSPA-91 that remain unresolved
- Identification of new issues in TSPA-93
- Suggestions for in-depth analyses

1.1 SCOPE OF TSPA-93

The stated objectives of TSPA-93 (Andrews et al., 1994) are to:

- Enhance realism/representativeness of the analyses
- Incorporate new information or designs into the analyses
- Test the impact/importance of certain assumptions on the behavior of the system
- Evaluate alternative measures of performance or safety

The following analyses are discussed by Andrews et al. (1994) and, therefore, are assumed to constitute the scope of TSPA-93:

- Container failure
- Waste mobilization
- Radionuclide transport and release from the engineered-barrier system (EBS)

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- Unsaturated- and saturated-zone aqueous flow and transport
- Unsaturated-zone gaseous flow and transport

1.2 STRUCTURE OF THIS REPORT

Chapter 2 of this report contains review comments generated from a comparison of TSPA-93 to TSPA-91. Issues that were identified in the review of TSPA-91 that still remain open after TSPA-93 are discussed in Chapter 3. Chapter 4 presents new issues identified as a result of the TSPA-93 review. Chapter 5 covers areas where in-depth analyses seem warranted. General observations, including the reviewers opinions as to how well the analyses met the stated objectives, are provided in Chapter 6.

2 COMPARISON TO TSPA-91

Comments resulting from a comparison to TSPA-91 (Barnard et al., 1992) are offered on five areas: (i) scenarios, (ii) consequence models, (iii) data, (iv) comparison limitations, and (v) open issues.

2.1 SCENARIO COMPARISONS

TSPA-93 adopted a broader definition of scenario than that conventionally used in performance assessment (e.g., combination of features, events, and processes that can affect the performance of the repository). Scenarios were considered to also include design alternatives. Unlike TSPA-91, TSPA-93 did not include disruptive scenarios (e.g., human intrusion, volcanic intrusion, or tectonism) since these effects were determined to be minor in the TSPA-91 analysis. The results of TSPA-91 were predicated on the models and data available at the time that TSPA analysis was performed. There is no mention in TSPA-93 about modeling advances or new data that could have been included in this iteration to re-examine the results of TSPA-91 regarding disruptive scenarios. Therefore, the elucidation of various disruptive scenarios still remains an open issue.

TSPA-93 considered a variety of waste emplacement, thermal loading, and waste package design scenarios for the purpose of determining the effect of design alternatives on the performance measures used. Sensitivity of the results to three thermal loads (28.50, 57, and 114 kW/acre), and multibarrier waste package containers (with inner and outer materials of various thicknesses) were examined. Thermohydrologic analyses were conducted to evaluate potential edge effects due to the presence of unheated portions of the repository. This represents an advance over TSPA-91, and as a result, potential impacts from design changes could be examined. TSPA-93 expanded the radionuclide inventory used in TSPA-91 and included both spent fuel (SF) and defense HLW; TSPA-91 did not include defense HLW. TSPA-93 also uses higher burn-up rates for SF than TSPA-91.

As in the TSPA-91, the cumulative release of radionuclides to the accessible environment was the main performance measure. This performance measure was applied at 10,000 years after closure of the repository, consistent with previous HLW disposal standards promulgated by the Environmental Protection Agency. In addition, the same performance measure was estimated at 100,000 years following closure of the repository. TSPA-93 also added an estimate of the peak individual dose over a 1,000,000-yr time period. An "expected value" calculation was also used in some of the comparisons and sensitivity analyses; this calculation was performed using the expected value of each of the uncertain parameters. While not a critical issue, it should not be construed that the "expected value" calculation produces an estimate of the "expected value" of the performance measure. It can be readily shown, for example, with the contaminant transport equation that, if the velocity consists of an expected value and a perturbation, the expected value of the concentration of the contaminant will depend on both the expected value of the velocity and the expected value of the product of the perturbations of the velocity and of the concentration.

2.2 MODEL COMPARISONS

The major modeling difference between TSPA-93 and TSPA-91 was the incorporation of the dependency of various processes and parameters in the thermohydrologic regime. Thermohydrologic analyses were used to determine temperature, aqueous flux, gaseous flux, and liquid saturation in the vicinity of the repository. This allowed incorporation of the effect of water saturation and temperature as the initiators for aqueous corrosion of the waste packages. Two corrosion models were used in TSPA-93 (Stahl model and Lamont model) to estimate the degradation time of the packages and permit examination of the effect of different waste package thicknesses on the time to failure. The waste alteration and dissolution rates were also a function of temperature. In TSPA-91, the thermally induced delay for aqueous corrosion was assumed to be somewhere between 300 and 1,300 years. In TSPA-93, the delay of the initiation of aqueous corrosion was estimated by both temperature and saturation criteria. The time to failure in TSPA-91 was assumed to be between 500 and 10,000 years following the thermally induced delay, whereas, in TSPA-93, time of failure was predicted using the corrosion model. While assigned distributions on parameters were used in TSPA-91, thermally dependent parameters were used in TSPA-93.

In TSPA-93, it was assumed that transport through the unsaturated zone was matrix-dominated, whereas in TSPA-91 both a composite-porosity model and a weeps (fracture-dominated) model were used. TSPA-93 accommodates the dependence of transport parameters and properties on temperature. The effect of climate changes was approximated in TSPA-93 by the product of the distribution of infiltration flux and the distribution of a flux multiplier that was expected to capture the impact of glacial conditions. TSPA-93 considered gas travel with a fully transient particle-tracking routine, which uses the two-dimensional (2D) transient gas phase velocity field generated with the code TGIF. TSPA-93 also considered thermally-perturbed gas transport parameters. In TSPA-93, a simple model for the biosphere was used, whereas TSPA-91 did not consider biosphere transport.

In TSPA-91, the TOSPAC computer code was used for the total-system simulation, whereas TSPA-93 relied on the Repository Integration Program (RIP). RIP only allows for very simple expressions; thus, a key aspect of the TSPA-93 modeling approach was the process of abstracting information from a variety of sources into simple expressions. The general probabilistic modeling approach consisted of three basic steps:

(i) Abstraction of primary functional relationships from either detailed process models or uncertain parameters

(ii) Definition of dependence of relevant radionuclides exposure, EBS release, and geosphere transport properties on the thermohydrologic regime

(iii) Incorporation of very simple relationships into the RIP

2.3 DATA COMPARISONS

TSPA-93 included thermally and geochemically dependent radionuclide solubilities and waste alteration rates. TSPA-93 solubilities were also pH dependent. TSPA-93 also expanded the number of radionuclides considered in the aqueous releases from 9 to 39. Burn-up rates for spent fuel in TSPA-93 were higher than in TSPA-91. The average burnup rate used in TSPA-93 was 36,437 MWd/MTHM. Radionuclide solubility and distribution coefficients were obtained from expert judgment elicitations similar to those obtained for TSPA-91; however, as opposed to TSPA-91, in which single-value solubilities and distribution coefficients were used, TSPA-93 used distribution functions that supposedly accounted for temperature and pH dependencies. In TSPA-93 glass dissolution rates were included for HLW which were not considered in TSPA-91. There is confusion, however, at several times in the report, because it is mentioned that solubilities and retardation factors were obtained from laboratory experiments conducted at the Los Alamos National Laboratory. No evidence of this data was found while Appendices G and H provide the results from the expert elicitations. Corrosion rates were estimated from expert judgments. Finally, data and parameter values used in TSPA-93 came from a variety of sources, such as TSPA-91, expert judgments, and recent studies. However, there is confusion on what data came from which source; in some instances it is stated that, to be consistent with other TSPAs, the same value of a given parameter is used, but almost immediately after such a statement is made, it is stated that a different value was used for another parameter without any reason being given. For example, the dispersivities used in TSPA-93 are different from those used in TSPA-91 and from those used in SNL's TSPA-93, but no rationale is provided for the values selected. It is very difficult to determine the ranges and distribution functions used for many key parameters. In some cases, the ranges of parameter values are manipulated, but neither the justification for nor the approach used in the manipulation are clearly explained.

It is unclear how the Darcy fluxes were determined. The differences between the Darcy (or percolation) flux, the infiltration flux, and the unsaturated zone flux might have been clearer. This is one of the key uncertain parameters, the range of values which was manipulated as stated above (see p. 3-3 of Andrews et al., 1994). The unsaturated zone percolation flux in TSPA-93 was half the value used in TSPA-91, and this effectively doubled the travel times leading to lower releases to the accessible environment. No justification is provided for the decreases in the Darcy flux.

2.4 COMPARISON LIMITATIONS

One of the drawbacks with the Andrews et al. (1994) report is that there are no direct comparisons of results from TSPA-93 to those from TSPA-91. Therefore, it is very difficult to determine whether or not the differences in models and data between the two TSPAs have had any significant impact on the results. In the Conclusions chapter, a short statement is provided saying that the estimates of performance measures in TSPA-93 were "better" than those in TSPA-91; however, "better" in that statement referred to TSPA-93 resulting in lower estimates of radionuclide releases than TSPA-91. This comparison difficulty is exacerbated because, as will be explained below, there were many implicit assumptions and judgments in the model abstraction process and in the ranges and distribution of values of uncertain parameters used in the calculations. Thus, determining the validity of the aforementioned statement is not possible because of the many implicit assumptions and judgments that permeated the calculations.

The use of the RIP as the performance assessment model introduces potential limitations that make it difficult to compare TSPA-93 to TSPA-91. The RIP is significantly different from the TOSPAC code used in TSPA-91. The RIP requires a complex model abstraction process to render the equations and other mathematical expressions amenable to the RIP. It was very difficult to figure out how the model abstraction process was implemented. For example, it is not possible, from the discussion in Section 3.2.2 of the Andrews et al. report to discern how the model and results from the Ross ^{14}C model in Appendix I were translated for incorporation into the RIP. Given the significance of ^{14}C to releases to the accessible environment over 10,000 years, the discussion in Section 3.2.2 is very lean. Many assumptions were apparently made in the abstraction process that are not explicitly discussed, some of these assumptions may have been due to limitations of the RIP or from expert judgments.

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2.5 OPEN ISSUES ADDRESSED IN TSPA-93

The only open issue addressed in TSPA-93 was the impact of the thermohydrologic regime on releases from the EBS and from the accessible environment. However, because (i) no direct comparisons between TSPA-93 and TSPA-91 were provided and (ii) many implicit assumptions and judgments permeated the analysis, it could not be ascertained whether significant progress was made to close the issue. On the contrary, the inclusion of the effects of the thermohydrologic regime seems to have introduced a new set of issues that will need to be addressed in future TSPAs.

3 ISSUES IDENTIFIED IN REVIEW OF TSPA-91

A number of issues were identified in the review of TSPA-91 that were are also issues in TSPA-93. These issues are summarized here.

3.1 UNCERTAIN PARAMETER DISTRIBUTIONS

Many assumptions and judgments were involved in the development of uncertain parameter distributions in TSPA-93. As a result, it was not possible to ascertain (i) the source of the data used to generate the ranges and distributions or (ii) the actual form of the distributions used. This is particularly critical for the uncertain corrosion rates for the two different corrosion models used.

3.2 GROUNDWATER FLOW AND TRANSPORT

Reliance on one-dimensional (1D) flow and transport models was raised as an issue in the review of TSPA-91, because the level of confidence that could be placed on predictions with such models was questionable. TSPA-93 was based on 1D models with few or no discussions on new information that would support a higher level of confidence in these models. The abstraction and manipulations of equations and mathematical expressions needed to apply the RIP code may have forced additional simplifications to the flow and transport models that could not be discerned. Therefore, the appropriateness of 1D models, in the absence of supporting results from 2D and three-dimensional (3D) models, makes the 1D models questionable.

3.3 RESULTS FROM DETERMINISTIC CALCULATIONS

The use of an "expected value" calculation based on the expected value of uncertain input parameters was again extensively used in TSPA-93. In many instances, it was the basis for comparisons among the different alternative designs considered for the EBS in the analyses. First, as stated earlier, it is questionable that such an approach would yield the expected value of the performance measure(s) of interest. Reliance on results from the "expected value" calculations need to be considered with caution. Estimating the expected value of the performance measure(s) from the results of a complete uncertainty analysis is known to be more reliable than from deterministic, average, or expected value calculations. This is particularly true in preliminary TSPAs, the objectives of which are to attempt and capture the most salient uncertainties so that insights for data collection and further research can be developed.

3.4 MODEL ABSTRACTION

The model abstraction process remains a key open issue in TSPA; however, the use of the RIP may have elevated this issue in TSPA-93. As has been discussed earlier, a considerable—and apparently complex—model abstraction process was employed in TSPA-93. Because of the significant impact that the model abstraction process can have on the results of the TSPA, the NRC may want to select specific examples of the abstraction process for detailed testing. Unfortunately, the report documenting TSPA-93 (Andrews et al., 1994) does not provide sufficient detail to allow a reviewer to follow and evaluate the model abstraction process used.

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3.5 EXPERT JUDGMENT ELICITATION

Expert judgment elicitation was used for radionuclide solubilities, retardation parameters, and corrosion rates. It seems that the corrosion rates were obtained from experts at the Lawrence Livermore National Laboratory using a fairly informal approach with no apparent documentation that would allow a reviewer to examine the judgments. Given that one of the key modeling advances in TSPA-93 was the consideration of different corrosion models and dependencies on the thermohydrologic regime, the use of, at least, a semi-formal elicitation for corrosion rates seems warranted.

The elicitation of judgments on solubility and retardation parameters, although better documented than that for corrosion rates, still lacks a level of formality necessary to provide sufficient confidence and credibility on the judgments. The approach to obtain these judgments was apparently the same as that used in TSPA-91.

3.6 CONSIDERATION OF COLLOID TRANSPORT

TSPA-93 did not consider the generation and migration of colloids; therefore, this still remains an open issue.

3.7 GAS FLOW AND TRANSPORT

The importance of gas flow and transport, particularly for releases to the accessible environment over 10,000 years, may warrant comparison of NRC and DOE models and results from these. The lack of details in the model abstraction process used to render the Ross ^{14}C model amenable for the RIP may prevent meaningful comparisons, and hence, the generation of key insights for data collection and other analyses and studies needed to elucidate the uncertainties associated with gas flow and transport. The release of ^{14}C was considered to be independent of the alteration rate of the waste form. Therefore, the impact of high temperatures on the gaseous release rate still remains an open issue.

3.8 DISRUPTIVE SCENARIOS AND CONDITIONAL COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

Except for climate change, TSPA-93 did not consider future disruptive events and processes. Therefore, the issues identified in the review of TSPA-91 related to (i) scenario development and screening, (ii) the modeling of specific disruptive scenarios (e.g., basaltic igneous activity), and (iii) the combination of conditional complementary cumulative distribution functions (CCDFs) from a set of scenarios still remain open. None of these issues were addressed in TSPA-93.

3.9 SENSITIVITY ANALYSIS

As in TSPA-91, only *ad hoc* sensitivity analyses were performed in TSPA-93 based on scatter plots and comparisons of results for different design considerations. Consequently, only partial results with respect to the relative importance of different parameters, alternative designs, and processes on the estimation of the performance measures considered were provided. The results of these sensitivity analyses may not be sufficient to develop a sound basis for additional data collection and analyses needed to reduce uncertainty. The sensitivity analyses conducted apparently did not account for the full range of uncertainty in the processes and parameters. This reduces the utility of the results of the sensitivity analyses conducted and the conclusions reached with respect to providing insight for data collection and future research.

4 NEW ISSUES

A number of new issues were identified in the review of TSPA-93 that require further analysis; these are summarized in this section. The primary sources of uncertainty in TSPA-93 are (i) panel- and drift-scale thermohydrologic analyses, (ii) initiation and rates of aqueous corrosion, (iii) ambient unsaturated zone percolation flux, (iv) gaseous and liquid flow, (v) biosphere transport, and (vi) functional dependency versus uncertainty in parameter distributions. Other sources of uncertainty that are related to the primary ones include (i) climate change, (ii) gaseous and liquid flow along un-backfilled repository tunnels and drifts, and (iii) screening process for selection of radionuclides to consider in the analyses

4.1 LIMITATIONS OF THERMOHYDROLOGIC ANALYSES

Thermohydrologic analyses in TSPA-93 were conducted at the panel scale to capture the edge effects caused by unheated portions (from defense HLW) of the repository. The model does not consider the very near-field environment or radial flow of heat or water. Therefore, the features that should be needed in drift-scale or repository-scale analyses to overcome the limitations of panel-scale thermohydrologic analyses are unknown.

4.2 INITIATION AND RATES OF AQUEOUS CORROSION

There is uncertainty in: (i) the initiation of corrosion, (ii) the rates of corrosion, and (iii) the conceptual models for corrosion. The progress made in TSPA-93 regarding aqueous corrosion notwithstanding, there still are significant uncertainties with corrosion phenomena and parameters. For example, in TSPA-93 it was shown that the specific initiator of corrosion (saturation or temperature) could have a significant impact on when corrosion starts and, hence, time to failure of the waste packages. However, it seems from the discussions in the TSPA-93 report that the selection of one or another initiator was done arbitrarily. Therefore, further studies are warranted on this issue. There seems to be an inconsistency in evaluating pitting corrosion at 100 °C when it is noted that aqueous corrosion is considered inactive above 96 °C. There should be some temperature at which aqueous corrosion is at a maximum that is below the point where the high temperatures dryout the rock.

Both the Stahl and Lamont corrosion models use pitting corrosion rates for the inner container failure. However, it is not known if the area of waste that becomes available for release is consistent with the pin-hole-sized failures expected in pitting corrosion. The entire surface of the fuel matrix was assumed to be wet in TSPA-93 (as opposed to half in TSPA-91). It seems that the available area might be limited by the size of the penetrations. However, this assumption may be deemed conservative.

TSPA-93 did not seem to provide insights as to which of the two conceptual models for corrosion (Stahl or Lamont) may be preferable, or what analyses or investigations may be needed to further elucidate the differences between the models and their impact on the estimates of performance measure(s). It is not clear if the two models capture the full range of conceptual models, hence conceptual model uncertainty remains an important issue.

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4.3 PERCOLATION FLUX

The percolation flux still remains the most important parameter insofar as unsaturated flow and transport is concerned. Many assumptions and implicit judgments were imbedded in the estimation of a range and distribution for the percolation flux, which makes the defensibility of the calculations difficult. No data or theoretical insight regarding percolation flux was provided.

4.4 GASEOUS AND AQUEOUS FLOW

The 1D gaseous and aqueous liquid phase flow models used in the analysis need to be supported by data or by the application of 2D and 3D models. The matrix-dominated transport model cannot be supported by the available data; therefore, results generated with it are questionable.

Climatic changes over 100,000 and 1,000,000 years were included in the total releases to the accessible environment calculations and in the peak dose calculations, respectively. The depth of the water table was assumed to remain constant during that time. Considering the impact of a change of water table level would be more appropriate with the estimates of infiltration rate variation over that time.

The models ignore both gaseous and liquid flow through the un-backfilled repository tunnels. Even with backfill, the estimated porosity (0.1 to 0.3) would be considerably greater than the surrounding rock, providing a potential flow path for the fluids.

4.5 BIOSPHERE TRANSPORT MODEL

A very simple biosphere transport model was used that basically multiplies the radionuclide releases to the accessible environment by a dose conversion factor. There are many uncertainties associated with the movement of contaminants in the biosphere that were not taken into account with the simple model used in TSPA-93. Therefore, the dose predictions may be questionable, and conclusions drawn from those calculations have to be considered with caution. There is no discussion in the TSPA-93 report as to how an improved biosphere transport model will be considered in the future. Dose conversion factors were taken fromthe PNL version of the TSPA-91 (Eslinger et al., 1993) or by the Waste Isolation Systems Panel (National Academy of Sciences, 1983).

4.6 FUNCTIONAL DEPENDENCY VERSUS UNCERTAINTY IN PARAMETER DISTRIBUTIONS

In the Conclusions chapter, the statement was made that incorporation of functional dependencies between parameters and processes may "not be dissimilar to broad uncertainty in parameters." This is a very strong conclusion and is highly speculative. While, for some parameters, such a statement may be applicable, the apparent generalization seems unwarranted and premature. For processes and phenomena characterized by nonlinear relationships, it is difficult to envision how their interdependencies can be captured, in a justifiable manner, by the distribution of uncertain parameter values.

5 IN-DEPTH ANALYSES

Several aspects of TSPA-93 were found to be in need of further analysis and investigations. These are: (i) assumptions about the properties of the backfill, (ii) several effects associated with waste package failure, (iii) thermohydrologic analysis in the near-field, (iv) validity of matrix-dominated transport, (v) the estimation of percolation flux and the effects of climate change, (vi) biosphere transport modeling, and (vii) sensitivity analysis. Each of these areas is discussed below.

Backfill assumptions have a great influence on the temperatures of the waste package and the delay of aqueous corrosion. A sensitivity analysis of the backfill parameters on the waste package temperatures with a drift-scale thermohydrologic analysis is needed.

The effects of cathodic protection of the inner barrier, the effect on cladding to delay alteration, and a better representation of the effective surface area for diffusive releases should be examined. Thermohydrologic analyses at the panel, drift, and waste-package scales are needed to better estimate the localized thermal response. The effect of "dryout" has not been explored and should be examined in the future. Detailed studies are also needed to: (i) distinguish between the Stahl and Lamont corrosion models, (ii) determine when corrosion should be temperature- or saturation-initiated, and (iii) obtain reliable corrosion-rate data. MPC design evaluation will include all the aforementioned studies.

The percolation flux estimate needs refinement through improved modeling of the extended dry condition and data gathered following the excavation of the Exploratory Studies Facility. A very simple climate model that assumes 100,000-year cycles ("dry" to "wet" to "dry" climates) was used in TSPA-93, which seems somewhat contradictory with recent studies such as DeWispelare et al. (1993). Supporting data that substantiate the model used in TSPA-93 needed to be developed or the model needs to be revised. In particular, the approach of just multiplying the percolation flux by a flux multiplier distribution without accounting for possible changes in the location of the water table does not seem appropriate, unless it is shown that the change in water table fluctuations will be negligible.

The validity of the matrix-dominated transport model needs to be explored in more depth. Also, the validity of 1D flow and transport models need to be supported using a combination of analyses with 2D and 3D models and site data. Transport through fractures should be included unless analyses demonstrate that it is not important.

Studies, as well as important site specific parameters, are needed to identify possible pathways and associated models for biosphere transport and dose estimation. The assumption that gaseous releases of ^{14}C will not be considered in individual dose calculations seems justified due to the relative short half-life of ^{14}C compared to the time frame of the calculations (1,000,000 yr). However, because the performance measure is peak dose, discarding ^{14}C could mean that some potentially high early doses may not be considered. The release of ^{14}C can be significant if the performance measure is the population dose. Therefore, the effect of releases of ^{14}C on peak dose deserves further study before a definitive decision is made on its inclusion as a dose-based performance measure.

The use of scatter plots to visually represent the sensitivity of a performance measure to a given parameter is useful insofar as illustrating the possible dependence of the former on the latter. However, scatter plots are not sufficient to develop necessary insights for data collection, needed analyses, and for effects to examine in future TSPAs. More detailed and complete sensitivity analyses are required to

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determine priorities for investigations and data collection. These sensitivity analyses were lacking in TSPA-93.

6 GENERAL OBSERVATIONS AND COMMENTS

There are a number of issues that are worth discussing regarding TSPA-93 as documented in Andrews et al. (1994). In the Introduction to this review report, it was mentioned that some general observations regarding how well, in the reviewers' opinion, the objectives of TSPA-93 were satisfied will be provided. Those observations are also summarized in this section.

6.1 GENERAL ISSUES/CONCERNS

In general, the reader gets a fairly good idea of the analyses in TSPA-93 and the results obtained from the Andrews et al. report. The impact of some key issues, like the effect of thermal loading and different design alternatives, on predicting the release of radionuclides from the EBS and into the accessible environment can be discerned from the results and the manner in which these are presented.

The biggest difficulty with the TSPA-93 report is the lack of discussions regarding the supporting information and/or rationale about numerous assumptions and decisions made in the modeling. To illustrate the nature of this concern, consider the following specific comments.

- Section 2.1.1, p. 2-3. The discussion on screening of radionuclides for inclusion in the analyses is not explained clearly. First, no really good reason is provided as to the need for screening radionuclides. Second, there is no discussion as to how daughters were considered in the screening; the criteria apparently used in the screening were based on the parent radionuclides. However, a potentially important daughter radionuclide can possibly be excluded from the analysis if the screening only considered the characteristics of the parent.

- Section 2.1.2.2, pp. 2-5 - 2-6. In discussing the Stahl Failure Distribution Description, the following statement is made: "These equations can be used to determine the penetration depth given constant temperature. For variable temperatures ..., the equations have been manipulated to determine the penetration depth for a particular time period at a particular 1time-varying temperature distribution." The equations these statements refer to explicitly account for temperature dependency as an adjustable parameter; thus, it is not obvious why they need to be manipulated to account for temperature distribution. Furthermore, the procedure used to manipulate the equations is not explained.

- Not all possible design alternatives based on the design parameters were considered in the analysis, but no explanation is provided why specific alternatives were not considered. For the sake of "completeness" decisions to exclude some alternative designs should have been discussed.

- The construction of the CCDFs for releases from the EBS and into the accessible environment were based on 100 simulations. Given the number of uncertain parameters, this seems a very low number of simulations, but the basis for selecting the number of simulations is not discussed.

- Section 2.2.4, p. 2-23. The discussion on sensitivity analysis for releases from the EBS begins with the following statement: "While the uncertainty of the waste package parameters is recognized, the parameters as input into RIP did not generally contain large uncertainty ranges." No explanation is provided. The uncertainty analyses and sensitivity analyses are suspect because the full range of uncertainty was not accounted for.

- While the emphasis of this TSPA was not on the subsystem requirements of 10 CFR 60.113, it would have been helpful to include some results comparing predicted release rates to the EBS release rate requirement in §60.113. More importantly, the reader cannot get any insights as to how the CCDFs for EBS release were used in the analysis of releases to the accessible environment. For example, were two separate sets of simulations conducted for the CCDF of EBS releases and for the ccdf of releases to the accessible environment, or was a single set of simulations used for constructing both CCDFs?

These are a few examples of assumptions, decisions, assertions, etc. made in the TSPA-93 report that make the analysis questionable, because no explanations, justifications, rationale, etc. were provided as supporting evidence.

Another issue of concern is that, after reading the report, one cannot obtain a good idea as to how the results of TSPA-93 will be used in providing guidance for data collection, further analyses, and future TSPAs. There is basically no discussion at all on how this TSPA will impact the direction of the DOE program. There is a lack of discussion of how this TSPA will be used, in conjunction with SNL's TSPA-93 to provide such guidance. There are apparently marked differences between the two versions of the DOE TSPA-93 with regard to model assumptions and parameter values. It would have been interesting and useful to have seen a discussion on how those differences will be reconciled to provide meaningful guidance to the research and development aspects of the DOE's Yucca Mountain program. Perhaps a task to evaluate the two TSPA-93 findings would be worth considering.

6.2 SATISFACTION OF TSPA-93 OBJECTIVES

The results of the analyses in TSPA-93 notwithstanding, it would have been useful for the report to have included a discussion on whether or not the stated objectives of the analysis were satisfied at the conclusion of the study. Therefore, the reviewers believed that it would be useful as a wrap-up to this review report to provide their views on whether or not those objectives were met. The reviewers' observations are summarized.

6.2.1 Enhance Realism/Representativeness of the Analyses

Insofar as the EBS is concerned, TSPA-93 did include a more realistic representation of the system into the analysis than that in to TSPA-91. There were also some enhancements to the gas transport model, primarily through the inclusion of temperature-dependent parameters. However, at the same time, there was a step backwards in the modeling of other components of the repository system, namely the geosphere. The use of a matrix-dominated transport model should not be construed as an enhancement over previous TSPAs.

Because TSPA-93 did not include the modeling of disruptive scenarios, no improvement was made in regards to models for such events and processes as volcanism, tectonics, and human intrusion. Climate change effects were incorporated through parameter distributions that do not constitute a modeling improvement. Therefore, it can be said that this objective was partially met, but this partial success is tempered by the step backwards in modeling the geosphere flow and transport and by the lack of consideration of disruptive scenarios.

6.2.2 Incorporation of New Information or Designs into the Analyses

Again, insofar as the EBS and gaseous transport are concerned, it is fair to say that TSPA-93 did indeed incorporate some new information and designs into the analysis. However, a similar statement is not possible for geosphere aqueous transport. The lack of information provided in the report makes it difficult to draw a conclusion to that effect. A more detailed source term study was performed by the inclusion of a large number of radionuclides to TSPA-93.

6.2.3 Test Impact/Importance of Certain Assumptions on Behavior of the System

In TSPA-93, the impact or effect of assumptions imbedded in the selection of specific models dealing with the thermohydrologic regime within the repository and different corrosion models was tested. It is the reviewers' collective opinion that the effect of the tested assumptions was clearly discernable from the results obtained and the manner in which these were presented in the TSPA-93 report. However, it is also our opinion that many other assumptions were imbedded in the analyses performed, the impact of which in the prediction of the selected performance measures was not tested. Therefore, this objective was partially met.

6.2.4 Evaluate Alternative Measures of Performance or Safety

Several performance measures were used in TSPA-93. One was cumulative releases to the accessible environment over 10,000 years, which was the main total system performance measure in the original Environmental Protection Agency HLW standard. The others were cumulative releases to the accessible environment over 100,000 years and dose to the maximally exposed individual over 1,000,000 years. These last two performance measures were apparently selected in anticipation of performance measures that the Environmental Protection Agency may consider for Yucca Mountain based on recommendations from the National Academy of Science.

In TSPA-93, the sensitivity of these performance measures to different thermal loadings, waste package and EBS alternative designs, and to specific radionuclides was examined. This examination, however, did not include an evaluation of the selected performance measures. In the reviewers' opinion, such an examination should have looked at the difficulties of estimating the performance measures, the soundness of the performance measures, etc. This type of examination did not take place in TSPA-93. Therefore, no insights were truly gained from TSPA-93 about the applicability, soundness, and meaning of new performance measures. Thus, it is the reviewers' opinion that this objective was not met in TSPA-93.

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