AUDIT REVIEW OF

DEPARTMENT OF ENERGY'S TOTAL SYSTEM PERFORMANCE ASSESSMENT

Bernard, et al., TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain, SAND91-2795, Sandia National Laboratory, Albuquerque, NM (1992)

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1 INTRODUCTION

An audit or screening review was conducted of the report entitled "TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain," SAND91-2795, UC-814, by Barnard et al. The review was conducted in accordance with requirements specified by the U.S. Nuclear Regulatory Commission (NRC) staff (FAX from Mike Lee to R. G. Baca in November 1992). In accordance with direction provided to the Center for Nuclear Waste Regulatory Analyses' (CNWRA's) staff, the scope of the technical review of this document focused on identifying: (i) major problems; (ii) areas of possible controversy; and (iii) topics for further evaluation in Phase 3 of the NRC's Iterative Performance Assessment (IPA).

The Total System Performance Assessment (TSPA) report, which was prepared by the Sandia National Laboratory (SNL), is designed to provide a preliminary TSPA of the proposed high-level waste repository at Yucca Mountain, Nevada. The primary purpose of the SNL's TSPA report was to develop sufficiently reasonable mathematical models of isolation performance that were amenable to probabilistic modeling. The second purpose of the TSPA was to evaluate the impact of parameter selection on the total system performance measure (i.e., the cumulative mass release of radionuclides to the accessible environment) and to compare the latter to the limits established by Environmental Protection Agency (EPA) in 40 CFR Part 191 (EPA, 1985).

Four categories of analyses were investigated by SNL: (i) Groundwater and Flow Transport; (ii) Gas Flow and Transport; (iii) Human Intrusion; and (iv) Basaltic Igneous Activity. Probabilistic modeling of these processes was used to generate a total-system complementary cumulative distribution function (CCDF). The total-system CCDF was obtained through a combination of the CCDFs from the four component analyses.

Technical review comments on the various chapters of the TSPA report are presented below. The comments are organized into four categories: (i) general comments, (ii) major problems, (iii) areas of possible controversy, and (iv) areas to be examined in greater detail.

2 REVIEW OF CHAPTER 3.0: PROBLEM SETUP

2.1 REVIEW OF SECTION 3.1: CONSTRUCTION OF RELATIONAL-DIAGRAMS AND SCENARIOS

2.1.1 General Comments

The TSPA methodology adopted by the authors [i.e., Future Events and Processes (FEP)] which is based on the six-step process proposed by Barnard (1992) provides a reasonable alternative to the one based on "event trees" proposed earlier by SNL (Barr et al., 1991). This alternative methodology may find some justification on the grounds that the amount of information available from the site is still limited. The four scenarios investigated in this report seem to have been dealt independently of each other. It remains to be seen how the authors plan to integrate some of the events and processes common to these scenarios, regardless of their probability of occurrence, in order to come about with a unified logic diagram which will meet to a reasonable extent the ultimate objective of the TSPA methodology.

2.2 REVIEW OF SECTION 3.3: DEVELOPMENT OF PARAMETER DISTRIBUTIONS

2.2.1 Major Problems

The elicitation process was not documented in enough detail to determine its validity (Bonano et al., 1990). The procedure followed for the entire elicitation, including selection of experts, training of experts, and the expert's rationale for his results, are conspicuous by their absence. This has the potential of a major problem if any of the elicited values are contentious.

2.2.2 Areas of Possible Controversy

Generally accepted elicitation practice does recommend the elicitations of physically measurable or realizable quantities (Kastenberg et al., 1987; Kouts et al., 1987). In Table 3-6, some of the hydraulic parameters are model coefficients and as such not directly realizable. This will be a point of contention since it deviates from accepted practice. Two resolutions are as follows: first, the justification of this elicitation of model parameters on the grounds that the expert who is elicited is not only an area expert (i.e., hydrology), but also an expert on the model for which the data is intended. Second, elicit other physical entity distributors and transform them to the required parametric distributions similar to what is done in Section 3.3.4 of the SNL report.

2.2.3 Areas to be Examined in Greater Detail

The comment on lack of training to control bias is a serious weakness which will draw heavy criticism. The resolution of this deficiency is either to repeat the elicitation after training including demonstration of bias, or a sensitivity analysis of the results showing the robustness of the simulation result to various errors in the parameter distributions. If sensitivity analysis is opted for, this would be a good candidate for IPA 3 activities.

2.3 REVIEW OF SECTION 3.2.2: ELICITATIONS

2.3.1 Areas of Possible Controversy

The schematic cross-section of unsaturated zone stratigraphy illustrated in Figure 3-2 could, as the authors of the report admit, be refined with the inclusion of additional stratigraphic detail. However, at the present time there appears to be little need to do this in light of the fact that the calculational results were apparently not sensitive to the detail which could be provided. Nonetheless, it should be kept in mind that this stratigraphic detail can be provided and included when the modeling requires it. Depending upon whether the NRC's IPA Phase 3 effort will be able to handle additional stratigraphic detail, changes could be made to increase the level of stratigraphic detail input into Performance Assessment (PA) models to test the sensitivity of results to this increased detail.

2.3.2 Areas to be Examined in Greater Detail

The simple geometry shown for the Ghost Dance Fault in the cross-section of Figure 3-2 has been shown by the recent work of U. S. Geological Survey (USGS) geologists to be inaccurate. R. Spengler (Personal communication, 1992) of the USGS has defined the main trace of the Ghost Dance to be about 1-2 m in width with a displacement of about 50 m at the mapping locale. However, the Ghost Dance is "bordered" by a zone of faulting about 700 feet in width, wherein the subsidiary faults comprising the zone were characterized by offsets of 3-4 m on individual faults. The rock materials are strongly brecciated both in the fault zone and along the trace of the Ghost Dance Fault, with the breccias being rather well indurated perhaps by carbonate cement. It may be worth considering whether the NRC's IPA Phase 3 effort should model the Ghost Dance, with inclusion of the fault zone, to test the sensitivity of the results to a wider zone of faulting. The fact that the SNL modeling does not currently treat the fault zone (at least partially because the data are new) may be considered by some to be a problem until it is determined whether such a fault zone may adversely affect the modeling results.

2.4 REVIEW OF SECTION 3.4: GEOCHEMISTRY DATA

2.4.1 Major Problems

This section addresses retardation factors based on bulk distribution coefficients (K_d). A large number of unrealistic assumptions are made, which are mostly conservative. Minimum K_d's were adopted for strongly sorbing species; no retardation was adopted for weakly sorbing species; and probability distributions of K_d were adopted for intermediate sorbing species. The empirical data base for K_d's presented is sparse, and probability distributions are based on admittedly subjective interpretations of sparse data. K_d's used for the carbonate aquifer at Yucca Mountain are based on data developed for the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) site, where the water chemistry is notably different.

The K_d approach is well established to be incapable of accurately representing aqueous transport in geologic media (Reardon, 1981). The numerous simplifying assumptions adopted, the limited data base, and the use of K_d's render the results of the assessment unrealistic. Granting an absence of physical realism in the approach adopted, its acceptability must be based on conservatism. The following issues (among others, most likely) violate the conservatism of the approach.

- No possibility is acknowledged for species such as colloids and organic complexants that may greatly augment transport.

- The range of conditions under which K_d experiments have been conducted is limited. For example, there are no data for the carbonate aquifer, the pH range studied is limited. The pH is not the only variable of significance (how about bicarbonate, nitrate). J-13 well water (the likely solution in experiments) differs significantly from unsaturated groundwater at Yucca Mountain.

- Anomalously rapid transport of radionuclides as anionic species has been observed at contaminated sites for species that exhibit large K_d's in laboratory experiments.

- Anion exclusion can lead to negative retardation, i.e., transport rates that exceed flow rates, or transport rates that exceed those calculated using a static system distribution coefficient (K_d). This is a clear possibility for iodide or other anionic species.

- The experimental data are probably all for 25°C, however the ambient temperature at the repository is about 30°C; and, for example, after 4000 years the temperature will be above 60°C from the water table to about half way between the repository to the ground surface. K_d's at higher temperatures are probably mostly smaller than at lower temperatures.

In conclusion, the treatment of retardation is indefensible because it is unrealistic and not necessarily conservative. It is recommended that SNL should undertake auxiliary analyses to establish the conservativeness of selected values.

Many other issues of geochemistry data exist with regard to engineered barrier and waste form performance, and hydrodynamic properties of the repository. These issues are not examined in this section on geochemistry data.

3 REVIEW OF CHAPTER 4.0: GROUNDWATER FLOW AND TRANSPORT

3.1 REVIEW OF SECTION 4.2: METHOD

3.1.1 Areas of Possible Controversy

The authors have selected two alternative conceptual models for analyzing groundwater flow and solute transport in the unsaturated and saturated zones of Yucca Mountain. The first, which is based on a "modified version" of the double porosity modeling concept, has yet to receive acceptance, and the second, which is closely related to the former one, displays an extra degree of conservatism. The level of confidence inherent to the predictions of these one-dimensional (1D) models will remain questionable as long as these are not evaluated against results obtained from more sophisticated two-dimensional (2D) or three-dimensional (3D) models and experimental data which is being acquired in the site characterization process. These conceptual models must be designed to cope adequately with: (i) the current geological properties of the site, including randomly distributed fracture networks; and (ii) the hydrological events based on more realistic boundary conditions.

3.2 REVIEW OF SECTION 4.3: RADIONUCLIDE SOURCE TERM FOR AQUEOUS RELEASES

3.2.1 Major Problems

p. 4-14. line #1: ".... 60% pressurized water reactor (PWR) spent fuel with burnup of 33,000 MWd/MTHM and boiling water reactor (BWR) fuel with burnup of 27,500 MWd/MTHM."

It is important to recognize that these burnup figures are low. Although they may represent the figures previously considered for the Site Characterization Plan (SCP), currently reactor fuels routinely achieve burnups of over 40,000 to 50,000 MWd/MTHM for PWRs, and of over 30,000 to 35,000 MWd/MTHM for BWRs. Furthermore, the trends are towards even higher burnups. For PWRs, fuel fabricators are currently targeting (and for some fuel designs warranting) burnups of 60,000 MWd/MTHM. Realizing that current inventory of spent fuel in the country represents less than one-third of all the spent-fuel assemblies that are being considered for eventual emplacement in the Yucca Mountain repository (if selected), the TSPA should be based on higher burnups, which are more realistic representation of the bulk of spent fuel, than those being considered by SNL. Higher burnups, are likely to change the spent fuel materials characteristics including isotopic and fractional distribution of radionuclides within the matrix, grain boundaries, and the fuel-cladding gap.

p. 4-19/4-20. Section 4.3.5. Line #7: "Thus, for advection, alteration-limited release, $t_{0,t,s}$ = 0, $t_{1,t,s}$= 0, $t = [Ad_{film}\ f_{ws}]/[A_{cross}f_{in}q_s]$, where A is the total surface area of the spent fuel rods in a container,...."

This assumption is not realistic, as the surface area of the fuel would be much larger than the nominal external surface of the fuel rods, prior to irradiation and would be even greater after irradiation. An increase of any order or more in magnitude in the fuel surface area due to fracturing of the pellets during service in-pile is possible (Manaktala et al., 1991). Additional, wide variability in the spent fuel surface area from which radionuclides could be released comes from the inherent fuel rod and assembly designs. For example, it is expected that 3 PWR fuel assemblies will be loaded per spent fuel container regardless of the assembly design. This would lead to substantially higher surface area of the spent fuel for 17 x 17 design PWR assemblies versus 14 x 14 (the external dimensions of the assemblies are relatively same). The BWR assemblies are much smaller, ranging from 7 x 7 to 10 x 10. However, the BWR fuel rod diameters are much larger than PWR fuel rods. As a result, the total surface area of the (unfractured) fuel will be smaller for BWR than that for a container with PWR assemblies. Accounting for the larger surface area of the fuel compared to the external surface of the fuel rod, and further taking into consideration the fracturing of the fuel due to operation in the reactor will lead to more realistic (and much higher) releases per container.

In addition, the TSPA does not consider the possibility that the spent fuel might be exposed to several years/decades of low-moisture or dry air prior to coming in contact with water. Should this happen at a sufficiently elevated temperature, the fuel pellets could literally be in a form of powder rather than monolith or larger size fragments (Einziger, 1990). The increase in the surface area of the spent fuel in such a case could be several (3 or even 4) orders of magnitude as compared to as-fabricated fuel, with obvious consequences on the amount of radionuclide release rates.

p. 4-20. Paragraph 3. Sentence #3: "It would probably be preferable to use different retardation factors for this near-field transport than are used for the far-field transport, but for simplicity (and in the absence of detailed information about near-field conditions) the same values were used for both."

As stated by the authors, the retardation factors are likely to be different in the near-field compared to the far-field. The over-simplified use of the same retardation factors in the near-field as in the far-field are most likely non-conservative. As such, the calculated releases in the near-field (source-term) may be erroneous. The error will be propagated into the calculations of transportation/releases in the far-field. Therefore, it is important that retardation factors appropriate to near-field should be used for source-term modeling.

p. 4-29. Table 4-2.: "Spent-fuel surface area, A (m^2) = 140".

This assumption is based on the external geometric surface area of roughly 900 to 1,000 PWR fuel rods. As stated earlier, the actual free surface area of irradiated fuel could be 100 to 10,000 times greater than this assumed area depending on time of failure of the container, environmental exposure of the spent fuel after emplacement in the repository, and the time of contact of water with the spent fuel. Therefore, a much more realistic higher value for the spent fuel surface area per container should be used.

No scheme for modeling releases from 2 percent of the failed fuel rods at the time of container loading with spent fuel assemblies (SNL assumption) is provided. It may be technically unfeasible (due to difficulty in positive identification and the added risk of damaging other rods) to segregate/remove such "leakers" from the fuel assemblies for separate disposal.

It is not clear how the information related to the spent fuel will be input into the TSPA code, such as, burnup, fuel type (BWR or PWR), grain boundary area, fission gas amount, and fabrication, performance, or post-discharge characteristics.

3.2.2 Areas of Possible Controversy

p. i. Abstract. Sentence 4: "The study shows that models of complex processes can be abstracted into more simplified representations that preserve the understanding of the process and produce results consistent with those of more complex models".

The above statement cannot be justified from the body of the report (p. 4-10 through 4-30). If fact, there are many assumptions, discussed later, which are made solely to make the calculations simple and to reduce computational time. Whether the results of the simplified models are consistent with those of more complex models can only be made by comparison. Such comparisons are not provided.

p. 4-14. line #5: ".... there should be a small fraction of glassified high-level waste, but the glass waste is neglected in this TSPA."

The reason for neglecting the glass wasteform is not clear. Since the glass wasteform is expected to be relatively cooler at the time of emplacement, and will generate much less heat as a result of radioactive decay of its contents, the containers with glass wasteform are likely to get wet earlier that the spent fuel containing containers. Assuming that wet containers will fail earlier than dry containers (due to corrosion, etc.), the corrosion products of the glass wasteform containers and the leached products from the glass wasteform may adversely affect the failure rate (or failure distribution) of the spent fuel containers. Therefore, the possible consequence of early failure of glass wasteform containers compared to spent fuel containers should be taken into account. It is important to realize that in terms of the sheer numbers, the number of glass wasteform containers are disproportionately larger compared to its radioactive inventory — practically 40 to 50 percent of the total number of containers are expected to contain glass wasteform. p. 4-18. Section 4.3.4. Paragraph 2. Sentence #2: "Also, only a portion of the spent fuel is being modeled - the most important portion, to be sure - the spent fuel pellets themselves. The fuel-rod cladding and the fuel-assembly structural parts also have significant amounts of radioactivity (Wilson, 1991), but to include releases from them would require adding additional submodels to the source model."

If the radioactivity in the structural parts is significant (as the authors state it), and if it is transportable, e.g., via spalling of the surface oxide, etc., then it should be addressed in the TSPA. Another important observation related to this section of the report is that it appears that authors have ignored the presence of the fuel cladding. While, this may ease the calculations the results may be unrealistic. There may be approximately 600 to 900 PWR fuel rods per spent fuel container, with 98 percent plus of them intact at the time of loading them into the containers (per SNL assumptions). Without any basis, it is difficult to accept that all 900 rods will have breached prior to the failure of the container (assumed 300 to 1,300 years in the study). If there are no calculational basis for predicting cladding failure, at least some distribution could/should be assumed instead of assuming failure of 100 percent of the fuel rods prior to or exactly at the time of the failure of the container.

The failure rate/distribution of the cladding will have direct bearing on the amount of fission gas inventory available for immediate release. (The referenced SNL study assumes a time period of 2 years as a representative of immediate release scenario.) Also, the TSPA model should make provision for distinguishing between fuel rods of different characteristics, e.g., fission gas release. Among the existing inventory of spent fuel there is an order of magnitude difference between rods with low fission gas release as compared to those with high fission gas release. The quantity of fission gas produced is a function of a number of fabrication and operational parameters, and is not correlatable in a simple way with the total burnup. (Data related to fission gas release for high burnup fuel of the future, e.g., 60,000 GWd/MTHM for PWRs, are relatively scarce.)

p. 4-21. First paragraph. Last Sentence: "A simple picture is being used in which rubble fills the air gap to some height and a water film covers the fuel rods to the same height (Figure 4-8)."

Better assumption which may provide the bounding calculations would be to assume that the air gap is completely filled with the rubble and then to calculate for the case in which the air gap is completely filled with water. These two calculated values would provide bounds for the cases with partial filled air gap (either with water or rubble).

What is the basis for the distribution and inventory of radionuclides in the spent-fuel matrix, grain boundary, and pellet-clad gap?

3.2.3 Areas to be Examined in Greater Detail

Liquid Release: The strengths and weaknesses of the treatment are fairly obvious and probably apparent to the report authors. Basically, the analysis consists of developing pseudo triangular probability distributions for everything and propagating the distributions through the analysis. This is consistent with the desire to develop a fast running probabilistic analysis in a short amount of time. The justification for each of the distributions ranges from little to none. This type of analysis can be useful for what if questions (e.g., could we meet the standards with a 500 year container lifetime?), but gives little information concerning actual or bounding performance. The container lifetime is simply assumed to be between 500 to 10,000 years subsequent to wetting. This may be a reasonable assumption, but it has no basis.

The analysis was simplified to largely eliminate chain decay and the presence of multiple isotopes of the same radionuclide. Justification of the simplifications will require more detailed auxiliary analyses not present or referenced in this report. The simplifications will be more difficult with dose based standards.

Very little basis is given for the information in Table 4-2 even though the entire analysis is dependent upon the information in the table. The solubilities appear optimistic.

p. 4-16. Line #7: "(1) Containers with both advective and diffusive releases. The fraction of containers in this category is $f_s f_r$".

Condition stated above in (1) appears to be bound by (2) and (3) stated on the same page. It appears that there is no need for making separate calculations for condition (1).

p. 4-30. Fifth paragraph. First sentence.: "Each solubility distribution goes from a factor of 100 below a "nominal" value to a factor of 3 above the nominal value."

The reason/basis for such a seemingly odd variation scheme for the range for the solubility distribution is unexplained. Is the upper limit restricted to a factor of 3 over solubility limit as in principle (chemically/thermodynamically) it is impossible to go above that limit even in a super saturated state?

No container failure model is incorporated in the TSPA model. Instead the failure time is arbitrarily assumed to be 300 years for early failures and 1,300 years for longer-time failures. Many investigators assume or believe that the container closure may be the weakest part of the waste package, as such it may fail before the container fails as a result of general or localized corrosion (pitting, etc.). Incorporation of a container failure distribution based on closure or container localized failure would be desirable.

3.3 REVIEW OF SECTION 4.4: UNSATURATED ZONE FLOW MODELS

3.3.1 Areas of Possible Controversy

The authors suggest that an equivalent-continuum model and a model restricting liquid flow exclusively to fractures is likely to describe the gross behavior of groundwater at Yucca Mountain. Although they do acknowledge the existence of other modeling methods (e.g., discrete fracture and dual porosity models), there is no evidence or suggestion on their part to see that these methods will be considered in their future performance assessment investigations.

For steady-state flow, the composite-porosity model is claimed to yield identical results as "other classical models" yet it is not clear as to which models they are referring to (page 4-35, paragraph 2).

The authors report a relation for the fracture conductivity K_f (see Eq. 4.45) based on the assumption of laminar flow and, subsequently, derive an expression of the flux in the fracture using the same K_f for a turbulent flow system. This is an inconsistency which could lead to erroneous results.

Although the connectivity factor has been considered by the authors, it may be desirable to see that an additional statistical property of the fractures, such as correlation between fracture length and aperture, be also considered in their future investigations.

The discussions pertaining to the calculation of the number of fractures likely to intersect the containers occupy a large portion of this section. This topic should be addressed separately under a heading such as: "probabilistic assessment of fractures intersecting containers" and expanded in a manner to take into account earlier work performed by SNL under NRC sponsorship (Harbaugh, 1989).

3.4 REVIEW OF SECTION 4.5: SATURATED ZONE FLOW MODELS

3.4.1 Areas of Possible Controversy

Czarnecki's 2D model treats the geologic strata in the third dimension (depth) as a single composite medium. The fluid flow properties associated with this medium consist of a combination of the tuffaceous and carbonate aquifer, and based on an assumed saturated thickness of 1000 meters. It is likely that the saturated thickness through the region varies and that the flow patterns and velocities within the tuffaceous and carbonate aquifers are distinctly different. There also may be areas where the two aquifers are connected. Consequently, this is one area of possible controversy in assessing the accuracy of results obtained from the horizontal flow tube analysis used in TSA calculations to model the saturated zone.

As mentioned above, the one material used to simulate the third dimension (depth) of the model was taken to be some average of the tuffaceous and carbonate materials used in Czarnecki's model. In addition, these material property values are assumed to be a composite of the matrix and fracture properties of the medium. Due to the very limited drill hole data currently available at the site on fracture and matrix properties, some controversy may exist on the use of only one equivalent "lumped" material property in the flow and transport calculations within the saturated zone to the accessible environment.

3.5 REVIEW OF SECTION 4.6: TRANSPORT MODEL

3.5.1 Areas of Possible Controversy

Since the equations describing 1D solute transport in rock and fracture (Eq. 4.55) do not account for the fracture aperture, their use will be "restricted" to fractures with uniform aperture.

The investigations which have lead the authors to generate the velocity probability density function as shown in Figure 4-28 is speculative. Moreover, the adoption of a single fixed migration length of 5,000 m for the modelled region to delineate the accessible boundary limit from the repository location seems to be too restrictive in light of the discussions presented in Section 4.5. In addition, the impact of the variation in thickness of the saturated zone which plays a primary role in the computation of the cumulative mass release of a typical radionuclide has been overlooked. This is a major departure from the assumptions used in modeling the saturated zone, where the vertically integrated model accounts for the areal variation of the saturated thickness of the aquifer. The inclusion of thickness in Eqs. (4.55) through (4.57) becomes imperative.

3.6 SECTION 4.7: RESULTS

3.6.1 General Comments

Results yielded by a deterministic method based on an average value of the system parameters are known to be less reliable than a stochastic based one, particularly in the case of highly nonlinear problems. However, the reported results indicate that the deterministic investigations have been dealt in a very simplistic fashion. It would have been desirable to see an investigation of the average case carried out using a first order second moment method (Benjamin and Cornell, 1970) which would have resulted in a more balanced set of results. This approach would have provided an estimate of the relative importance of the parameters of the system to the selected performance measure (i.e., cumulative mass release at some observation points of the accessible environment) obtained through a first order sensitivity analysis, and also an overall variance of the performance measure resulting from the various uncertainties incumbent to the various random variables.

4 REVIEW OF CHAPTER 5.0: GAS FLOW AND TRANSPORT

4.0.1 General Comments

No originally defective containers were considered.

4.0.2 Areas to be Examined in Greater Detail

The model for gas flow is largely based on the work of Ross et al. (1992). The gas flow model is subject to significant and generally recognized uncertainties, particularly with regard to permeability. Ross et al. (1992) used relatively high permeabilities, which would be conservative. An upward gas flow rate out the top of Yucca Mountain under ambient conditions is calculated to be about 1 m per year. It is stated on page 5-15 that "Thorstenson's measurements of C-14 abundance also provide some qualitative validation of the gas-flow model, because the measurements found C-14 abundances of a fourth to a half of the modern abundance, and the calculated C-14 travel times for ambient conditions are a few times the half life of 5700 years." This is misleading, and derives from the Ross et al. (1992) report. First, the measurements of Thorstenson show that C-14 concentrations continuously decrease with depth from the top of the mountain. This is the opposite of the direction they would decrease if C-14 transport was by advection as calculated in the Ross et al. (1992) model. Second, the travel times cited for C-14 are from the repository horizon to the surface. In the interpretation of the ambient system, the source of C-14 is the atmosphere, so the travel times for the entire C-14 path would be very much longer than those from the repository horizon to the surface. Dead carbon would be introduced by the gas flow system. At Yucca Mountain, C-14 must be introduced to the subsurface from the surface, e.g., by barometric gas pumping or episodic water recharge.

The C-14 transport model is based on a source term model, distributions of travel times based on the Ross et al. (1992) gas flow model, and a "permeability/retardation" factor that accounts for uncertainty in these parameters. Again, there are many simplifying assumptions that are recognized in the report, and generally accommodated by conservatisms. Some of the principal assumptions are reviewed below.

It is likely that the gas flow model and the C-14 transport model neglect variable water saturation, with possible nonconservative implications. As the near-field environment dries and gas filled porosity increases, the gas permeability would increase. Increased porosity would lead to increased gas flow, although most gas permeability is associated with fractures, and most increased porosity is in the matrix. Also, as the system dries, the mass of water available to retard gas-phase $14CO_2$ transport is diminished. However, complementary water condensation in areas at lower temperatures in the farther field would increase the amount of water for retardation there, where temperatures are lower and retardation factors are greater.

Temperature in the assessment of gaseous transport of C-14 is assumed everywhere to be approximately the maximum temperature (at the center of the repository). Retardation is generally greater at lower temperatures, so despite the misrepresentation of the thermal regime the assumptions appear to be conservative.

Large uncertainties exist with regard to the C-14 inventory and distribution in the waste, because it is largely a function of relatively uncontrolled nitrogen contamination. The TSPA adopts one estimated inventory (from Roddy et al., 1986) which is large relative to another (Van Konynenburg, 1989). It is unclear that conservatively large limits of total inventory and distribution (e.g., gap-grain boundary inventory) have been considered.

Release of C-14 from cladding and hardware is neglected, except for that portion estimated to be part of a "quick release" from the cladding (0.5 to 5.0 percent of the cladding inventory). This is a major assumption because over 60 percent of the total C-14 inventory is assumed to be in the cladding and hardware.

Cladding failure time is neglected, which is conservative.

Gas-liquid equilibrium is assumed for CO_2. This may be unrealistic for relatively large gas flow rates in fractures and relatively low gas flow rates and CO_2 diffusion in the matrix. In other words, the aqueous phase buried in pores in the matrix may not equilibrate with the gas phase streaming through the fractures. Disequilibrium would decrease retardation and increase the rate of C-14 release.

Retardation is based on retardation factors calculated as a function of temperature and rock type reported by Ross et al. (1992), but derived from "a forthcoming Pacific Northwest Laboratory report" (Ross et al., 1992). It is therefore impossible at present to review these retardation factors. Many of the features of the conceptual model for carbon distribution outlined in Ross and others appear to be reasonable. However, Ross et al. (1992) state that "Sufficient calcium carbonate is present in the unsaturated zone to dominate the aqueous chemistry and buffer the pH of the water." This assumption is almost certainly false. Some calcium carbonate (calcite) is present, but it is a minor phase, and its presence would not buffer the system pH.

The gas and heat flow models assume steady state temperature distributions and gas flow rates. This approximation may be unrealistic if the gas flow regime adapts on a time scale that is long relative to the time of important variations in the thermal regime. Also, repository temperature variations are likely to be fast relative the time required to establish a steady state temperature field. The significance of these inaccuracies is unclear with regard to performance.

The release rate of most carbon-14 is controlled by the same spent fuel alteration rate used for the liquid release. At high temperatures, it is possible that the release is limited by dry oxidation of the spent fuel pellets which can occur at a faster rate. This could occur with initially defective containers.

5 REVIEW OF CHAPTER 6.0: HUMAN INTRUSION

5.0.1 General Comments

The methods used by SNL to evaluate the effects of human intrusion on the performance of the potential repository in Yucca Mountain are similar to the methods used by the NRC/CNWRA's performance assessment model. However, there are differences between the two methods which are important to note, even if they do not represent major problems with the SNL's approach. The SNL's approach calculates releases at the earth's surface and at a subsurface regulatory boundary, in this case the underlying saturated zone. This differs from the CNWRA's approach in which only surface releases are modeled, however, the nuclide inventory at the time of drilling does account for transport of nuclide inventory out of the repository and rock column into the saturated zone. The SNL's surface release scenario occurs under two mechanisms; first, a direct hit of a waste canister, and second, a near miss of a waste canister, removing contaminated rock in the near-field region of the waste canister. The NRC/CNWRA's model only accounts for direct hits.

The subsurface release model in the SNL's performance assessment code assumes that waste falls down the drill hole into the underlying saturated zone, where it dissolves and is transported to the accessible environment by the saturated-zone flow. The NRC/CNWRA's code, as indicated above, does account for the loss of nuclide inventory due to efflux from the repository and underlying rock column, into the saturated-zone, but it does not consider this to be a direct release mechanism by drilling.

The SNL's model assumes that the waste canisters are emplaced vertically, that the working fluid for the drilling operation is a liquid (water or a drilling mud) with sufficient density and viscosity to entrain the fragments of waste material, and that the entrained waste travels directly through the drill hole to the surface. These assumptions are identical to those in the NRC/CNWRA's model. For the saturated-zone release scenario, the SNL method assumes that it is possible for the contents of a waste package to fall over 200 m to the saturated tuff zone. This assumption is somewhat contradictory to the assumptions used for surface release, but it appers to be a conservative assumption. This may be a point for controversy, in that the assumptions used for surface release contradict the subsurface release assumptions making the two mechanisms exclusive events.

The probability of occurrence of a drilling scenario is assumed by SNL to consist of two components: (i) the probability that drilling operations will be conducted at Yucca Mountain, and (ii) the probability that a waste package or contaminated rock will be intersected by the drill string (if drilling occurs). SNL assumes that the probability that drilling operations will occur is 1 for the 10,000 year life of the repository. The probability of a hit by a drill string is determined from geometric considerations only (i.e., it depends on the area of the drill bit and the area of the waste container perpendicular to the drill string). This method of calculating the probability of a hit is similar to the NRC/CNWRA's method. However, the SNL method assumes that the repository has a uniform distribution of waste packages (the CNWRA's model breaks the repository into seven different regions with different distributions of waste packages). The SNL code also appears to use a fixed radius for the borehole of 0.305 m, whereas the CNWRA's model uses a variable borehole radius. The calculation of the probability of a near miss is based on the same assumptions as for a direct hit; that is, using the ratio of the area of contaminated rock to the total repository area.

The extent of the region of contaminated rock in the vicinity of the waste package in the TSPA is calculated as resulting from molecular diffusion only, and tracks only those nuclides that have little retardation. The line of waste packages in an emplacement drift are considered to be a line source, and the fractional concentration as a function of time and distance is calculated based on the diffusion equation where the diffusion coefficient is based on molecular considerations only. The limit of the contaminated rock is then defined to be within the boundary of the fractional concentration of 0.001. A time delay of 300 years is enforced in the analysis to account for a period with no failed containers.

In the case of release to the saturated zone, the SNL model neglects all nuclides with large retardations, assuming that they will not be transported to the accessible environment within the regulatory time period.

The parameters used in the SNL model do differ from those being used in the CNWRA's model. For example, the initial inventory of nuclides and their half-lives are different than those being used by the CNWRA. The differences in parameters and initial conditions may be another source of controversy.

The surface release calculations are performed as follows. For each borehole, the time of occurrence of the drilling event is randomly selected from a uniform probability density function (PDF), then the probability of hitting is randomly selected from another uniform PDF, then the probabilities of a direct hit and a near miss are calculated as indicated above. If the probability of a hit is greater than the probability of a near miss, then no release occurs. If the probability of a hit is greater than the probability of a direct hit but less than the probability of a near miss, then a near miss has occurred. And, if the probability of a hit is less than the probability of a direct hit, then a direct hit has occurred. The amount of waste available for release is then described by another uniform PDF ranging from 0 to the entire waste package. To establish the number of curies released, the radioactive decay from time zero to the time of the incident is determined. Both decay and ingrowth from decay chains are calculated. These inventories are then converted into the EPA ratio for each isotope, which are finally combined to give the normalized EPA sum. For the case of a near miss, to reflect the fact that the concentration decreases with distance from the waste package, the amount of nuclides available for release is specified as a random variable ranging over three orders of magnitude (the range of variation in concentration that may develop). The CNWRA's model for direct release assumes only direct hits occur, however, the inventory in the repository and the underlying rock column are explicitly accounted for with the proper efflux of nuclides into the rock column being predicted by Source Term Code (SOTEC) and the proper efflux of nuclides from the rock column being predicted by NEFTRAN and FLOWMOD.

The conclusions the authors draw from their analysis are that the release as a result of drilling do not have a significant probability of exceeding the EPA standard. A variation of key parameters did not alter this conclusion. The most significant change in system response occurs when the maximum number of boreholes is increased; however, even a twenty fold increase did not cause the CCDF to exceed the EPA standard. Finally, the composite conditional CCDF is dominated by the surface-release component. The largest releases resulted from surface release, and any aqueous contributions were approximately three orders of magnitude below the surface releases.

5.0.2 Areas of Possible Controversy

The subsurface release mechanism of waste dropping to the bottom of the drill string (200 m below) is an unlikely scenario for which the entire model maybe improperly formulated. The details of this portion of the analysis is briefly presented which makes evaluation difficult. A more logical model would account for the efflux of waste from the repository to the rock column and then into the saturated zone, rather than the instantaneous release mechanism to the saturated zone presented by SNL, where the material instantly dissolves and is transported by the saturated-zone flow.

Another possible point of controversy concerns the selection of state parameters and initial conditions of isotope inventories. A common set of state parameters need to be defined so that all assessment models may simulate similar base cases and avoid a possible controversy over the selection of initial conditions.

The saturated-zone model is described only briefly; however, the assumptions stated suggest that this model is limited in it predictive capabilities. The code is a 1D, time-dependent groundwater flow and solute transport model, using a steady-state groundwater flow field. The assumption of a steady state flow field over a 10,000 year period may not be realistic and may provide a point for controversy.

5.0.3 Areas to be Examined in Greater Detail

The results of their analysis need to be studied in greater detail with a focus on their significance and relevance.

The saturated-zone model requires further investigation and analysis beyond that presented in this chapter. The relevance of this model to the assessment of repository performance must be accurately evaluated.

A set of comparison simulations should be performed by the CNWRA's assessment code using this set of parameters and initial conditions. This would allow the CNWRA staff to perform a more detailed review and analysis of the SNL effort.

6 REVIEW OF CHAPTER 7.0: BASALTIC IGNEOUS ACTIVITY

6.0.1 Major Problems

Consequence assessment in the TSPA report is based on two models. The first method involves development of a geometric model to estimate the amount of waste entrained in an ascending dike. In this model it is assumed that the amount of waste entrained is directly proportional to the size of the dike. In a second approach, the proportion of shallow crustal xenoliths identified in the Lathrop Wells cone and other cinder cones in the Great Basin is used to estimate the likely amount of waste entrainment.

Method 1: Several assumptions are implied in the application of method 1 to the problem. Some of these assumptions are discussed in Valentine et al. (1992), others are not. Method 1 assumes: (i) any magma which intrudes the repository will have a low volatile content; (ii) any igneous event will involve the intrusion of a single igneous dike; (iii) the repository itself will have no affect on magma flow or eruption dynamics; (iv) magmatic events are of relatively short duration; and (v) groundwater, possibly derived from a perched water table, will not interact with magma.

The projected total volatile content of the magma has very serious implications in consequence modeling. In Valentine and others (1992) model, on which assumptions of xenolith transport are based, volatile contents are never expected to exceed 0.5 wt percent. This low value is based on Hawaiian analogs, particularly the Puu Oo eruptions. These eruptions are considered to be low energy strombolian eruptions and are actually remarkable for their low volatile content. Magmas with volatile concentrations of 0.5 percent or less will have very shallow fragmentation depths (50 m or less) and relatively low eruption velocities (100 m/s). The fragmentation depth is the depth at which the exsolved volatile concentration reaches 76 percent and the magma becomes explosive (Sparks, 1976; Wilson, 1980). Low volatile concentrations and shallow fragmentation depths will lead to small ash column heights and very weak dispersal of the pyroclastics and xenoliths.

However, total volatile contents, at least in the initial phases of eruption, are normally much higher in basalts erupting in a continental environment (2-5 percent). Evidence for > 2 percent total volatiles in the Quaternary Crater Flat Volcanic Zone eruptions includes: the presence of amphibole at several vents, high vesicularity of mafic cinders (Vaniman and Crowe, 1981), the presence of olivine as the only phenocryst at some vents (Knutson and Green, 1975). This high volatile content results in much greater eruption velocities (200 - 500 m/s) and much greater ash column heights (6 - 15 km). Most historical cinder cone eruptions in continental settings have had sub-plinian to plinian initial eruption phases. For example, the Great Tolbachik fissure eruption, Russia, had an initial ash column height of 13 km (Fedotov et al., 1983), column heights reached 6 km during eruptive activity at Paricutin, Mexico, during its first six months (Williams, 1950), and the April, 1992, eruption of Cerro Negro, Nicaragua, produced column heights of 8 km (GVN, 1992). Even in oceanic settings, basaltic sub-Plinian eruptions are relatively common. For example the 1947 eruption of Hekla, Iceland, resulted in a column that was initially 10 km in height and the 1875 eruption of Askja, Iceland, was reported to have had a similar column height (Thorarisson, 1950). Isopach data collected at Sunset Crater, Arizona, a one thousand year old cinder cone in the San Francisco volcanic field, also indicate sub-plinian activity (Amos et al., 1981). These large ash column heights only can be produced by magmas with exsolved volatile concentrations of 2-5 percent (Wilson, 1980). Fragmentation depths associated with these eruptions are on the order of 200 m to 700 m (Wilson, 1980; Wilson and Head, 1981). Erosion of the conduit wall will increase dramatically above this fragmentation level, especially if the rocks are easily erodible (Wilson, 1980), such as the repository fill. The repository will also affect the depth of magma fragmentation. It is more likely that fragmentation will take place beneath the repository because the repository itself will alter the lithostatic pressure gradient. Using previously developed numerical models (e.g., Wilson and Head, 1981) it should be possible to evaluate the impact of higher volatile concentrations on eruptive scenarios, the amount of waste entrained as a result of this activity, and its dispersal. These models can also take into account the interaction between intruding magma and a perched water table above the repository. Such phreato-magmatic eruptions can be highly explosive. There is reasonable evidence that Lathrop Wells cone experienced a phreato-magmatic phase early in its eruption sequence (Crowe et al., 1983).

Extremely little is known about the duration of volcanic activity at basaltic cinder cones in the Great Basin. It is clear from historical activity elsewhere that activity can continue for short periods of time (e.g., Hekla, Iceland) or intermittently for decades (Paricutin, Mexico) or centuries (Cerro Negro, Nicaragua). There is also clear evidence for multiple eruptions (polycyclic activity) at most of the Quaternary cinder cones in the Yucca mountain area. Longer periods of activity are likely to be accompanied by multiple dike intrusions and significant chemical and thermal perturbations in and around the repository. Any model of the effects of igneous activity should attempt to take these effects into account.

Method 2: Method 2 seeks to categorize risk by estimating the lithic fraction in scoria cones in the Crater Flat Volcanic Zone. This is thought to be proportional to the amount of waste entrained, should a basaltic eruption occur through the repository. The utility of lithic fraction data collected from a scoria cone itself is questionable because the vast bulk of the cone is built after the conduit has been cleared and a relatively open path has been established to the surface. Therefore the initial "conduit clearing" phase of activity, which may also be highly dispersive, as in the case of Sunset crater (Amos et al., 1981), may have a higher lithic fraction which is obscured by subsequent cone-building activity. Also, the proportion of ash and lithics distributed far beyond the cone itself is difficult to quantify. Crowe and others (1983) note that deposits associated with the initial phase of activity are likely to be the most widely dispersed and the most contaminated. Some of these scoria deposits, where they are preserved elsewhere, have lithic fractions as high as 0.4 percent (Crowe et al., 1983). The volumes of magma dispersed by the initial explosive events usually are comparable to, or exceed by as much as 13:1 (Self, 1976) and often by 5:1 (Crowe et al., 1983), the volumes of the cinder cones themselves. Therefore the use of 0.06 percent as a maximum value for lithic concentration seems inappropriate and the calculation of the released radionuclides due to this type of activity is underestimated. Parenthetically, it is notable that, except in low volatile eruptions, lithics are not completely encapsulated in basalt as the authors say would likely be the case in the event of eruption at the repository site. Lithic fragments in Crater Flat valley are usually not encapsulated.

In summary, the CCDF's computed for igneous activity are based on inadequate information or improper assumptions about the volcanological aspects of the problem, particularly in consequence assessment. Estimates of the probability of igneous activity may be conservative. However, these models do not take into account basic geological information, such as the episodic nature of volcanism in the Great Basin and the relationship between tectonic deformation and magmatism. The consequence models developed in the report rely on assumptions which are inaccurate and overly simplistic. Critical parameters in the consequence analysis, such as erosion depth, conduit shape, speed of entrainment, and total lithic fraction, are underestimated by this performance assessment model. Altering these parameters to more reasonable values will increase the predicted volume of waste material involved in disruptive magmatic activity and the amount of radionuclide released as a result of this activity. Furthermore, the consequence models do not attempt to account for activity of long duration (decades to centuries) within or near the repository. The authors' conclusion that EPA limits will not be exceeded by igneous activity is based on assumptions which are not conservative.

Recommendations: Several of these difficulties can be alleviated with additional work. Certainly it is possible now to model eruption dynamics through the repository assuming a reasonable range of initial total volatile concentrations and mass flows. Models developed by Wilson (1980) and others can be modified to take into account the affects of the repository horizon. This will result in a much improved understanding of the possible radionuclide release and its likely dispersal. Additional factors, such as the affect of a perched water table above the repository horizon on eruption dynamics should also be considered. Eventually, volatile data will be available to provide bounds on these models. It may be particularly fruitful to couple Wilson's (1980) 1D solutions of bubble nucleation rates with models of dike propagation to predict the behavior of the magma when it reaches the repository horizon, as the exact configuration of any conduit (i.e., the depth of erosion in the repository) will depend on the relative strength of repository fill and near-surface welded tuffs.

Work is continuing to provide better constraints on the probability of volcanic eruptions through the repository. One possible approach is to use data on vent spacing elsewhere in the Great Basin to better assess the probability of magmatism at the repository site. Another avenue of investigation should be further research on the relationship between structural deformation and magmatism.

6.0.2 Areas of Possible Controversy

The chapter on basaltic igneous activity by Dockery and Barnard contains several major problems which will lead to controversy and which should be examined in greater detail. These problems can be addressed with additional research. The authors state at the outset that they have simplified the scenario for basaltic igneous activity. However, some of the simplifying and/or implied assumptions do not reflect current understanding of volcanic processes and therefore are not conservative.

Two aspects of igneous processes are addressed by the report. First the probability of volcanic events disrupting the repository, and second, the consequences of igneous activity in terms of release of radionuclides.

Probability Models for Igneous Activity: Probability models for the frequency of eruption in the Great Basin are based on estimates of the number of eruptions which have occurred in the Crater Flat Volcanic Zone and elsewhere in the Great Basin in the Quaternary. The recurrence rate table given in Crowe and others (1992) gives predicted recurrence rates of between 1.2e-6 and 2.8e-5, where events are averaged over the Quaternary. The figures used in the performance assessment model agree well with these figures. However, it should be noted that elsewhere in the Great Basin, volcanism has been highly episodic on the scale of 10^5 years, therefore averaging the number of events over the Quaternary may be inappropriate.

Models for the probability of eruption at the repository are Gaussian and Bayesian (Ho, 1992). None of these models have yet attempted to incorporate geological information into the model, such as attempting to quantify the likelihood of an igneous event should substantial slip occur along the Ghost-dance fault. Also, these models do not address numerous studies that clearly show episodic behavior in volcanic eruption rates. At this time this simplification is appropriate because the geologic studies are still underway. It has been estimated that the likelihood of a repository disrupting event to be 2.4e-4. However, Ho (1992) has recalculated the likelihood of site disruption during a 10,000 year period and placed it between 1e-3 and 6.7e-3 with 90 percent confidence. These conflicting probability estimates are indicative the need for additional geologic constraints on the problem.

7 REVIEW OF CHAPTER 8.0: COMBINATION OF CONDITIONAL CCDF'S

7.0.1 Major Problems

There is a fundamental problem with the "probabilistic sum" method for combining component CCDF's as it is applied to combining the CCDF's from the six columns which are used to describe 1D flow and transport through the unsaturated zone using the composite model for matrix/fracture flow. It is stated on page 8-9 that "(t)his method of CCDF combination is appropriate when the scenario categories being combined are completely independent (have no influence on each other)." It makes sense to use this procedure for combining CCDF's from the so-called "scenario categories" (volcanism, human intrusion, nominal flow regime) which are, for the most part, independent. To use this probabilistic combination method to coalesce the individual CCDF's from the six vertical columns and arrive at a composite CCDF for aqueous phase transport assuming the composite model is neither physically intuitive and nor does it seem to be mathematically correct.

The six column model of aqueous transport through the unsaturated zone as described in chapter 4 and depicted in Figure 4-30 appears to be designed to incorporate some of the lateral spatial variability of the rock hydraulic properties evident at the proposed Yucca Mountain site without resorting to more computationally expensive 2D models. As shown in Figure 4-30, the radionuclide releases from each of the columns are combined and then distributed uniformly within the 25 m saturated source region of the 1D saturated flow tube which extends from beneath the repository to the accessible environment. Each column is assumed to represent one-sixth of the area of the repository and would therefore receive one-sixth of the net infiltration applied over the repository, although this is not made clear in the text.

On page 4-73 it is stated that 300 realizations of the rock hydraulic parameters were generated for each of the six columns. The STEADY and TRANS modules of TOSPAC were then used to model flow and transport, respectively, through each column using each realization for a total of 1800 separate deterministic calculations. It is readily apparent that no spatial correlation is assumed to exist between the six columns other than the underlying continuity of the mildly dipping layered tuff units. Moreover, on pages 8-9 and 8-10 it is stated that the parameter values in one column are assumed to be uncorrelated with parameter values in the other five columns. The implication here is that each of the six columns and therefore each of the 1800 calculations of flow and transport represent independent models of aqueous radionuclide release. This appears to contradict the conceptual model described in the text wherein each column "collects" one-sixth of the aqueous radionuclide release from the repository.

If, in fact, this interpretation of the conceptual model of aqueous radionuclide release depicted in Figure 4-30 and described on page 4-37 is correct, then the use of the "probabilistic sum" method to combine the CCDF's would appear to grossly underestimate the probability of exceeding both the NRC release rate limit and the EPA total release limit. It seems that the correct method of combining these six columns is simply to collect the total release of radionuclides at the transition from the unsaturated zone to the saturated zone and either completely mix the radionuclide release before transmission to the saturated flow path or, as in a manifold, combine the releases sequentially as each "runner" (column) connects to the "plenum" (saturated flow path).

7.0.2 Areas of Possible Controversy

The assertion made at the bottom of page 8-1 that "(t)here is a logical difficulty in separating 'alternative conceptual models' from simple parameter variation, because normally alternative models are arrived at by choosing discrete, possibly extreme, values of some parameter or parameters" appears to grossly simplify the process of constructing alternative conceptual models. As an example the authors cite the composite porosity and the weeps model of aqueous phase transport through the unsaturated zone as alternative conceptual models which could be derived from a "...more general model of flow and transport, one with an infinite value of a matrix/fracture coupling parameter and the other with a zero value for the coupling parameter." Alternative conceptual models are generally arrived at in a wholly different manner than that which the authors describe, moreover, most alternative models cannot be regarded as parametric variations of some more general model unless one is willing to construct some rather trivial models.

For example, let it be assumed that 1D and 3D mass conservation equations for fluid flow in a repository represent wholly different conceptual models. The 1D model can either be derived directly from first principles or from the more general 3D form by integrating over the two spatial dimensions normal to the assumed uni-dimensional flow field. Note that in either case the hydraulic parameters of the 1D equation are fundamentally different from those of the 3D equation due to the spatial averaging process, and cannot be obtained simply by parametric variation. An attempt to construct a general 1D and/or 3D model of mass transport can be made by constructing

$$M_{General} = \delta M_{1D} + (1-\delta)M_{3D},$$

where δ is a binary variable taking the value 1 for a 1D model and 0 for the 3D model. Either conceptual model can be extracted by simple "parametric variation" of δ. It is easy to concoct even more general models of FEP's, however, the point to be made is that the notion of selecting alternative conceptual models is distinctly different from taking a specified model and varying the value of its parameters to account for spatial heterogeneity of uncertainty. The attempt by the authors to equate" alternative conceptual model" with "parametric variation" may simplify the terminology used in the TSPA but it also obscures the very real differences between the procedures.

7.0.3 Areas to be Examined in Greater Detail

The effects of the assumptions of statistical independence of the scenario categories on the construction of the composite CCDF outlined on page 8-4 should also be investigated, particularly for volcanism and aqueous and gaseous transport. It may difficult to assess the effects of all volcanism scenarios on the nominal flow regime, but perhaps some bounding cases can be constructed against which the implications of the independence assumption may be compared.

8 REVIEW OF CHAPTER 9.0: COMMENTS AND COMPARISONS

8.0.1 General Comments

The authors claim that the "lowest flux was useful for confirming that saturation values were comparable for the 1D and 2D analyses." It is an obvious fact that a 2D model analysis will yield similar results to a 1D one, if the imposed boundary conditions in the 2D model constrain groundwater movement to a quasi-vertical direction. This conclusion also suggests that the 2D model has not been used effectively to show the proper behavior of pathlines in the presence of perched water or its impact in dealing with the water table fluctuations resulting from a three order of magnitude increase of the infiltration rate. The omission of the seepage face calculation by restraining the width of the modeled region may cause severe drawbacks in the correct prediction of the pathlines in the unsaturated region, particularly in the presence of fractures. In addition, the assumption of material isotropy does not seem to correspond to the properties of rock samples collected at Yucca Mountain which indicate otherwise. The isotropy assumption suggests that streamlines and equipotentials are orthogonal in such a system, this is not true in the investigated case. We also recommend that more realistic boundary conditions be adopted in the use of 2D regional flow models which must be accompanied by sensitivity studies.

9 REVIEW OF CHAPTER 10.0: CONCLUSIONS AND SUMMARY

9.0.1 General Comments

It appears that computational costs coupled with the modest amount of data available at Yucca Mountain have played a decisive role in the author's decision to select groundwater and solute transport models which have allowed them to perform deterministic and stochastic analyses addressing issues proposed in their FEP diagrams. However, these conceptual models are not deemed to be sufficiently adequate to generate qualitative forecasts which may be appropriately compared to NRC or EPA standards.

9.0.2 Summary and Recommendations

The authors do not have any additional comments/suggestions other than as given in this document.

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